OCS Study
BOEM 2013-0114

BOWHEAD WHALE FEEDING ECOLOGY STUDY (BOWFEST) IN THE WESTERN BEAUFORT SEA

Final Report

National Marine Mammal Laboratory
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
7600 Sand Point Way NE, Seattle, WA 98115-6349

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Cover photo credit: Julie Mocklin (NMML-AFSC), Bowhead whales (*Balaena mysticetus*) off Barrow, Alaska, September 2008. NMFS Permit No. 782-1719

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Prepared for:

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EXECUTIVE SUMMARY

The Bowhead Whale Feeding Ecology Study (BOWFEST) was initiated in May 2007 through an Interagency Agreement (formal title: *The bowhead whale feeding variability in the western Beaufort Sea: feeding observations and oceanographic measurements and analyses*) between the Minerals Management Service (MMS, now the Bureau of Ocean Energy Management (BOEM)) and the National Marine Mammal Laboratory (NMML). The goal of this 5-year study was to facilitate development of future oil and gas development-related mitigation by estimating relationships among bowhead whale prey, oceanographic conditions, and bowhead whale feeding behavior in the western Beaufort Sea, with emphasis on identifying predictable aspects in those relationships. The study had five principal objectives:

1. Document patterns and variability in the timing and locations of bowhead whales feeding in the western Beaufort Sea.
2. Estimate temporal and spatial patterns of habitat use by bowhead whales in the study area.
3. Document bowhead whale prey distributions and abundance in the immediate vicinity of feeding bowhead whales as well as in neighboring areas without whales.
4. Document “fine scale” oceanographic and other relevant environmental conditions both near feeding bowhead whales and in neighboring areas without whales.
5. Characterize oceanographic features on a “coarse scale” relative to the study area.

The objectives of BOWFEST were addressed using multiple research platforms in the BOWFEST study area, continental shelf waters between the coast and 72°N, and between 152º and 154º west longitudes, which is north and east of Point Barrow, Alaska (Fig. ES-1). Data were collected over the short-term (late August to mid-September each year) during aerial surveys, tagging studies, zooplankton and oceanographic sampling, and passive acoustic monitoring; and long-term from year-round passive acoustic and oceanographic moorings, summer small boat surveys, and stomach contents and digestive efficiency from bowhead whales harvested during the spring and fall migrations. Results of this research may help explain increased occurrence of bowheads feeding in the western Beaufort Sea (U.S. waters), well west of the typical summer feeding aggregations in the Canadian Beaufort Sea. Information from this study will be used by BOEM for pre- and post-lease analysis and documentation under the National Environmental Policy Act (NEPA) for Beaufort Sea and Chukchi Sea Lease Sales. Abstracts from each project discipline and a synthesis of project results are presented herein.

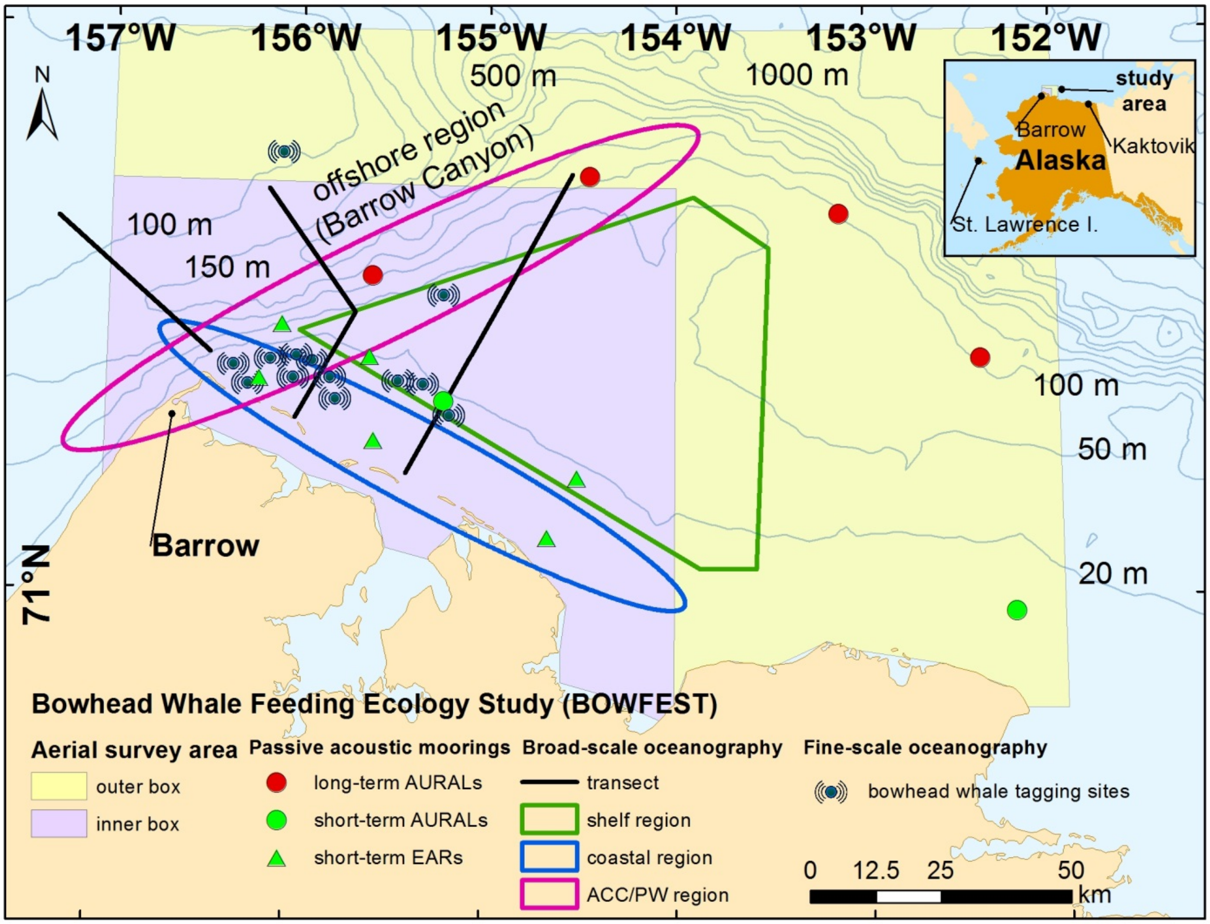

***Figure ES-1**.—The Bowhead Whale Feeding Ecology Study (BOWFEST) area (2007-2012). Sampling included aerial surveys (2007-2011), small boat surveys (2008-2012 within the inner and outer aerial survey boxes), passive acoustic monitoring (2007-2012 general locations shown), broad-scale oceanography (2007-2011 primary transects shown, though sampling also occurred within each region (shelf, coastal, ACC/PW (Alaska Coastal Current/Pacific water), and offshore)), fine-scale oceanography and whale tagging (2009-2011), and collection of stomach samples and digestive tracts at Barrow and other Alaska Eskimo Whaling Villages (2007-2012).*

Section I. Aerial Surveys

The aerial survey component of BOWFEST was designed to document patterns and variability in the timing and locations of bowhead whales, as well as to provide an estimate of temporal and spatial habitat use in the study area. In addition, aerial photography provided information on residence times (through reidentification of individual animals) and sizes of whales (through photogrammetry) as a proxy for age. Using NOAA Twin Otters, scientists from NMML conducted aerial surveys from 23 August – 11 September 2007 (31 flight hours), 27 August – 16 September 2008 (43 flight hours), 29 August – 18 September 2009 (18 flight hours), 31 August – 18 September 2010 (33 flight hours), and 25 August – 17 September 2011 (47 flight hours). The surveys were flown over continental shelf waters from 157° W to 152° W and from the coastline to 72° N, with most of the effort concentrated between 157° W and 154° W and between the coastline and 71° 44'N. There were 16 bowhead sightings (an estimated 68 whales) in 2007, 56 sightings (195 bowheads) in 2008, 29 sightings (55 bowheads) in 2009, 102 sightings (452 bowheads) in 2010, and 18 sightings (68 bowheads) in 2011.

The photographic system involved two handheld cameras (both Nikon D200 with 55mm and 180mm lenses) in 2007, one mounted and one handheld camera (Canon EOS-1DS Mark III; 50mm and 70-200mm zoom lenses) in 2008 and 2009, and three mounted cameras (Canon EOS-1DS Mark III; 85mm Zeiss lenses) in 2010 and 2011. During the 5-year study, a total of 1,605 photographs were taken containing 2,387 images of bowhead whales. After matching and removing duplicate photos from multiple aerial passes, we identified 762 unique whales from 1,415 images.

Bowhead feeding behavior was characterized by an open mouth, multiple swim directions, a fecal plume, mud plumes, or mud on the dorsal surface of the whale. Observers reported these behaviors during 50% of sightings in 2007, 7% in 2008, 21% in 2009, 28% in 2010, and 11% in 2011. With the exception of 2007 (at 37% of photo images), photographs documented feeding behaviors more frequently than aerial observers with 16% in 2008, 23% in 2009, 51% in 2010, and 22% in 2011. Mapping locations of feeding bowhead whales revealed that 91% of individual bowhead whales showing photographic evidence of feeding were located in shelf waters, predominantly along the 20 m isobath. More feeding behavior was observed and photographed during years when most sightings occurred on the shelf (2007, 2009, and 2010).

"Traveling" was the most commonly recorded behavior (45% for all years combined), but direction of travel was highly variable among years, suggesting animals were not necessarily migrating through the area. Only in 2008, was swim direction significantly clustered around a mean (295°T, n = 21 sightings, Rayleigh Z = 7.103, p = 4.82E-4), and clearly westward. Within the limited sampling period, there was no apparent increase in sightings from late August to mid-September. The paucity of individual resightings (based on photographic recaptures) between survey days (3 matches out of 762 identified whales) suggested very low residence times off Barrow. However, none of the whales resighted within a season had moved west of the original sighting; as would be expected during the fall migration; all subsequent sightings were to the east. Age composition varied from year to year but on average was evenly represented by juveniles and adults.

The majority of bowhead whales were in relatively shallow water (80% of sightings in waters <=50m). Habitat partitioning was evident among the cetacean species observed in greatest numbers: bowhead, gray, and beluga whales. In general, each species occupied a unique region within the study area, bowheads on the continental shelf in waters <50 m deep (in all years except 2011); belugas over the deep Barrow Canyon and offshore slope waters; and gray whales near the 50 m isobath along the edge of Barrow Canyon. Belugas were seen in all years except 2009; although survey effort was restricted to the inner box that year (Fig. ES-1), beluga sightings were also low the previous and following year. Gray whales were present during every survey year, and sighting numbers were fairly consistent year to year, with the exception of 2010 when their numbers were at their lowest and bowheads at their highest.

When examining bowhead whale habitat preferences based on all years of the aerial survey data, we considered four parameters in the model: bathymetry, bathymetric slope, distance from shore, and distance from the shelf break. Both distance from shore and distance from the shelf break were significant in predicting the presence of bowhead whales ($p < 0.01$). Bowhead whales preferred to be close to shore and to the shelf break; therefore, their preferred habitat were areas where the shelf break came closest to shore. However, the model was only able to correctly discriminate between the presence (bowhead sighting) and absence (random points) 67% of the time. As mentioned earlier, feeding bowheads were predominantly found in shelf waters. Bathymetry, as well as bathymetric slope, distance from shore, and distance from the shelf break were significant in predicting gray whale presence ($p < 0.01$). Gray whales preferred to be in waters along the shelf break. The model was able to correctly classify gray whale presence and absence 96% of the time. Of the four parameters included in the model, only bathymetry was significant in predicting beluga whale presence ($p < 0.01$). These animals preferred to be in deeper water than would be predicted at random and the model correctly discriminated sightings from non-sightings 82% of the time. While there was a large portion of overlap for these species, there is clear spatial separation in their preferred habitats. Bowhead whale preferred habitat, regardless of behavior observed, included shelf, shelf break, and canyon waters primarily north and east of Barrow, beluga whale habitat primarily included the canyon, while gray whale preferred habitat located at the interface of bowhead shelf and beluga canyon habitat – following the shelf break.

Section II. Passive Acoustic Monitoring

This study examined the spatio-temporal distribution of bowhead whales in the BOWFEST study area off Barrow, Alaska from August 2007 through August 2012 using passive acoustic monitoring. Long-term (year-long) autonomous passive acoustic recorders were deployed on subsurface moorings along the 100 m isobath from Point Barrow to Cape Halkett in all years. These long-term recorders had a sampling rate of 8192 Hz and were run on a 20-45% duty cycle. They were also equipped with a built-in temperature sensor which sampled one near-bottom temperature measurement per recording period. Short-term (week to month-long) autonomous passive acoustic recorders were deployed closer inshore and in shallower water (~20 m) from 2008 to 2012, and ran on a higher duty cycle and sampling rate (80-90% and 12.5 kHz to 40 kHz, respectively). Over the course of the BOWFEST study period, 6,056 days of data were collected from the long-term moorings and 366 days from the short-term moorings (3.72 TB of data in total). In addition to the vocalization and temperature data, ice data were obtained from the NOAA CoastWatch, Aqua AMSR-E, Near Real Time, Global (1 Day Composite) ice coverage dataset.

Here, we show the use of passive acoustic recorder moorings is an effective tool for monitoring not only the spring and fall migrations of bowhead whales through the BOWFEST study area, but also the presence of bowheads in this area throughout the summer. The spring migration was detected from 2009 through 2012 (earliest onset in 2011, latest in 2012). In all four years, a sudden and near-simultaneous onset of calling was observed at the long-term sites around the beginning of April. The peak in this calling occurred under 100% ice cover, most likely because the spatial resolution of the satellite ice data is not of a fine enough scale to capture the leads through which the bowheads were migrating. Small temperature peaks seen prior to the spring calling peak in all years may be indicative of leads forming at those times. Fall migration was detected in all five years of the study. The main pulse of the fall migration, however, had a lower peak and was much more compressed in time than the spring migration peak. The end of the main pulse of calling for the fall migration varied between early November (2007) to mid-November (2008 to 2011). The decrease in calling was inversely proportional to the percentage of ice coverage (and the simultaneous dip in water temperature) in all years. The strongest correlation between temperature and calling was seen in 2007, suggesting that bowheads may use temperature as a cue to start migration. Differences in detection timing among the recorders suggest there were different fall migratory paths taken among the years. These paths (inshore vs. offshore) broadly agree with the findings from the aerial survey team. The most interesting result from the long-term passive acoustic recordings was the continual presence of bowheads in the study area throughout the summer, and not solely during the spring and fall migrations. This can be seen clearly in 2009 and 2011, where peak or near-peak presence continued between the migrations. Although acoustic data do not provide the means to determine if feeding was occurring, these data reinforce past evidence that bowheads are using the BOWFEST area as a feeding ground and not just as a migratory corridor.

Section III-A. Moorings

The mechanisms for trapping and aggregating krill, a key food source of bowhead whales, are not well understood. Current velocity and relative acoustic backscatter measurements were acquired by using year-round and short-term current meters moored in Barrow Canyon and in the shallow waters of the western Beaufort shelf from 2006-2011. These measurements, in combination with wind velocity data from Barrow, were used to identify generalized wind-driven circulation patterns and infer relative krill abundances associated with these circulation patterns. Two wind-current regimes collectively define a krill trap conceptual model for the BOWFEST study area. Moderate-to-strong upwelling-favorable winds from the east bring krill onto the shallow western Beaufort shelf. Subsequent relaxation of the winds and shelf currents promotes the retention and aggregation of krill on the shelf. Consequently, the krill trap conceptual model predicts that feeding opportunities for bowhead whales tend to be limited during moderate-to-strong upwelling-favorable winds from the east and enhanced when weak winds follow upwelling-favorable winds.

Section III-B. Broad-Scale Oceanography

The shelf near Barrow, Alaska, is a feeding hotspot for bowhead whales during the whales' fall migration from the Canadian Arctic to the Bering Sea. The oceanographic conditions producing this hotspot and interannual variability in biological and physical ocean conditions near Barrow were described from 2007-2011. Interannual variability in physical and biological conditions was observed over the five years. Multiple water masses were observed each year and the overall physical conditions were determined by larger scale meteorological patterns and the presence of sea ice. Zooplankton community composition varied between years and hydrographic/geographic regions. Two patterns were particularly striking, with 2007 being characterized by high proportions of the small copepod *Pseudocalanus* spp. on the shelf and 2011 being marked by high proportions of benthic and echinoderm larvae at all locations across the study area. Short-term variability in conditions on the shelf, including euphausiid abundance and distribution, was intimately tied to the direction and strength of the local winds. Elevated concentrations of euphausiids were found on the shelf in response to shelfbreak upwelling of water and euphausiids forced by east winds that were followed by south or weak winds that confined the Alaska Coastal Current against the eastern flank of Barrow Canyon, trapping and concentrating the upwelled water and euphausiids on the shelf. The relative proportion of upwelling krill trap days varied interannually, with the lowest proportion in 2009 (0.7) and highest proportions in 2007 and 2011 (1.7, 1.5 respectively). The distributions and persistence of euphausiids on the shelf reflected these proportions, with euphausiids abundant and distributed broadly on the shelf in 2009 but much less so in 2007 and 2011 when abundances on the shelf were quite low. The abundance and relative proportions of larger adult and juvenile vs. smaller furcilia euphausiids also varied interannually, with euphausiid abundances in 2009 being dominated by large juvenile/adults, 2010 and 2011 being dominated by small furcilia, and 2007 and 2009 having more equivalent proportions of the two size categories. These differences likely were related to larger scale patterns in euphausiid population structure, abundance, and transport from the Bering Sea. The distributions of bowhead whales from boat-based oceanographic work reflected these differences in their prey availability, with bowhead whales in 2011 being found primarily in Barrow Canyon rather than on the shelf and in 2009 being widespread on the shelf, coincident with the distribution of their prey. Of the five years of the study, 2009 provided the most favorable feeding conditions for the whales, with large, high-biomass euphausiids being delivered across the shelf. Other years, although providing concentrations of euphausiids, might be considered less favorable simply because the euphausiids were dominated by smaller life stages that provided lower biomass.

Section IV. Tagging and Fine-Scale Oceanography

The diving and foraging behavior of bowhead whales was studied on the western Beaufort Sea shelf to better understand the factors that influence the whales' feeding behavior and movements. Our specific objectives were to investigate associations among whale diving behavior, the distribution of prey in the water column, and the physical features that may contribute to the concentration of prey at particular depths. Diving behavior was monitored by attaching archival tags to bowhead whales for short periods of time (1-3 hours). Suction-cup attached tags were found to perform poorly owing to the whales' rough skin; therefore, a new dermal attachment tag was designed and used in the field project during 2009-2011. The short- and long-term behavioral and health effects of this tag were studied in humpback whales in spring 2009, and the tag was deemed to be sufficiently benign for use on bowhead whales. Tagged whales were tracked closely with the aid of a high-frequency acoustic transmitter incorporated in the tag. Oceanographic conditions and prey distribution were monitored as close in space and time to the tagged whales as possible using a profiling instrument package that measured temperature, salinity, chlorophyll fluorescence, and zooplankton abundance throughout the water column. Profiles with the instrument package were collected every 15 minutes along the tagged whale's track. Tagged whales traveled extensively while they were monitored; some remained at the surface during these traveling periods, while others made repeated and regular dives to near the sea floor. The regular diving behavior was very suggestive of prospecting or searching behavior. Zooplankton abundance, particularly that of the whales' putative primary prey (euphausiids and large copepods), was low in proximity to the tagged whales. Sampling both in the presence and absence of bowhead whales indicated no relationship between the occurrence of the whales and zooplankton abundance. In contrast, the occurrence of North Atlantic and North Pacific right whales, morphologically similar species to the bowhead, is very closely correlated with the abundance of their copepod prey. These results suggest that the western Beaufort Sea shelf may only be an occasional feeding area for bowhead whales, and that their presence in this region may be related to factors other than feeding, such as socializing or coordination during migration.

Section V-A. Local Boat Surveys

The North Slope Borough Department of Wildlife Management (DWM) coordinated small-boat surveys during the BOWFEST study from 2008 to 2012. The study area spanned the nearshore waters (to ~15 miles offshore) from approximately Cape Simpson to 25 miles SW of Barrow. The vast majority of the surveys were conducted by chartering local hunters and their boats. For all five years, a total of 1,427 marine mammals were recorded (469 sightings) of which 650 were bowheads (175 sightings). Total effort was about 1,400 hours. We found that bowhead whales summer in the study area in low numbers but show considerable annual variation. Local knowledge and results of our surveys suggest that numbers may have increased over the last 30 years. Gray whales consistently feed near Barrow during summer. While their relative abundance varies annually, gray whale occupancy is more predicable in local feeding areas during summer than bowhead whales. Bowhead and gray whales show clear spatial segregation in the study area with gray whales using deeper waters to the west associated with Barrow Canyon and bowheads targeting shelf waters to the east, with some overlap north of Point Barrow. For the entire study period, about 50% of the bowheads sighted were scored as feeding but there was considerable variation by year. The largest aggregations of bowheads seen were near the barrier islands. Sighting rates (whales seen/hour) were higher in the study area in 2009 and 2010 (July to September) than other years. Sighting rates tended to be higher for bowhead whales than gray whales, but surveys were more often conducted in areas frequented by bowheads. Sighting rates for bowheads in August and September 2011 were very low despite the highest survey effort of any season. Possible explanations include a delayed migration from Canada associated with high prey abundance, delayed sea ice development, low prey densities near Barrow, or some combination of these factors. Locally-operated boat surveys proved to be an effective, relatively low-cost method to locate whales, support community-based science, and estimate distribution and relative abundance.

Section V-B. Diet Studies

This study examined the diet of bowhead whales harvested by Alaska Natives at Barrow (western Beaufort Sea) and Kaktovik (eastern Alaskan Beaufort Sea) during 2007-2012. We additionally describe prey identified from stomach and/or fecal samples from bowhead whales harvested near Saint Lawrence Island in the northern Bering Sea. Our objectives were to: 1) identify the proportion of harvested whales that had been feeding; and 2) describe diet based on ingested prey samples. Field examinations of 149 whales were conducted to determine the status of feeding as well as describe the diet. During the fall, a higher proportion of animals had been feeding near Barrow (92%) than at Kaktovik (54%) during the study period. A higher proportion of animals had been feeding near Barrow during the fall (92%) than the spring (10%). During the spring, a larger proportion of bowhead whales near Saint Lawrence Island (73%) were feeding than at Barrow (10%). There was no difference in the proportion of harvested whales feeding seasonally (spring 73% vs. fall 75%) near Saint Lawrence Island.

For whales harvested near Barrow, amphipods and mysids occurred more frequently in whales harvested during the fall than for whales harvested during the spring. During the fall, amphipods, fish, and euphausiids occurred more frequently in bowhead whales harvested near Barrow than whales harvested near Kaktovik. Near Saint Lawrence Island, euphausiids were the only prey taxa with a seasonal difference with euphausiids occurring more in fall harvested whales. During the fall at Barrow, percent by volume during 2007-2009 were dominated by euphausiid prey (82%). During 2010, the dominant prey by volume switched to copepods (88%). A diversity of prey types dominated the fall 2011-2012 samples from Barrow and included isopods, mysids, copepods, amphipods, and fish. Our results agree with previous works that indicate bowhead whales fed regularly in the Alaskan Beaufort Sea during the fall and that the diet samples of bowhead whales in the northern Bering Sea indicate bowhead whales feed commonly in the northern Bering Sea before and after their annual migration to the Beaufort Sea.

Section V-C. Bowhead Whale Digestive Efficiency

Prey density is of paramount importance to filter feeding cetaceans to maintain energy balance, yet little is known about bowhead metabolic demands and digestive efficiency of their common zooplankton prey. Samples of fresh zooplankton and digestive contents were taken along the alimentary tract of subsistence-harvested bowheads (2009-2012) from the forestomach, fundic and pyloric chambers, duodenal ampulla, small intestine, and large intestine. We used proximate composition analyses (% lipid, % protein) and bomb calorimetry to assess changes in energy density and composition of digesta. Assimilation efficiency was calculated based on “start” composition of forestomach contents to “end” composition of colon contents and was between 40-50% for gross energy density. Protein digestion occurred in the forestomach, consistent with chitinolytic, microbial fermentation leading to lipid release from prey. Lipids were not taken up until the duodenum (consistent with typical mammalian digestion) with an efficiency of approximately 50-60%. Due to the high caloric density of lipids, this trend was repeated in gross energy content. Digestive efficiency was calculated using published or estimated data on daily food intake and defecation volumes of bowhead whales and was on average 77%. Proportions of individual fatty acids change along the alimentary tract; the proportions of saturated fatty acids (SAFA) increase in the colon compared with ingested food. Specifically, long chain SAFAs (e.g., 20:0 and 22:0) appear in the colon, but are not present in the diet pointing to bacterial synthesis in the gut. In contrast, polyunsaturated fatty acids (PUFA) are taken up, in particular essential fatty acids, such as 20:4 ω6, 20:4 ω3, and 22:6 ω3, and do not occur in the colon. Using respiratory frequency of migrating whales and lung volume estimates, we determined metabolic rate (MR) of an average-sized (9m) whale as ~4.3kW (1.1x Kleiber) when migrating and 7.9kW (2x Kleiber) when feeding. Estimates of daily energy intake indicate that whales may expend as much energy when feeding/migrating as is gained (~8kW for a 9m whale) with a digestive efficiency of 77%. This emphasizes the importance of finding high density prey patches and minimizing the search, but also indicates that migrating whales can acquire sufficient energy near Barrow to offset their migratory costs and avoid expending energy gained on the summer foraging grounds. Fat reserves stored in bowhead blubber far exceed thermoregulatory requirements; we estimate that a 9m bowhead could fast over 1 year (migratory MR, assuming no MR adjustments), suggesting a built-in fail-safe for years with unfavorable prey densities.

Section VI. Project Integration and Conclusions

Objective 1. Documenting presence and distribution of bowhead whales within the study area was fairly straightforward (Objective 2), however, determining where and when whales were feeding was another matter altogether. Feeding bowhead whales were observed during aerial surveys, small boat surveys and tagging studies, and based on stomach content analyses. Feeding behaviors included open mouth (skim feeding), multiple swim directions, coordinated group feeding (echelon feeding), a fecal plume, mud plumes and/or mud on the dorsal surface (epibenthic feeding) of the whale. Mapping locations of feeding bowhead whales photographed during aerial surveys revealed that 91% were located in shelf waters, predominantly along the 20 m isobath. More feeding behavior was observed and photographed during years when most sightings occurred on the shelf (2007, 2009, and 2010). Similar to the aerial survey results, boat-based observers reported feeding bowhead whales more often in 2009 and 2010, than in other years. During those two years, whales were found in waters averaging ~25 m in depth versus the 40+ m depths in other years. Tagged whales traveled extensively while they were monitored; some remained at the surface during these traveling periods, while others made repeated and regular dives close to the sea floor. The regular diving behavior was very suggestive of prospecting or searching behavior related to feeding during two of the four events in 2009 and one of eight events in 2010. It is likely much more feeding was occurring than was evident from the aircraft, aerial photographs, or boat-based surveys. Based on stomach examinations, 92% of bowhead whales harvested near Barrow during the fall migration had food in their stomachs in stark contrast to the spring harvest when only 10% of the whales had food in their stomachs.

Objective 2. Temporally, bowhead whales were seen or heard in the study area during all seasons but winter. The low resighting rate during the aerial surveys (3 out of 762 identifiable whales photographed) suggests the Barrow area is not necessary preferred by a small, select group of individuals during late summer but instead is visited periodically by the large open population of western Arctic bowhead whales. During the summer months, the temporal and spatial distribution of bowhead whales within the study area varied from year to year. Physical characteristics of the BOWFEST study area include lagoons, barrier islands, a broad shelf, steep slope, and the Barrow Canyon. With the exception of the lagoons, bowhead whales were at times found in close proximity to the islands and in waters ranging from the shelf to the canyon. The spatial and temporal differences observed year to year may, in part, be reflected in prey distributions which are discussed under Objective 3.

When examining bowhead whale habitat preferences based on all years of the aerial survey data, we considered four parameters in the model: bathymetry, bathymetric slope, distance from shore, and distance from the shelf break. Both distance from shore and distance from the shelf break were significant in predicting the presence of bowhead whales ($p < 0.01$). Bowhead whales preferred to be close to shore and to the shelf break; therefore, their preferred habitat were areas where the shelf break came closest to shore. However, the model was only able to correctly discriminate between the presence (bowhead sighting) and absence (random points) 67% of the time. As mentioned earlier, feeding bowheads were predominantly found in shelf waters. Habitat partitioning within the study area among cetacean species (bowhead whales, gray whales, and beluga whales) was also evident during the aerial and small boat surveys.

Objective 3. Although bowhead whales exhibited foraging behavior during tagging operations that were conducted during the same time period as the aerial surveys, they did not appear to target available euphausiid or copepod swarms. Zooplankton sampling both in the presence and absence of bowhead whales indicated no relationship between the occurrence of the whales and zooplankton abundance. Of the five years of the study, 2009 provided the most favorable feeding conditions for bowhead whales, with large, high-biomass euphausiids being delivered across the shelf. The large copepod *Calanus glacialis*, one of the important prey items of bowhead whales, was seen consistently only in the offshore region, in particular in 2010. During all years of the aerial study, muddy whales were photographed, however only in 2010 and 2011 were photographs obtained showing open mouth (skim) feeding. Muddy whales and mud plumes were also observed during small boat surveys with surface (skim) feeding noted, in particular in 2009. Fast swimming euphausiids may account for the preponderance of surface feeding observed in 2009 and 2010. In 2010, groups of bowhead whales were observed swimming in echelon formation during the aerial survey, and in an unusual position, on their sides instead of upright. Side-feeding of bowhead whales in concert with echelon formation swimming can increase feeding efficiency and/or decrease the overall energy cost of locomotion when foraging.

Depending on prey type, feeding efficiency and/or energy cost may change from year to year. Part of the BOWFEST study also included examining stomach contents of whales harvested during the migration period and calculating their digestive efficiency. Though sampling was not during the summer period, whales were feeding in the BOWFEST study area just after the conclusion of our observations and our expectation is that prey community composition would be similar to that observed in summer. The importance of the region near Barrow as a feeding area during the fall migration is also reflected in the proportion of harvested animals that had been feeding near Barrow (92%) versus at Kaktovik (54%). Bowhead whales that were harvested in late fall near Barrow had more euphausiid prey (82% prey by volume) in 2007-2009, but in 2010 the dominant prey was copepods (88%). This pattern follows the broad scale oceanographic results where euphausiid size classes included larger adults and juveniles advected onto the shelf during 2007-2009, but mostly smaller furcilia in 2010, which may have been targeted by side-swimming echelon groups while other bowheads fed on larger copepods offshore. Digestive efficiency was lowest (64%) in 2010 and highest (83%-84%) in 2009 and 2011, respectively. This emphasizes the importance of finding high density prey patches and minimizing the search, but also indicates that migrating whales can acquire sufficient energy near Barrow to offset their migratory costs and avoid expending energy gained on the summer foraging grounds. Generally, fat reserves stored in bowhead whale blubber far exceed thermoregulatory requirements; for example, the sample results from a 9 m bowhead indicate it could fast over 1 year, suggesting a built-in fail-safe for years with unfavorable prey densities. An adult can likely fast several years on an insufficient diet. Regardless of the prey consumed, bowhead whale digestive efficiency remained at ~80%, which was lower than efficiencies reported for minke (*Balaenoptera acutorostrata*) or North Atlantic right whales (*Eubalaena glacialis*).

Objective 4. Fine scale oceanographic data (temperature, salinity, and chlorophyll fluorescence) were collected near tagged whales. In 2009, one of the tagged whales made repeated dives into a cold, salty water mass, and these dives were characterized by longer bottom times than previous dives, suggesting prospecting or searching. Upon review of the VPR casts with the dive profiles, a reasonably high abundance of euphausiids was observed in proximity to this whale, yet the whale did not demonstrate feeding behavior. In 2010, bowhead whale movements did not appear to be associated with any fine-scale oceanographic features on the shelf. Colder and fresher conditions prevailed to the east (near three tagged whales), and warmer saltier water likely of Pacific origin were predominant in the western part of the study area (near two tagged); and in some cases, tagged whales crossed over the boundary between these two water masses (three whales). Both along-shelf (one whale) and cross-shelf (three whales) movements were observed.

On a broader scale, multiple water masses were observed each year, and zooplankton community composition varied between years and hydrographic/geographic regions. Greatest chlorophyll concentrations were present both in melt water and in the upper portion of the Winter Water (WW) because of the greater nutrient concentrations found in those water masses. With the exception of periods when the krill trap (see below) had advected euphausiids onto the shelf, greatest abundances of euphausiids were found in the offshore regions, presumably in the WW at depth. Profiler data from moorings at the shelf break indicated that these euphausiids were upwelled onto the shelf along the Beaufort Shelf break from the WW rather than from the shallower ACC. In Barrow Canyon, these krill are preferentially associated with cold, salty WW. It is inferred from this association that these krill are advected from the Bering Sea and across the Chukchi Sea via currents other than the warm, fresh ACC. It is now thought that euphausiids are resident in the WW found at depth below the ACC and offshore. Short-term variability in conditions on the shelf, including plankton abundance and composition, are tied to the direction and strength of local winds. In certain combinations, this affects krill concentrations (the "krill trap"), that is, when weak or southwesterly winds follow moderate-to-strong, upwelling-favorable easterly winds, there is a convergence of ACC waters from Barrow Canyon with Beaufort shelf waters, leading to the trapping and aggregation of krill on the western Beaufort shelf adjacent to the southeastern edge of Barrow Canyon. Therefore, it appears that krill are more likely to be present in higher densities on the western Beaufort shelf during weak-wind active krill trip conditions than during upwelling wind conditions. The krill trap was active the greatest proportion of days (45%) in 2009, and was active for ~10% fewer days in the other four years.

Objective 5. Oceanographic conditions near Barrow are complex and are characterized by the juxtaposition of two oceanographic regions – the Chukchi and Beaufort Seas – and several water masses. A submarine canyon (Barrow Canyon) just offshore markedly impacts local conditions. Relatively warm, fresh Alaska Coastal Water (ACW) from the Bering Sea flows northward through the Chukchi Sea and exits the oceanographic shelf through Barrow Canyon with annual mean transports varying according to atmospheric conditions in the Arctic. Variability in the northward transport of ACW introduces variability in fluxes of heat, salt, nutrients, and plankton entering the Arctic, in turn impacting the Arctic ecosystem; in which, there is a close coupling between water mass type and biological characteristics. Dramatic changes in sea ice extent suggest this region is highly susceptible to climate change. Both long-term and short-term variability are important in establishing the presence of a favorable feeding environment for bowhead whales near Barrow. The period of the study, 2007-2012, coincides with a period of dramatic physical change in the Arctic and particularly in the western Arctic. The BOWFEST sampling years encompassed some of the lowest total summer sea ice extents in satellite-documented history, with 2012 and 2007 being the lowest and second lowest years on record, respectively. All years of the field study occurred during a period of on average declining sea ice extent in the Western Arctic, although there was individual variation both among years and locally in the Barrow area. These ice conditions were reflected in the hydrographic conditions in the BOWFEST study area.

Conclusions. The BOWFEST study area, northeast of Point Barrow, is characterized by complex bathymetry with shallow shelf waters bordering a deep marine canyon. The canyon provides a conduit for relatively warm water and biological matter into the Arctic Basin as well as onto the Beaufort Shelf. Further complicating the nature of the area, sea ice varies from complete coverage in the winter to partially or totally absent in the summer, and the extent has been changing inter-annually. This variety in habitat characteristics may be elemental to the rich marine fauna found in the area, and accordingly, bowhead whales exploring feeding opportunities throughout the summer. Not only is the Barrow region important during the summer months for some bowhead whales, but also during the fall as whales depart the Beaufort Sea, as an additional feeding area for maintaining (for sub-adults) and even replenishing (for larger age classes) their energy stores before reaching wintering grounds in the Bering Sea.

The BOWFEST results are also supported by the multiyear BOEM-funded Bowhead Whale Aerial Surveys where some of the highest densities (whales/transect km) of bowhead whales in the western Beaufort occurred in the Barrow area. BOEM-funded satellite telemetry studies found some tagged bowhead whales spending remarkably long periods (one up to 32 days) near Barrow, presumably feeding, even after transiting 725 km west to Wrangel Island before returning to Barrow region. Clearly, bowhead whales are travelling, prospecting, searching, and feeding near Barrow during the summer and fall, primarily in shelf waters, but also in Barrow Canyon, taking advantage of changing prey assemblages and oceanographic conditions.

INTRODUCTION

Bowhead whales (*Balaena mysticetus*) are distributed in seasonally ice covered waters of the Arctic and near Arctic, generally north of 54°N and south of 75°N in the Western Arctic Basin (Moore and Reeves 1993). For management purposes, four bowhead whale stocks are currently recognized by the International Whaling Commission (IWC) (IWC 2010). These stocks occur in the Okhotsk Sea (Russian waters), Davis Strait and Hudson Bay (western Greenland and eastern Canadian waters), in the eastern North Atlantic (the Spitsbergen stock near Svalbard), and in the Bering/Chukchi/Beaufort seas. The latter is the Western Arctic stock, the largest remnant population and only stock found within U.S. waters (Rugh et al. 2003). This stock migrates annually from the Bering Sea through the Chukchi Sea to the Beaufort Sea, traversing areas of interest for petroleum extraction. These whales are important to Native subsistence hunters of Alaska and Russia and are protected under the U.S. Marine Mammal Protection Act and U.S. Endangered Species Act. As such, increased understanding of bowhead behavior and distribution is needed to minimize potential impacts from petroleum development.

The waters off Barrow, Alaska, are one such area of concern. Barrow is the largest of the Native subsistence whaling villages, landing over half of the total number of bowhead whales hunted each year. During the spring migration, bowhead whales typically begin arriving in the Barrow area in early April and continue migrating past Barrow until well into June. Most of this migration appears to be a fairly steady flow of whales traveling from the Chukchi Sea to the Beaufort Sea, but late in the spring some whales have been seen making frequent turns in a small area, presumably feeding (Carroll et al. 1987). Bowheads with mud on their dorsal surfaces have also been reported during the spring migration, indicating that they were near the sea bottom, presumably feeding on epibenthic prey (Angliss et al. 1993, Mocklin et al. 2012). Bowhead whale feeding activity has been well documented in the eastern Beaufort Sea (e.g., Richardson et al. 1987) but only occasionally observed in other areas along their migratory route. Braham et al. (1979) stated that Eskimo whalers have occasionally seen bowheads near Point Barrow during the summer, and some whales were feeding east of Point Barrow close to shore. In 1989, bowhead feeding activity was reported off Barrow from late July to mid-August (George and Carroll 1989). Moore (1992) compiled additional records of bowhead whales in the northeastern Chukchi Sea, comprising 26 sightings that occurred from late July to early September and spanned from 1975 to 1991. This indicated that bowheads can continue to occupy areas near Barrow during the late summer months.

In 2005, Moore et al. (2010) flew nine aerial surveys near Point Barrow from 27 August to 9 September with the intention of documenting marine mammal distribution. In total, 145 bowheads were seen in 121 sightings, most of which (133 bowheads) were encountered on 8 September 2005 in two groups, one about 20 km north of Barrow and the second about 50 km southeast of Point Barrow (near Cooper Island). Most whales were quite large (13-17 m) and were heavily scarred, indicating they were old animals. The whales seen near Barrow in September 2005 had mud on their heads, and one was photographed at the surface in a lateral orientation with its mouth open. It appeared to the researchers that essentially all of these animals were feeding. George et al. (2006) reported observations of local hunters who have seen bowhead feeding behavior near Barrow. On 25 August 2002, Rubin Aiken photographed an aggregation of about 30 whales near Cooper Island in what appeared to be echelon feeding (animals lined up in a v-shaped pattern, head to tail), and a local elder (J. Aiken, Sr.) described bowheads as having a diurnal onshore-offshore movement pattern in this area. In 2006, another aerial survey off Barrow recorded groups of feeding bowhead whales in late summer (Moore et al. 2010). Biologists flew six surveys between 1-6 September and witnessed groups of feeding bowhead whales, including dramatic examples of bowheads lunging out of the water synchronously with heads together in a manner reminiscent of cooperatively feeding humpback whales. These observations suggested a need for a more systematic, scientific approach to assess the relative scale of feeding and the consistency of this behavior relative to season, year, age-class, etc., along with relevant ecological parameters, such as bathymetry, currents, temperatures, ice conditions, and prey availability.

The Bowhead Whale Feeding Ecology Study (BOWFEST) was initiated in May 2007 through an Interagency Agreement (formal title: *The bowhead whale feeding variability in the western Beaufort Sea: feeding observations and oceanographic measurements and analyses*) between the Minerals Management Service (MMS, now the Bureau of Ocean Energy Management (BOEM)) and the National Marine Mammal Laboratory (NMML). The goal of this 5-year study was to facilitate development of future oil and gas development-related mitigation by estimating relationships among bowhead whale prey, oceanographic conditions, and bowhead whale feeding behavior in the western Beaufort Sea, with emphasis on identifying predictable aspects in those relationships. The study had five principal objectives:

1. Document patterns and variability in the timing and locations of bowhead whales feeding in the western Beaufort Sea.

2. Estimate temporal and spatial patterns of habitat use by bowhead whales in the study area.

3. Document bowhead whale prey distributions and abundance in the immediate vicinity of feeding bowhead whales as well as in neighboring areas without whales.

4. Document “fine scale” oceanographic and other relevant environmental conditions both near feeding bowhead whales and in neighboring areas without whales.

5. Characterize oceanographic features on a “coarse scale” relative to the study area.

The study focused on late summer oceanography and prey densities relative to bowhead whale distribution over continental shelf waters between the coast and 72°N, and between 152º and 154º west longitudes, which is north and east of Point Barrow, Alaska. Aerial surveys and passive acoustic monitoring provided information on the spatial and temporal distribution of bowhead whales in the study area. Oceanographic sampling identified sources of zooplankton prey available to whales on the continental shelf and the association of this prey with physical (hydrography, currents) characteristics which may affect mechanisms of plankton aggregation. Prey distribution was characterized by examining temporal and spatial scales of the hydrographic and velocity fields in the study area, particularly relative to frontal features. Results of this research may help explain increased occurrence of bowheads feeding in the western Beaufort

Sea (U.S. waters), well west of the typical summer feeding aggregations in the Canadian Beaufort Sea. Information from this study will be used by BOEM for pre- and post-lease analysis and documentation under the National Environmental Policy Act (NEPA) for Beaufort Sea and Chukchi Sea Lease Sales. Final reports for each project discipline and a synthesis of project results are presented herein.

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SECTION I - AERIAL SURVEYS

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Abstract

The aerial survey component of BOWFEST was designed to document patterns and variability in the timing and locations of bowhead whales, as well as to provide an estimate of temporal and spatial habitat use in the study area. In addition, aerial photography provided information on residence times (through reidentification of individual animals) and sizes of whales (through photogrammetry) as a proxy for age. Using NOAA Twin Otters, scientists from the National Marine Mammal Laboratory (NMML) conducted aerial surveys from 23 August – 11 September 2007 (31 flight hours), 27 August – 16 September 2008 (43 flight hours), 29 August – 18 September 2009 (18 flight hours), 31 August – 18 September 2010 (33 flight hours), and 25 August – 17 September 2011 (47 flight hours). The surveys were flown over continental shelf waters from 157° W to 152° W and from the coastline to 72° N ("outer box" boundaries), with most of the effort concentrated between 157° W and 154° W and between the coastline and 71° 44'N ("inner box" boundaries). There were 16 bowhead sightings (an estimated 68 whales) in 2007, 56 sightings (195 bowheads) in 2008, 29 sightings (55 bowheads) in 2009, 102 sightings (452 bowheads) in 2010, and 18 sightings (68 bowheads) in 2011.

The photographic system involved two handheld cameras (both Nikon D200 with 55mm and 180mm lenses) in 2007, one mounted and one handheld camera (Canon EOS-1DS Mark III; 50mm and 70-200mm zoom lenses) in 2008 and 2009, and three mounted cameras (Canon EOS-1DS Mark III; 85mm Zeiss lenses) in 2010 and 2011. During the 5-year study, a total of 1,605 photographs were taken containing 2,387 images of bowhead whales. After matching and removing duplicate photos from multiple aerial passes, we identified 762 unique whales from 1,415 images.

Bowhead feeding behavior was characterized by an open mouth, multiple swim directions, a fecal plume, mud plumes, or mud on the dorsal surface of the whale. Observers reported these behaviors during 50% of sightings in 2007, 7% in 2008, 21% in 2009, 28% in 2010, and 11% in 2011. With the exception of 2007 (at 37% of photo images), photographs documented feeding behaviors more frequently than aerial observers with 16% in 2008, 23% in 2009, 51% in 2010, and 22% in 2011. Mapping locations of feeding bowhead whales revealed that 91% of individual bowhead whales showing photographic evidence of feeding were located in shelf waters, predominantly along the 20 m isobath. More feeding behavior was observed and photographed during years when most sightings occurred on the shelf (2007, 2009, and 2010).

"Traveling" was the most commonly recorded behavior (45% for all years combined), but direction of travel was highly variable among years, suggesting animals were not necessarily

migrating through the area. Only in 2008, was swim direction significantly clustered around a mean (295°T, n = 21 sightings, Rayleigh Z = 7.103, p = 4.82E-4), and clearly westward. Within the limited sampling period, there was no apparent increase in sightings from late August to mid-September. The paucity of individual resightings (based on photographic recaptures) between survey days (3 matches out of 762 identified whales) suggested very low residence times off Barrow. However, none of the whales resighted within a season had moved west of the original sighting; as would be expected during the fall migration; all subsequent sightings were to the east. Age composition varied from year to year but on average was evenly represented by juveniles and adults.

The majority of bowhead whales were in relatively shallow water (80% of sightings in waters <=50m). Habitat partitioning was evident among the cetacean species observed in greatest numbers: bowhead, gray, and beluga whales. In general, each species occupied a unique region within the study area, bowheads on the continental shelf in waters <50 m deep (in all years except 2011); belugas over the deep Barrow Canyon and offshore slope waters; and gray whales near the 50 m isobath along the edge of Barrow Canyon. Belugas were seen in all years except 2009; although survey effort was restricted to the inner box that year, beluga sightings were also low the previous and following year. Gray whales were present during every survey year, and sighting numbers were fairly consistent year to year, with the exception of 2010 when their numbers were at their lowest and bowheads at their highest.

When examining bowhead whale habitat preferences based on all years of the aerial survey data, we considered four parameters in the model: bathymetry, bathymetric slope, distance from shore, and distance from the shelf break. Both distance from shore and distance from the shelf break were significant in predicting the presence of bowhead whales ($p < 0.01$). Bowhead whales preferred to be close to shore and to the shelf break; therefore, their preferred habitat were areas where the shelf break came closest to shore. However, the model was only able to correctly discriminate between the presence (bowhead sighting) and absence (random points) 67% of the time. As mentioned earlier, feeding bowheads were predominantly found in shelf waters. Bathymetry, as well as bathymetric slope, distance from shore, and distance from the shelf break were significant in predicting gray whale presence ($p < 0.01$). Gray whales preferred to be in waters along the shelf break. The model was able to correctly classify gray whale presence and absence 96% of the time. Of the four parameters included in the model, only bathymetry was significant in predicting beluga whale presence ($p < 0.01$). These animals preferred to be in deeper water than would be predicted at random and the model correctly discriminated sightings from non-sightings 82% of the time. While there was a large portion of overlap for these species, there is clear spatial separation in their preferred habitats. Bowhead whale preferred habitat, regardless of behavior observed, included shelf, shelf break, and canyon waters primarily north and east of Barrow, beluga whale habitat primarily included the canyon, while gray whale preferred habitat located at the interface of bowhead shelf and beluga canyon habitat – following the shelf break.

Introduction

Bowhead whales of the Western Arctic stock migrate each spring from the Bering Sea, through the Chukchi Sea, to the eastern Beaufort Sea where they spend most of the summer (Moore and Reeves 1993). By early September, bowheads begin their fall migration, leaving the eastern Beaufort Sea and moving past Barrow during September and October before heading west across the Chukchi Sea (Moore and Reeves 1993). Although bowheads are more commonly seen off Barrow during the spring and autumn migrations, there have also been reports of whales feeding near Barrow from late July to early September (Moore 1992; Moore et al. 2010a; Moore et al. 2010b; George et al. 2006). Through work conducted as part of the BOWFEST aerial project, we examined whether these animals were traveling through the area or were effectively residents during the summer.

The BOWFEST aerial surveys focused on determining the scale to which bowheads spent time feeding near Barrow in late summer and the consistency of this behavior relative to location within the study area, year, and age class (using whale size as a proxy for age). BOWFEST also explored the ecological relationship between feeding bowhead whales and relevant oceanographic parameters -- such as bathymetry, currents, temperatures, and ice conditions -- to assess whether oceanographic features indirectly affected the location of bowhead feeding aggregations by influencing prey distribution. The aerial survey component of BOWFEST included a combination of systematic transects and photography to document patterns and variability in the occurrence of individual bowhead whales as well as provide descriptions of spatial habitat use within the sample period.

Methods

Study Area and Trackline Design

Study area – The study area included continental shelf waters and deep sea canyons between 157° W and 152° W and from the Alaska coastline (barrier islands) to 72° N (Fig. I-1). This area was divided into a two-part sampling scheme with increased sampling in an area accessible to BOWFEST vessel-based operations and reduced sampling in the outer section of the study area. The inner section of the study area was 7,276 km^2, and the outer section was 12,152 km^2 (total = 19,428 km^2).

Trackline design – The design of the sampling scheme was based on six years of data (2000-2005) from the Bowhead Whale Aerial Survey Project (BWASP), operated by Minerals Management Service (MMS). These data provided information on bowhead whale density (whales per unit effort) northeast of Barrow. This helped stratify and ultimately determined the distribution and quantity of survey effort relegated to the inner and outer sections of the BOWFEST study area. From the BWASP data, the density of bowhead whales in the inner section was approximately six times greater than in the outer section. Using equations 7.1, 7.2, and 7.4 from Buckland et al. (1993), we calculated the total effort needed in each of the two sections to obtain a detection probability sufficient for determining relative densities of whales. Because small boats have limited range to collect oceanographic data, and much of the intent of BOWFEST was to compare ecological parameters relative to whale distribution, we arbitrarily decreased the effort for the larger section.

Trackline orientation was based on the pre-determined oceanographic tracklines which originally ran in a northeasterly direction at 66° True (i.e, perpendicular to the generalized coastline). The study area contained approximately 5,011 km of trackline, of which 3,554 km were in the inner section and 1,457 km in the outer section (Fig. I-1; note: there were slight variations in the early study years; see Annual Reports 2007-2011 in Appendices 1-5 for details). Tracklines were flown sequentially west to east in order to minimize the probability of resighting the same whale(s) on the assumption that there may have been a westward migration underway.

Trackline spacing – The tracklines in the inner section were spaced 2 km apart while lines in the outer section were spaced 8 km apart. The placement of the first (most westward) survey line in the inner section of the study area (closer to Barrow) was determined by random selection. We purposely used the same random value to calculate placement of the first line in both sections of the study area in order to align the tracklines in the inner study area with the tracklines in the outer study area (Fig. I-1). This method simplified flight logistics and minimized transit time between tracklines. Subsequent tracklines were parallel to the first trackline.

Sampling schemes – In order to prevent overlap in survey effort due to tightly spaced tracklines, sampling schemes were devised (see Fig. I-1 for schemes used 2009-2011; see Appendices for 2007-2008). Sampling schemes consisted of shifting the trackline array short distances to the east or west, removing the likelihood that any tracklines would be flown twice within a season. The first scheme (Scheme 1) was created by selecting the first line from the west side of the study area and every fourth line thereafter. Using the same method, beginning with the second through fourth lines from the west side of the study area, the three remaining schemes were created. As a result, tracklines for each scheme were spaced approximately 8 km and 32 km apart in the inner and outer sections of the study area, respectively (Fig. I-1).

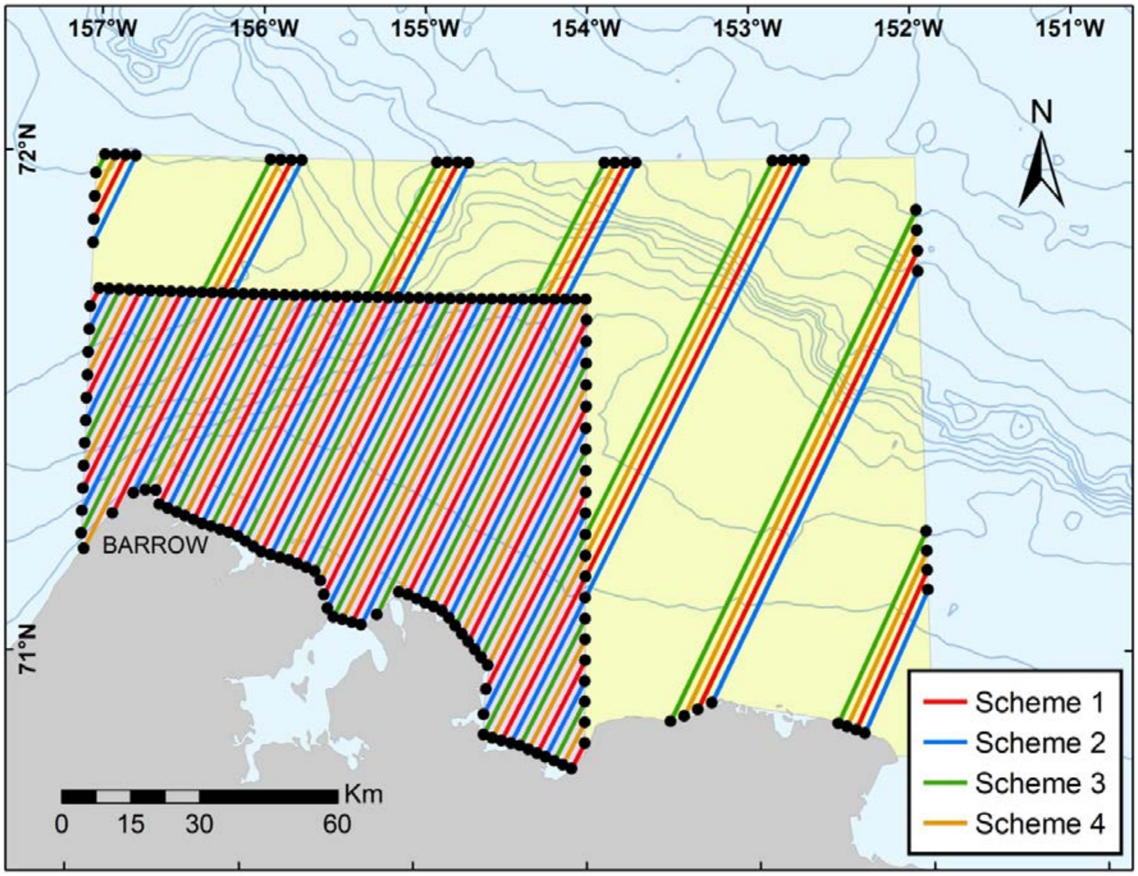


Figure I-1. *The four survey schemes for the 2009-2011 BOWFEST aerial surveys. See Appendix 1 and 2 for schemes from 2007 and 2008. Note most of the effort concentrated between 157° W and 154° W and between the coastline and 71° 44'N (the "inner box" boundaries).*

Survey Protocol

Aircraft – The BOWFEST aerial survey aircraft was a NOAA Twin Otter (N56RF/N48RF in 2007, N48RF in 2008, N57RF in 2009, and N56RF in 2010/2011). These aircraft have twin engines, high wings, and approximately 5 hours of flying capacity. Two large bubble windows provided views ahead of and beneath the plane for the left and right observers and an open belly window/camera port allowed for vertical photography. Communication among observers, pilots, and data recorder occurred via an intercom system. Pilots reported whale locations to the oceanographic vessels via VHF radio/satellite phone. Aircraft speed was approximately 185 km/hr (100 knots). Survey altitude was 310 m (1,000 ft); most photography passes were between 210 m (700 ft) and 240 m (800 ft)[1].

Survey effort – During flight, effort was categorized as: deadhead (transiting between tracklines or bee-lining for a location); trackline (systematic search along designated transects);

[1] NMFS Permit No. 782-1719 (years 2007-2010) and Permit No. 14245 (2011)

circling (breaking from the trackline mode to investigate a sighting); and photo mode (also circling but specifically to collect photographs of whales).

Data entry – The data recorder used a custom-built aerial survey software program installed on a laptop computer which interfaced with a portable Global Positioning System (GPS – Garmin 76 CSx) (see Appendices I-1 through I-3 for a visual of the survey program and detailed survey data descriptions). The program saved sighting information, weather, effort (on or off), crew position, and photo data into an Access database. Position information (latitude, longitude, speed, altitude, and heading) was recorded automatically every five seconds; all others entries were entered manually including each start and stop of a trackline. Specific data entries for weather included overall percent ice cover, ice type (categorized using the Observers Guide to Sea Ice http://archive.orr.noaa.gov/book_shelf/695_seaice.pdf), sky condition, and sea state (on a Beaufort scale) as well as glare, visibility angle, and visibility quality for each side of the aircraft (see Appendix I-2 for definitions).

To obtain the visibility angle, observers used an inclinometer (0° = horizontal; 90° = straight down) to accurately determine the searchable distance out each side of the aircraft. Visibility quality within the given inclinometer angle was one of five subjective categories from excellent to useless; for example, a record of "20° good" meant that from the trackline out to 20° (0.8 km), sighting conditions were good, and farther from the trackline (<20°) the visibility worsened and was not recorded. Unsurveyed areas (i.e., off effort) included portions of the trackline where observers rated visibility quality as poor or useless on both sides of the aircraft. All marine mammal sightings included date, time, observer, inclinometer angle, group size, reaction to plane, and species; in addition, for bowhead whale sightings, observers reported calf number, travel direction, sighting cue, dominant behavior, group composition, and number of nearby vessels.

Sighting protocol – Immediately upon sighting a marine mammal, each observer reported the group size and species to the data recorder. If the sightings occurred ahead of the aircraft, when the plane came abeam of the sighting, the observer noted an inclinometer angle and whether or not there was an observable reaction to the aircraft. When a whale appeared to be only in a travel mode (not feeding, sleeping, etc.; see Appendices I-1 through I-3 for a visual of the survey program and other behavior code descriptions), it was recorded as "traveling," and a swim direction was given relative to an analog clock (aircraft nose is 12 o'clock) and later converted relative to global directions (0°T = north). The plane deviated from the trackline only when an observer was unable to identify the species identity of a large cetacean. If bowhead whale sightings occurred while on transect, typically the trackline was completed before going off effort to begin photographic passes. This method allowed for a systematic search effort along tracklines and minimized confusion in reporting sightings while off-effort.

Photographic Protocol

Cameras and lenses – Photographs were taken through a port in the belly of the plane (Fig. I-2A). The port was covered in optical quality glass in 2007; however, because glare on the window was problematic, the glass was removed for the 2008-2011 surveys. The photographic system included two handheld cameras (both Nikon D200 with 55mm and 180mm lenses) in 2007, one mounted and one handheld camera (Canon EOS-1DS Mark III; 55mm and 70-200mm zoom lenses) in 2008 and 2009 (Fig. I-2B), and three mounted cameras (Canon EOS-1DS Mark III; 85mm Zeiss lenses) in 2010 and 2011 (Fig. I-2C, D).

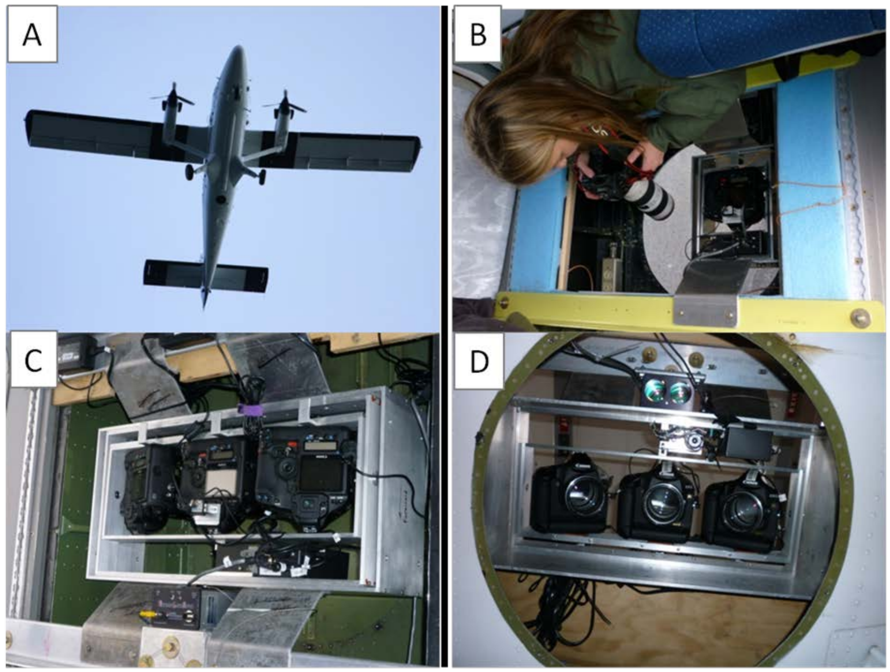


Figure I-2. *A) A NOAA Twin Otter with open belly port. B) Handheld Canon EOS-1DS Mark III with 70-200 mm lens used for photo-identification next to a mount for a single camera. C) A triple-camera forward motion compensating mount, as seen from above D) and below.*

Photogrammetry – In 2007, when both cameras were handheld, the photographer with the small, fixed lens (55 mm or 85 mm) made every attempt to hold the camera as level as possible (no angling) to obtain usable images for photogrammetry (i.e., measuring dimensions of the whales). In all other years, cameras used for photogrammetry were mounted (for 2010 and 2011, the camera in the center of the triple-camera array was prioritized for photogrammetry). The fixed lenses, having little or no magnification, were focused to near infinity, and taped to impede rotation. In 2008 and 2009, the photogrammetry camera was housed in a Forward Motion Compensation (FMC) mount (installed on the port side of the belly window) which uses a rocker mechanism to counter the forward velocity of the relative ground speed. In 2010 and 2011, three cameras were installed side by side in an FMC mount. These cameras were integrated with an autonomous radar altimeter (Honeywell AA300 model) in order to collect precise altitudes each time the cameras were fired (http://www.aerialimagingsolutions.com/fmcmount.html; Fig. I-2C). Unlike the handheld cameras, mounted cameras were fired using a custom built data acquisition system that automated the retrieval of data: altitude; time of camera firing; frame number; aircraft speed; and focal length of the camera lens. A keystroke on the computer triggered cameras to continuously fire so that each consecutive image overlapped the previous photo by 60%, adjusted for altitude. When three cameras were used, the left and right cameras overlapped the center camera by 20% by angling them slightly inward. Cameras recorded in RAW format, 21.0 megapixels (5616 x 3744) images and were set to shutter priority (1/1000 sec) and ISO 400-800.

Aerial passes – After breaking trackline effort, passes were flown over each bowhead group until the observers felt that most whales in the area had been photographed. During each photographic pass, the forward observer provided a countdown to alert the photographer(s) and data recorder when a whale was about to appear under the aircraft.

Land-based calibration target – Each year, calibration targets were photographed using the same cameras and lenses used to photograph bowhead whales. The land target, provided by Craig George (NSB), consisted of painted boards 3.8 cm thick by 24 cm wide (nominally 2" x 10") with precisely measured intervals that were visible at survey altitude (310 m [1,000 ft]) (Fig. I-3). NSB personnel positioned the calibration target on an abandoned airstrip north of Barrow near the former Naval Arctic Research Lab's aircraft hangar. Large painted numbers on the airstrip were also measured and photographed (not shown on Figure I-3). Altitudes for photogrammetric passes were at 30.5 m (100 ft) intervals ranging from 152 m (500 ft) to 457 m (1,500 ft), weather permitting. Measurements from the photographs provided a linear regression correction factor for the altimeter readings. This correction factor was then applied to photographs of bowhead whales used in the photogrammetric study.

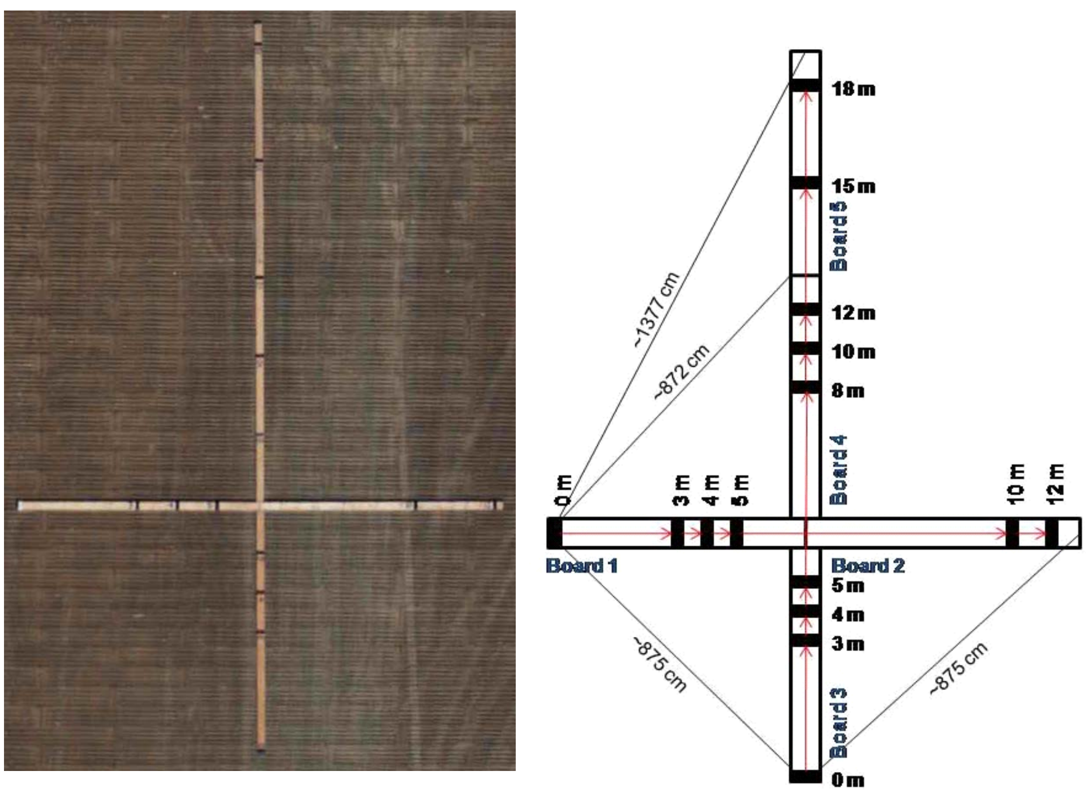


***Figure I-3**. Aerial image (left) and diagram (right) of the land-based calibration target.*

Floating target – In 2008 and 2009, photographs were taken of a floating water target to look for possible discrepancies between radar altimeter performance over land and water (see Mocklin et al. 2010). The target consisted of 60 m non-stretch rope attached to an array of floats (4 large and 1 small) followed by a 36-inch drogue to keep the line straight and reduce undulations (Fig. I-4). The drogue was attached to the rope by a 5/16" swivel to allow free rotation. A 27 ft motorboat towed this apparatus at sea and then in a lagoon not far from Barrow where sea surface conditions were fairly calm.

Figure I-4. *Aerial photograph of the 27 ft motor boat towing the water-borne calibration target in 2008.*

Photo data – After each survey, all photographs were geo-referenced using RoboGEO. The GPX file was downloaded from the GPS unit, and RAW images were converted to TIFF's in 2007 to 2009 and to JPG's in 2010 and 2011. We used the RoboGEO program to interpolate latitude and longitude from the GPX file based on time and to embed this position information in the exif data of each photograph. Since time is used to link photographs to the tracklog position, we synchronized the date and time on all cameras with the date and time on the GPS unit at the beginning of each survey. Once geo-referenced, all images and associated metadata were sent to Bill Koski of LGL for analysis of whale lengths.

Photo processing – Processing images for photo-identification of individual whales began with cropping and labeling images in a standardized way. These images were then archived in the large collections maintained by NMML and LGL. Whale images were scored for quality and identifiability (see Rugh et al. 1998). Quality scores of 1+ (best), 1-, 2+, 2- or 3 (worst) were assigned to four zones on the whale's body: rostrum, midback, lower back, and flukes. A zone scored as 3 was considered inadequate for purposes of reidentifying a whale. Identifiability scores for each zone included H+ or H- (highly marked), M+ or M- (moderately marked); U+, U- (unmarked); or X (meaning the zone was not depicted clearly enough in the photo to determine mark status). Scores of X almost always corresponded to quality 3.

Data Analysis

Daily summary reports of survey effort and sightings were uploaded to the NMML Bowhead Whale website throughout each field season (beginning in 2008) (http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_BOWFEST.php). Reports compiling the aerial survey data and the other components of BOWFEST (passive acoustics, oceanography, tagging, small boat surveys, and stomach analyses) were published annually to the same website for each year (2007 to 2011). For this final report, additional analyses of the aerial survey dataset include:

Distribution and habitat partitioning – Distribution maps for all sightings were created using ArcGIS 10.1. Bowhead whale sightings were linked to a raster bathymetry file (name: IBCAO_V3_500m_RR; Jakobsson et al. 2012) to determine depths (in meters) associated with each sighting. Distributions were compared for the cetacean species most frequently encountered during the study: bowhead, gray, and beluga whales. Each species distribution was weighted by group size using 1SD “directional distribution” ellipses in ArcView which captured ~68% of the sightings. Given increased effort in the inner study area box, additional analyses were run using only sightings within this region to confirm inner box distributions were not significantly different from analyses using all sightings.

Habitat preferences – Using ArcGIS 10.1, we linked all beluga, bowhead and gray whale sightings within the smaller study area to bathymetric depth (BATHY), bathymetric slope (SLOPE), distance from the shelf break (100 m isobaths - DISTSHELF), and distance from shore (DISTSHORE). The resolution of all spatial data layers was 100 X 100 m. For each whale species, random locations were generated to match the number of sightings within the smaller study area. In order to examine the structure within the data, we employed a logistic regression model. This type of analysis describes the presence or absence of sightings as a function on environmental, or explanatory, variables and yields the estimated probability of habitat use for a species. After examining the variables for colinearity, we used a backward elimination method to assess the significance of the environmental variables in predicting habitat use. Akaike information criteria (AIC), which seeks to maximize the likelihood and minimize the number of model parameters, was used to select the final model for each of the three species. We determined the diagnostic accuracy of each of these models using a receiver operating characteristic (ROC) curve which is able to detect a signal in the presence of noise. This technique results in a threshold value, ranging from 0 to 1, that minimizes false positive and false negative values. The area under the ROC curve (AUC) ranges from 0 (no discrimination ability) to 1 (perfect discrimination ability) against false positives and false negatives. Values greater than or equal to this threshold value were classified as preferred habitat.

Travel direction – Swim direction at the time of sighting was compared for all bowhead whales with “travel” noted as the primary behavior. A Raleigh uniformity test (Rayleigh test; KCS, 2012), run in the software program Oriana, determined whether clustering around a mean swim direction occurred within each survey year.

Residency times – All images were compared to each other to determine if some individual whales were photographed multiple times. Following intrayear comparisons, whale images were compared to images from other BOWFEST years.

Feeding behavior – When each bowhead sighting was entered, the recorder noted whether feeding had occurred and the activity associated with feeding (mud on the whale, mouth open, fecal plume, mud plumes, or echelon formation). Photographs were also reviewed for evidence of feeding. The primary feeding strategy photographed was epibenthic feeding which often left a coating of mud on the dorsal surface of the whale (Mocklin et al. 2012). Other photographed indicators of feeding were an open mouth (skim feeding) or the presence of feces.

Results

Survey Effort

Flight hours – Aerial surveys occurred in the BOWFEST study area from the end of August to mid-September of 2007 to 2011 (Table I-1) for a total of 171.1 hours flown. Fog, low ceilings, and high winds limited flying conditions on many days, so the most that was ever flown in one year was 47 hours (of the 70 to 76 flight hours scheduled for the project each year) (Table I-1). In 2009, low ceilings, rain, snow, winds, and fog Most in-flight “on effort” survey time (52%) was spent on trackline, and most “off effort” time (43%) was during periods of bad weather (Fig. I-5).

Table I-1. *Survey days, flight hours, and percent time spent on trackline (in parentheses) during BOWFEST aerial surveys, late August to mid-September 2007-2011. Black boxes depict survey days; gray boxes depict days the aircraft and crew were available but precluded from flying due to weather (fog (F), low cloud cover (LC - <500 ft ceilings), winds (W - >20 kts),) rain (R), snow (S)), or mechanical issues (MI).*

Day	2007	2008	2009	2010	2011
22-Aug	LC				
23-Aug	6.7hr (38%)				
24-Aug	3.8hr (21%)				
25-Aug	F/LC				
26-Aug	LC/W				2.0hr (0%)
27-Aug	no aircraft	LC/W			F
28-Aug	no aircraft				F
29-Aug	no aircraft	4.9hr (35%)			F
30-Aug	no aircraft	3.9hr (25%)	W		F
31-Aug	no aircraft	LC/W	W	no fuel	F
1-Sep	no aircraft	LC/W	W	0.9hr (0%)	F
2-Sep	no aircraft	W	5.7hr (46%)	no fuel	3.2hr (35%)
3-Sep	no aircraft	F/W	W/R	F/LC/R	F
4-Sep	no aircraft	LC	4.3hr (36%)	F	F
5-Sep	F/LC	6.3hr (39%)	W	F	6.9hr (59%)
6-Sep	4.1hr (1%)	6.4hr (36%)	W/S	5.3hr (48%)	W
7-Sep	5.5hr (46%)	R/F/LC	4.4hr (7%)	F/LC	4.2hr (73%)
8-Sep	LC	R/F/LC	F/LC/R/S	3.9hr (44%)	4.8hr (57%)
9-Sep	2.5hr (53%)	R/F/LC	F/LC/R/S	F	4.5hr (54%)
10-Sep	LC	R/F/LC	F/LC/R/S	F	W
11-Sep	8.2hr (57%)	6.7hr (46%)	F/LC/R/S	F	W
12-Sep	LC/F/W	F/LC	F/LC/R/S	9.5hr (62%)	8.2hr (58%)
13-Sep	aicraft 100hr	10.9hr (49%)	F/LC/R/S	2.1hr (26%)	8.0hr (45%)
14-Sep		MI	1.0hr (0%)	F/W	4.3hr (63%)
15-Sep		2.4hr (18%)	2.7hr (33%)	4.4hr (60%)	W
16-Sep		1.1hr (40%)	LC	LC/W	0.7hr (39%)
17-Sep		W	LC	5.2hr (52%)	
18-Sep				1.6hr (0%)	
Total	30.8hr (39%)	42.6 (39%)	18.0hr (30%)	32.9hr (49%)	46.8 (53%)

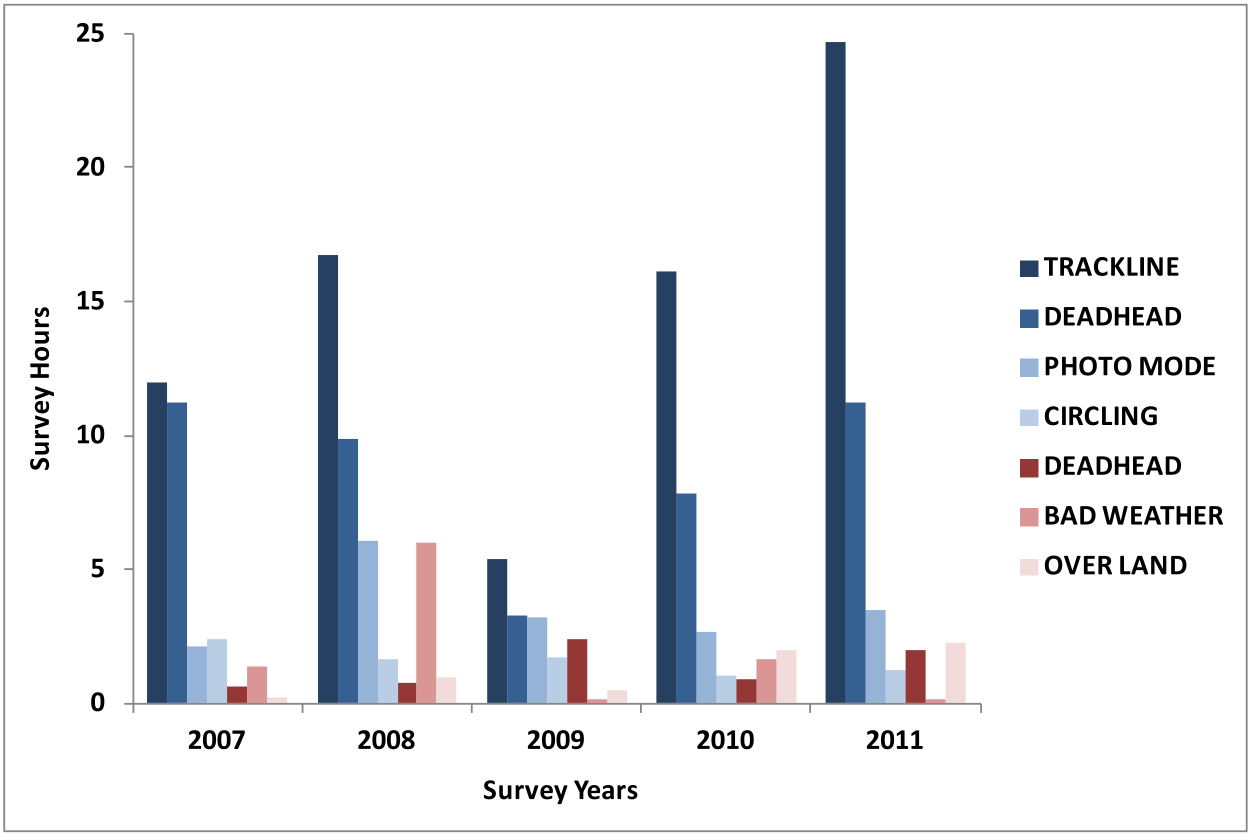
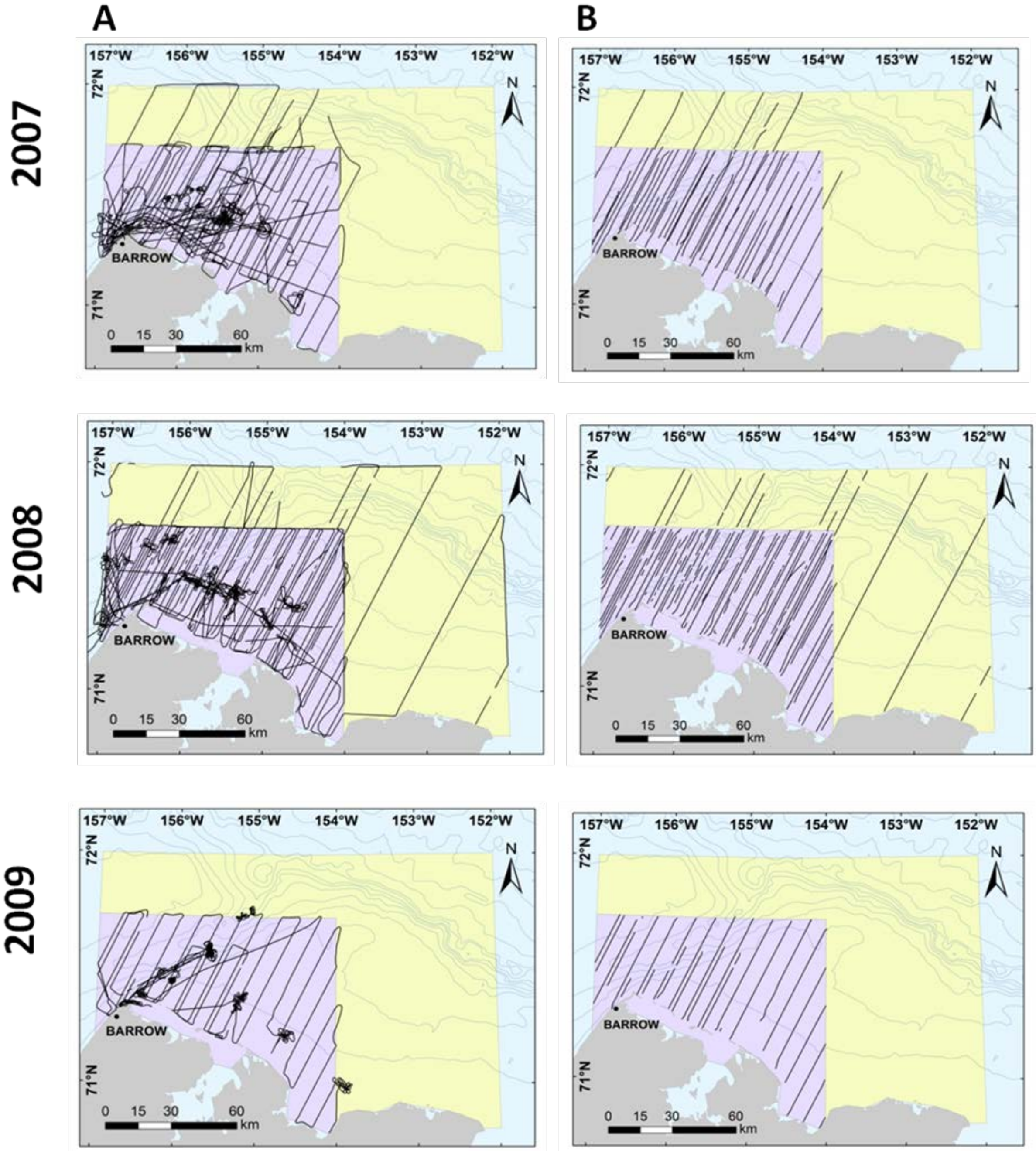


Figure I-5. *All in-flight effort modes during each BOWFEST aerial survey, late-August to mid-September 2007-2011. Blue is "on effort" and red is "off effort."*

Trackline effort – The sums of effort on systematic transects were 2,280 km in 2007; 3,083 km in 2008; 1,007 km in 2009; 3,060 km in 2010; and 4,611 km in 2011 with the greatest percentage (89%) of effort occurring within the smaller study area (Table I-2, Fig. I-6).

Table I-2. *Survey trackline effort during the BOWFEST aerial surveys for the inner and outer boxes, late August to mid-September 2007-2011. Total kilometers (km) flown in each area (3,554 km: inner box, 5,011km: outer box) and bowhead whale sighting rates are shown.*

	Inner box (km)	Inner box covered (%)	Outer box (km)	Outer box covered (%)	Sightings on trackline	Sighting rate
2007	2071.2	58%	208.6	4%	7	0.003
2008	2637.3	74%	445.5	9%	53	0.017
2009	1007.0	28%	0.0	0%	17	0.017
2010	2653.0	75%	407.5	8%	83	0.027
2011	4134.4	116%	476.5	10%	7	0.002


A
B
2007
2008
2009
157°W
156°W
155°W
154°W
153°W
152°W
72°N
71°N
N
BARROW
0 15 30 60
km

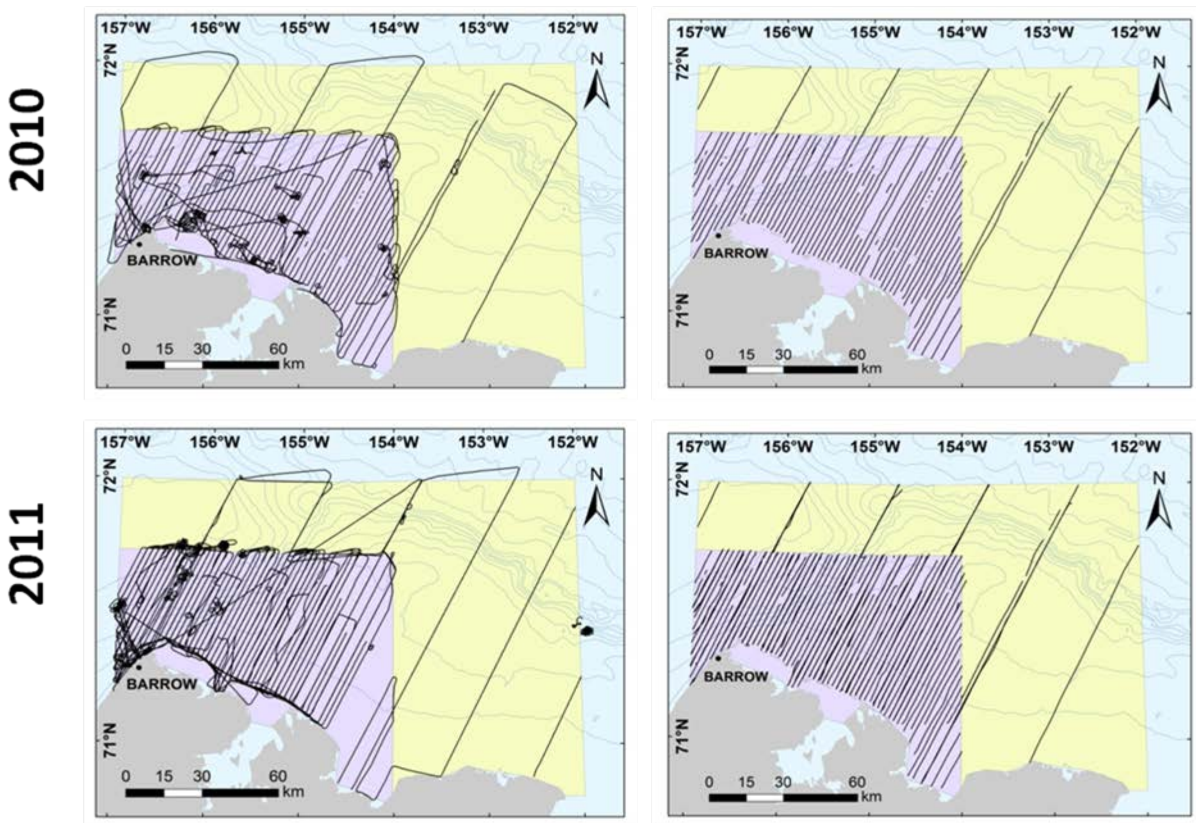


Figure I-6. *A) All search effort, including transect, circling, and photo effort; and B) dedicated transect effort during each BOWFEST aerial survey, late-August to mid-September 2007-2011.*

Poor visibility – Throughout the BOWFEST field seasons, a total of 10.3 hours of survey time (6.3% of all flight time) was in poor or useless viewing conditions, and there were 57 days without surveys due to weather (56% of all days when the aircraft was available for flying) (Table I-1). On flight days, 56% of the survey effort was over calm seas with few whitecaps (Beaufort Sea States 3 or lower (Fig. I-7), in general, whale sightings diminish as sea conditions worsen (i.e., the more sea surface disturbance there is, the harder it is to distinguish a whale). Sea states of 3 and lower are considered optimal for detecting most marine mammal species, however, observers reported 91% of survey effort as "fair" or better (Fig. I-8), suggesting despite higher sea states they felt confident they could detect bowhead whales.

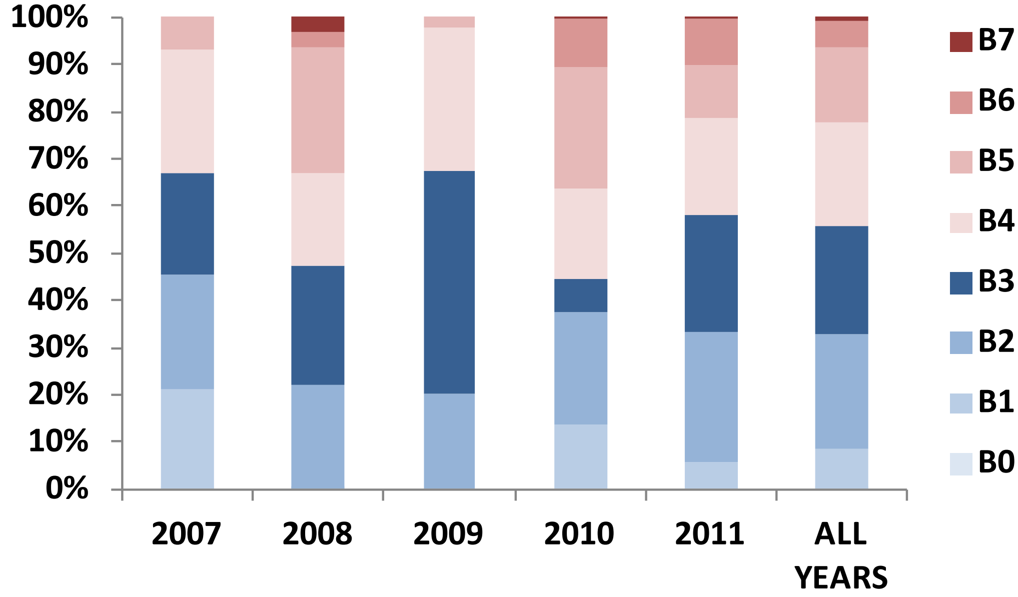


Figure I-7. *BOWFEST aerial survey effort (kilometers surveyed) conducted under varying Beaufort sea states (as described in Appendix I-2), 2007-2011.*

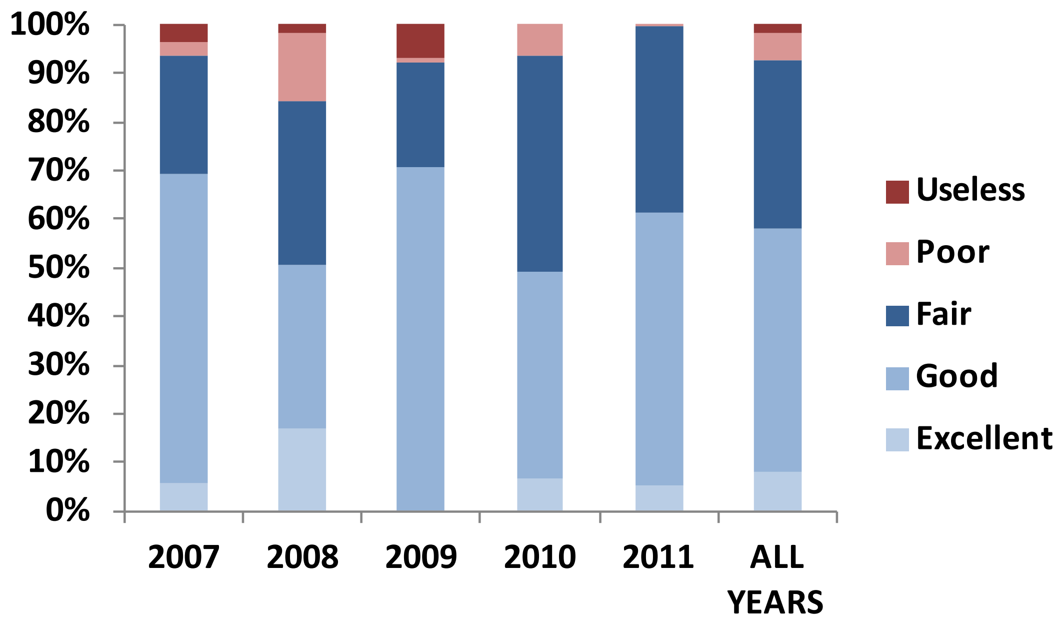


Figure I-8. *BOWFEST aerial survey effort (kilometers surveyed) conducted under varying qualitative visibility codes ranging from "excellent" to "useless", 2007-2011.*

Sightings

Species – Marine mammals observed within the study area were identified to species whenever possible (Table I-3). Over 1,000 sightings of marine mammals were recorded during the 5-year study. In addition to the focal species, bowhead whales, observers saw gray whales (*Eschrichtius robustus*), a humpback whale (*Megaptera novaeangliae*), beluga whales (*Delphinapterus leucas*), ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), walrus (*Odobenus rosmarus*), and polar bears (*Ursus maritimus*). Small pinnipeds, such as ringed seals and spotted seals (*Phoca largha*), were often difficult to differentiate and identify to species given our relatively high survey altitude (310m [1,000 ft]) (Table I-3). Bowhead whale counts usually increased when we went off trackline to circle or photograph groups of whales (in parenthesis in Table I-3). Bowhead whales seen between transects were also included in the grand total number.

Table I-3. *Summary of marine mammal sightings (and counts indicated by parentheses) made during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

	2007	2008	2009	2010	2011	Total
Species	Sightings/Count	Sightings/Count	Sightings/Count	Sightings/Count	Sightings/Count	Sightings/Count
Bowhead Whale	16/35 (68*)	56/191 (195*)	29/35 (55*)	102/396 (452*)	18/10 (68*)	221/667 (838*)
Gray Whale	20/29	22/39	22/30	6/10	26/34	96/142
Beluga Whale	18/30	2/2		2/5	95/460	117/497
Humpback Whale			1/1			1/1
Ringed Seal	73/119	4/6	2/2	8/40		87/167
Bearded Seal	31/89	9/9	6/6	3/3	21/22	70/129
Walrus	65/255		3/12	1/2		69/269
Polar Bear	2/2	4/5		16/23	6/6	28/36
Unid Large Cetacean		13/13	6/7	1/1	6/9	26/30
Unid Small Cetacean					1/1	1/1
Unid Pinniped	10/12	86/139	25/52	61/86	117/237	299/526
Total	**235/571**	**196/404**	**94/145 (162*)**	**200/566 (553*)**	**290/779 (836*)**	**1,015/2,465 (838*)**
Sightings/km	**0.103**	**0.064**	**0.093**	**0.065**	**0.063**	

* represents the number of bowheads counted after breaking trackline to circle, i.e., the final count

Distribution and habitat partitioning – Seals occurred throughout the study area (Fig. I-9). Counts per survey year were typically in the hundreds. In 2007 the majority of small seals were identified to species (i.e., most of the sightings depicted in Fig. I-9). However, after 2007, we decided to implement a more conservative approach due to the difficulty of identifying the species of small seals given our survey altitude. Therefore, most small pinnipeds seen after 2007 were recorded as "unidentified".

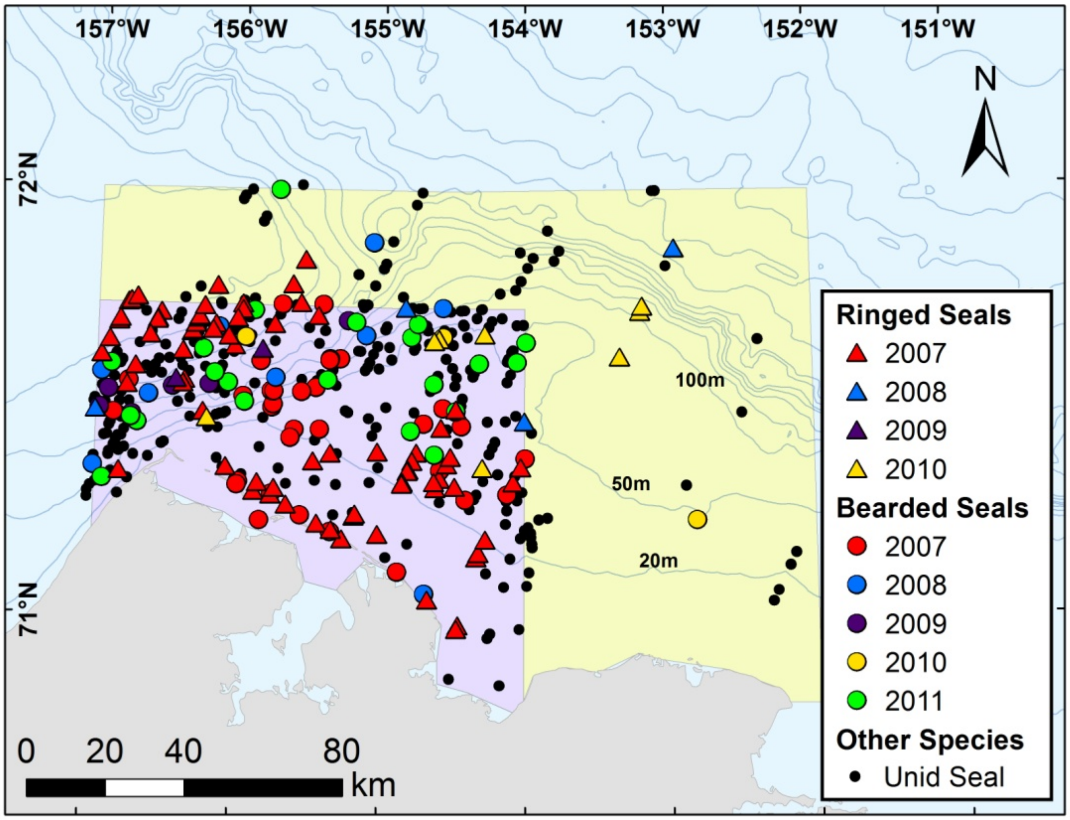


Figure I-9. *Map showing locations of seal sightings during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Walruses were not hauled out on land or ice in the study area (Fig. I-10). Most sightings occurred in 2007, with walrus primarily associated with the deeper waters of the Barrow Canyon.

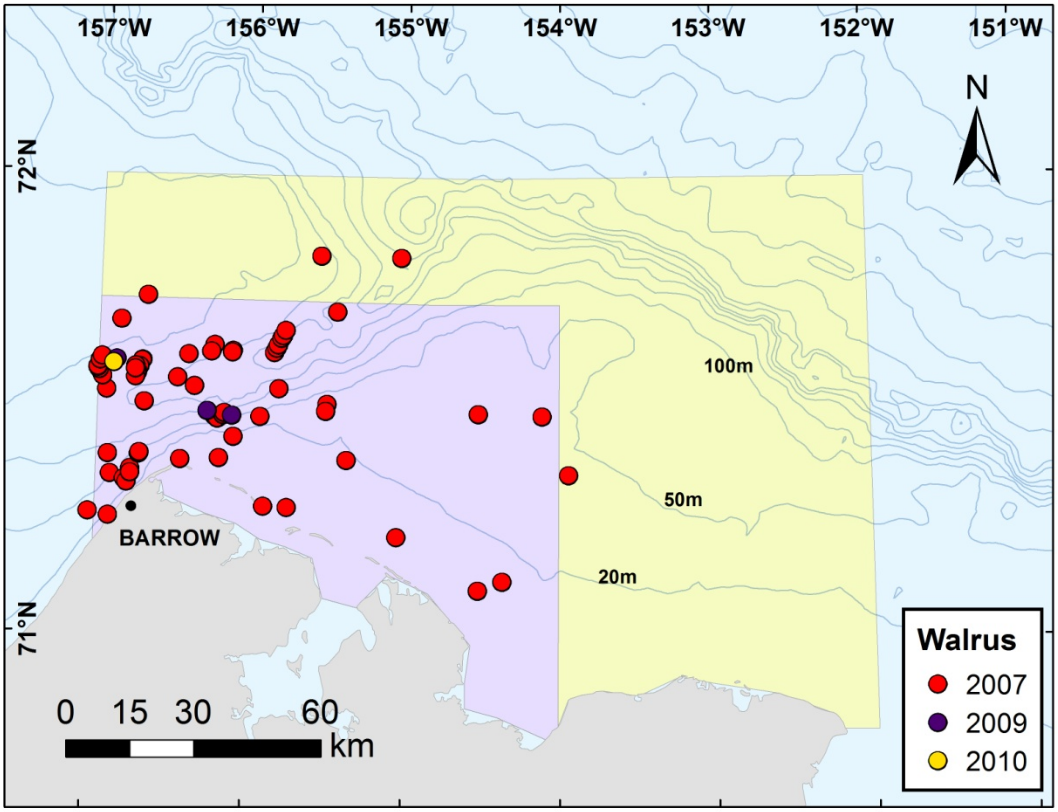


Figure I-10. *Map showing locations of walrus sightings during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Most of the polar bears (61%) were seen on land, generally on the barrier islands; one was resting on sea ice; all others (36%) were swimming relatively close to shore (Fig. I-11). Polar bears were not seen during the 2009 survey, but the following year numbers were over twice that of other survey years.

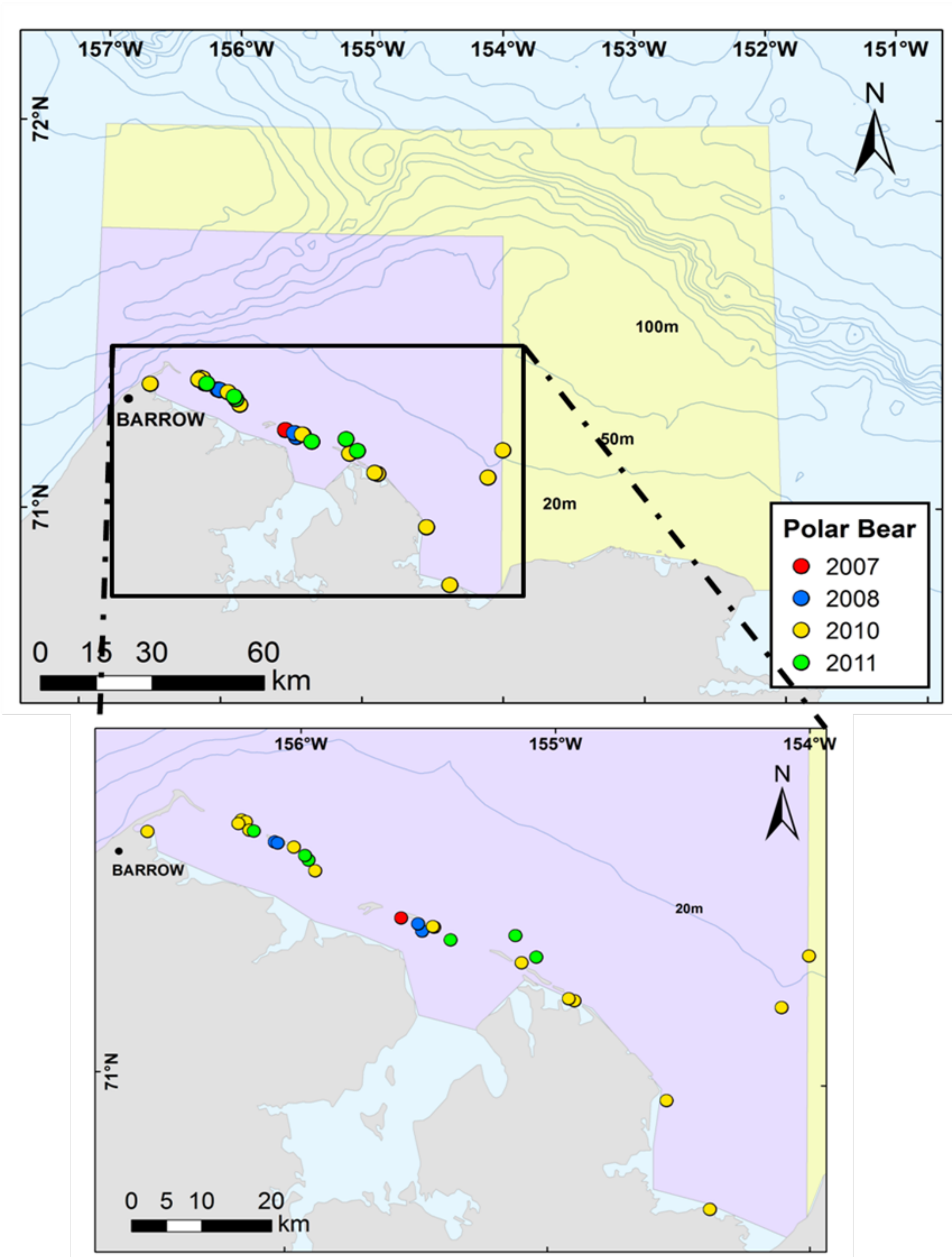


Figure I-11. *Map showing locations of polar bear sightings during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Of the cetaceans, the only odontocetes observed were beluga whales (Fig. I-12). Though not seen during BOWFEST aerial surveys, harbor porpoise (*Phocoena phocoena*) also occur off Barrow (Suydam and George 1992), and occasionally killer whales (*Orcinus orca*) (Braham and Dahlheim 1982). Belugas were seen in all years but 2009, and although survey effort was restricted to the inner box that year, sighting numbers were also low the year preceding and following 2009. In general, belugas were found in slope waters and over the deeper waters of the Barrow Canyon (Fig. I-12), though in 2011, groups were also observed swimming near the barrier islands.

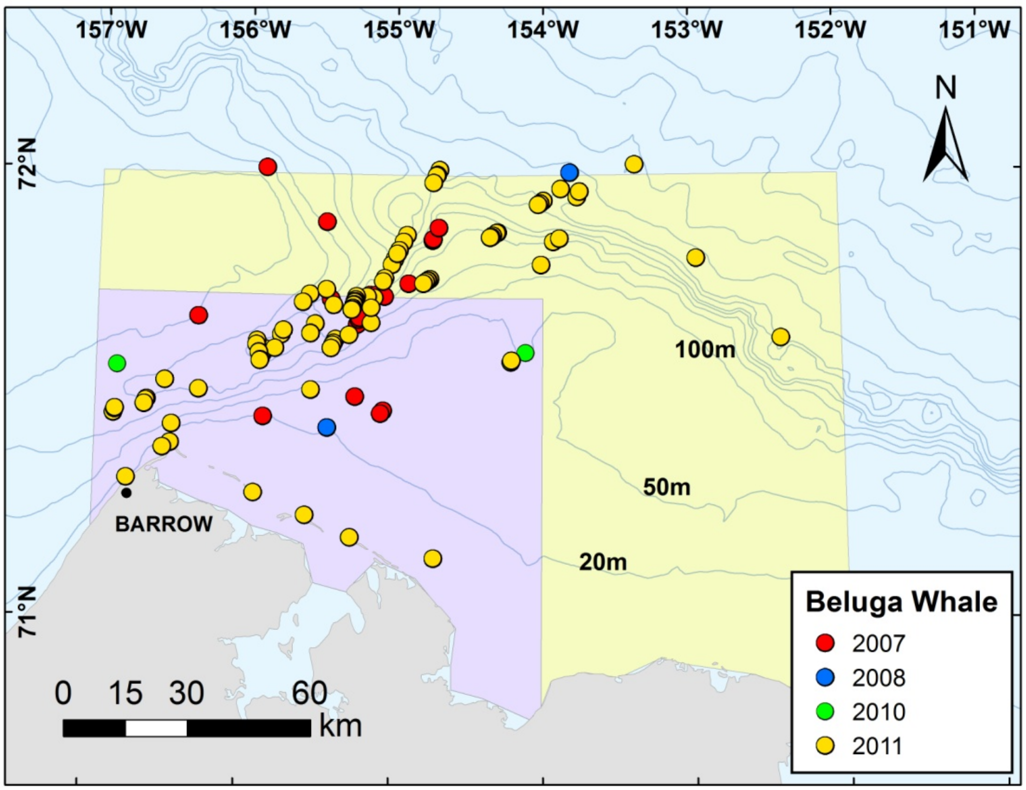


Figure I-12. *Map showing locations of beluga whale sightings during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Three species of baleen whales were seen during BOWFEST: bowhead, humpback, and gray whales. In 2009, a lone humpback whale associated with a group of gray whales was observed in shelf waters off Point Barrow (Fig. I-13). Gray whales were present during every survey year, and sighting numbers were fairly consistent year to year, with the exception of 2010 when their numbers were at their lowest and bowheads at their highest (Table I-3). Almost all gray whale sightings occurred along the 50 m isobath of Barrow Canyon (Fig. I-13).

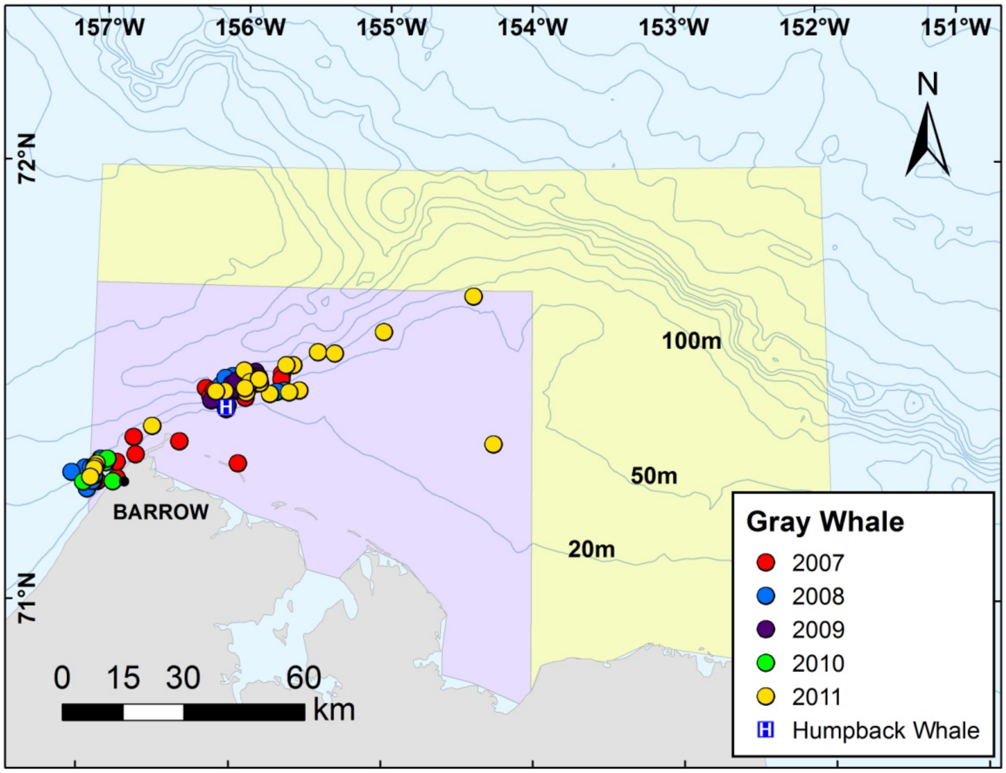


Figure I-13. *Map showing locations of humpback whale and gray whale sightings during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Bowhead whale presence and sighting numbers were variable from year to year (Table I-4; see also Table I-2 for sighting rate/km by year). Within the limited sampling period of these surveys, from late August to mid-September, there was no apparent increase in bowhead sightings (Table I-4), as might be expected with the onset of the fall migration. Most sightings occurred over continental shelf waters east of Point Barrow (Fig. I-14). With sightings binned into four depth ranges (Fig. I-15), most bowhead whales were in relatively shallow water; 72% of the sightings were in water depths < 30 m and 80% were in waters < 50 m. The remaining bowhead whales were in waters between 50 and 100 m (8%), and greater than 100 m (12%).

Table I-4. *Survey days (black boxes) and all on/off trackline bowhead whale sightings and counts (in parentheses) during BOWFEST aerial surveys, late August to mid-September 2007-2011. Gray boxes depict days available to fly; black boxes show days flown.*

Day	2007	2008	2009	2010	2011
22-Aug					
23-Aug	10 (59)				
24-Aug	6 (9)				
25-Aug					
26-Aug					0
27-Aug					
28-Aug					
29-Aug		2 (5)			
30-Aug		3 (17)			
31-Aug					
1-Sep				0	
2-Sep			5 (16)		1 (1)
3-Sep					
4-Sep			9 (21)		
5-Sep		5 (14)			4 (8)
6-Sep	0	23 (103)		7 (33)	
7-Sep	0		5 (5)		0
8-Sep				7 (11)	0
9-Sep	0				4 (17)
10-Sep					
11-Sep	0	9 (11)			
12-Sep				21 (89)	3 (7)
13-Sep		14 (45)		1 (2)	4 (31)
14-Sep			0		2 (4)
15-Sep		0	10 (13)	19 (68)	
16-Sep		0			0
17-Sep				42 (223)	
18-Sep				5 (26)	
Bowhead sightings (count)	**16 (68)**	**56 (195)**	**29 (55)**	**102 (452)**	**18 (68)**

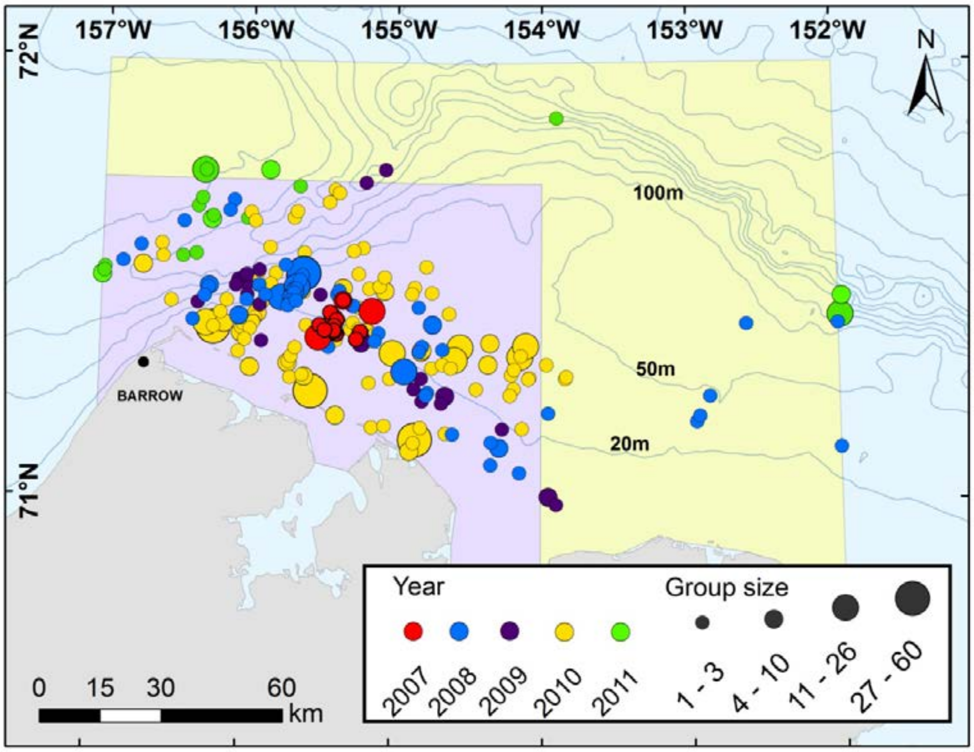


Figure I-14. *Map showing locations and group sizes of bowhead whales during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

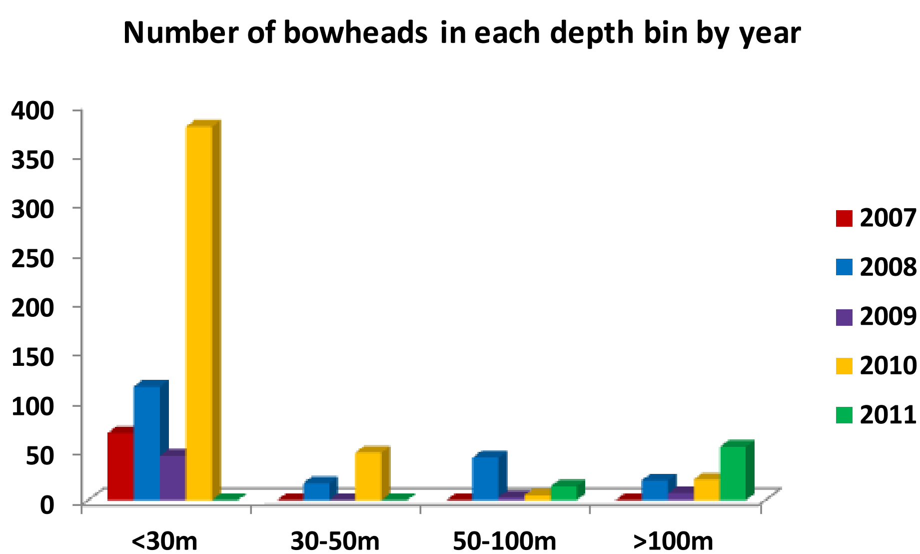


Figure I-15. *Depths at which bowheads were seen during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Habitat partitioning between gray whales and bowhead whales was evident in all survey years, and among gray, bowhead, and beluga whales in years that belugas were present in large numbers (Fig. I-16). Overall, each species occupied a unique region within the study area, bowheads on the continental shelf in waters <50 m deep (in all years except 2011); belugas over the Barrow Canyon and offshore slope waters; and gray whales near the 50 m isobath along the Barrow Canyon (Fig. I-17).

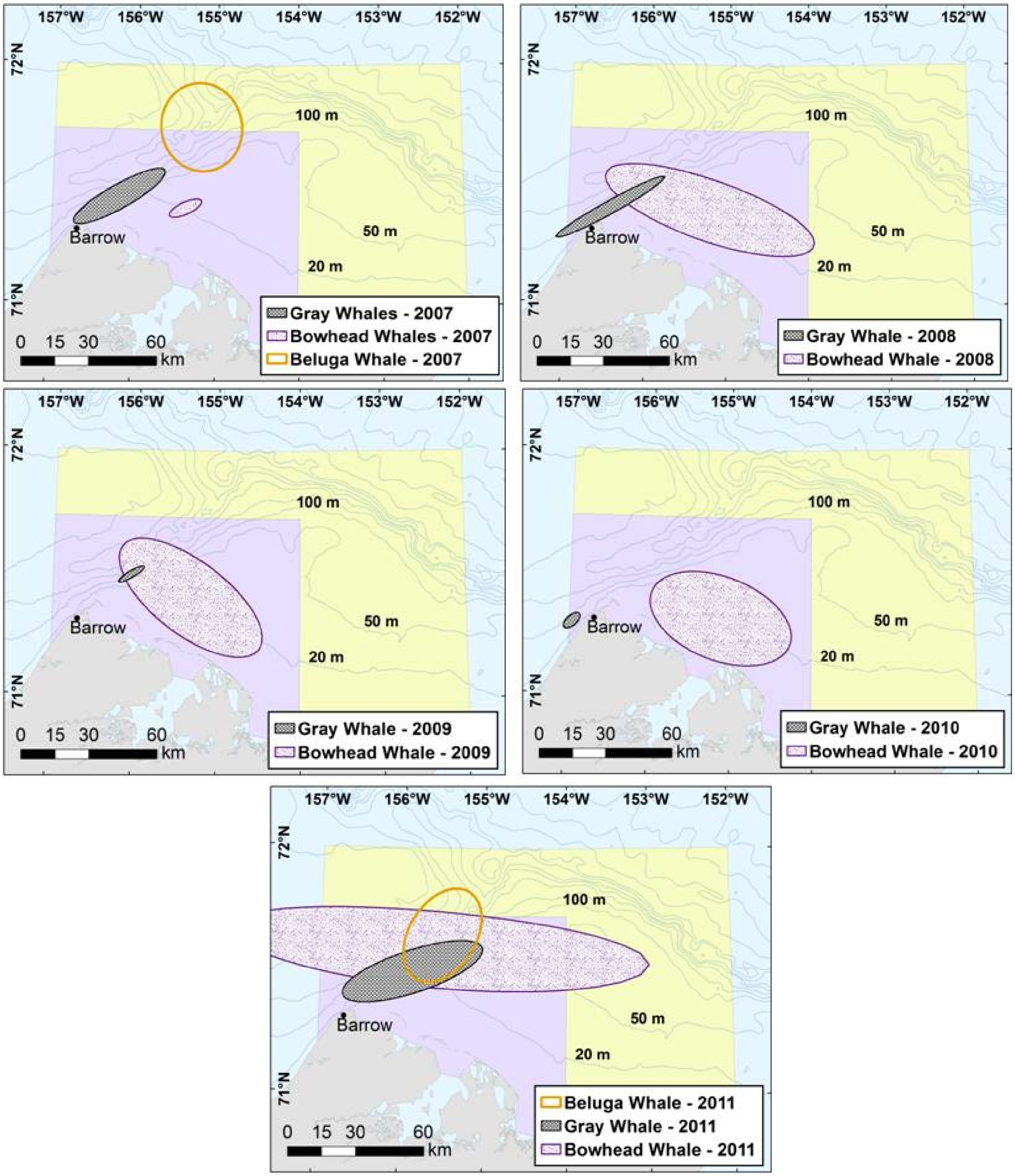


Figure I-16. *Standard deviation ellipses (capturing ~68% of sightings weighted by group size) showing the regions occupied by bowhead, gray, and beluga whales during BOWFEST aerial surveys, late August – mid-September in 2007, 2008, 2009, 2010, and 2011. Note: beluga sample sizes were too small in 2008-2010 to create ellipses.*

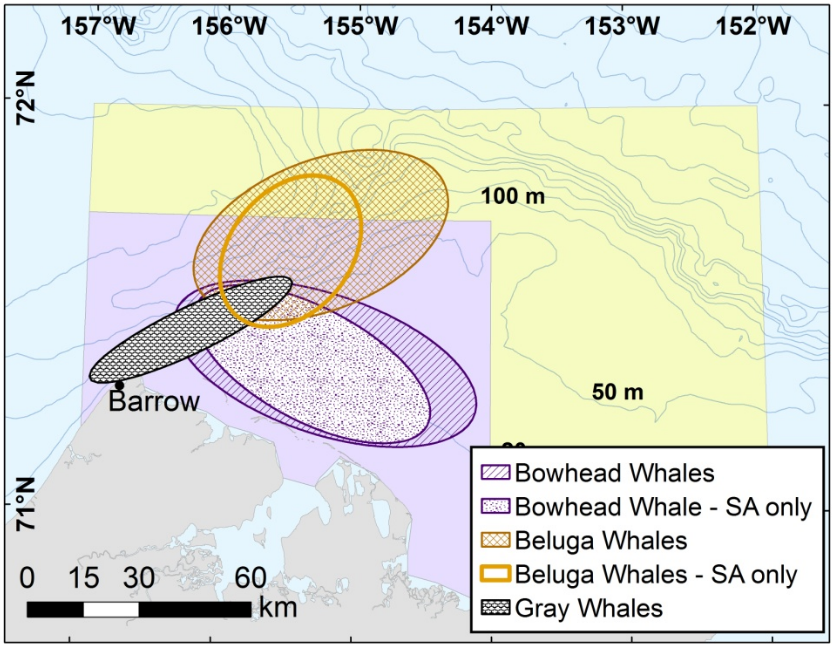


Figure I-17. *Standard deviation ellipses (capturing ~68% of sightings weighted by group size) showing the regions occupied by bowhead, gray, and beluga whales during BOWFEST aerial surveys, late August – mid-September 2007-2011. Note: given increased effort in the inner box (SA), additional analyses were run using only sightings within this region to confirm inner box distributions were not significantly different from analyses using all sightings.*

Habitat preferences – Both distance from shore and distance from the shelf break were significant in predicting the presence of bowhead whales ($p < 0.01$, Table I-5). Bowhead whales preferred to be close to shore and to the shelf break; therefore, their preferred habitat were areas where the shelf break came closest to shore (Fig. I-18). Although these two parameters were significant in determining preferred habitat, the AUC value was only 0.67, indicating that the model was only able to correctly discriminate between the presence (bowhead sighting) and absence (random points) 67% of the time. The 0.51 threshold value resulted in ~2,576 km^2 of preferred bowhead habitat (~38% of the smaller study area).

Of the four parameters included in the model, only bathymetry was significant in predicting beluga whale presence ($p < 0.01$, Table I-5). These animals preferred to be in deeper water than would be predicted at random. An AUC value of 0.82 indicates that the final model correctly discriminated sightings from non-sightings 82% of the time and resulted in 1,948 km2 of preferred habitat or ~29% of the smaller portion of the BOWFEST study area (Fig. I-19).

Bathymetry, as well as bathymetric slope, distance from shore, and distance from the shelf break were significant in predicting gray whale presence ($p < 0.01$, Table I-5). Unlike beluga whales, gray whales preferred to be in shallow water. In addition, they preferred to be closer to shore and the shelf break. A 0.96 value for the AUC indicated that the model was able to correctly classify gray whale presence and absence 96% of the time. The 0.61 threshold value resulted in 802 km^2 of preferred habitat, approximately 12% of the smaller portion of the BOWFEST study area (Fig. I-20).

Figure I-21 shows the predicted habitat of bowhead, beluga and gray whales in the smaller portion of the BOWFEST study area. While there is a large portion of overlap for these species, there is clear spatial separation in their preferred habitat. Bowhead whale preferred habitat is located in the central portion of the study area, stretching south to the shore while beluga whale habitat was stretched from the center to the northern portion of the study area. Gray whale preferred habitat was located at the interface of bowhead shelf and beluga canyon habitat – following the shelf break.

Table I-5. *Logistic regression and ROC model results: final model parameters, AIC scores, AUC and threshold values, habitat preference areas, and the proportion habitat in the smaller portion of the BOWFEST study area for bowhead, beluga, and gray whales.*

Species	Model	k	AIC	AUC	Threshold	Habitat Area (km^2)	Percent of SA
Bowhead Whale	DISTSHORE + DISTSHELF	2	532.39	0.67	0.51	2575.81	37.96
Beluga Whale	BATHY	1	107.14	0.82	0.40	1947.94	28.71
Gray Whale	BATHY+SLOPE+DISTSHORE+DISTSHELF	4	137.81	0.96	0.61	801.64	11.81

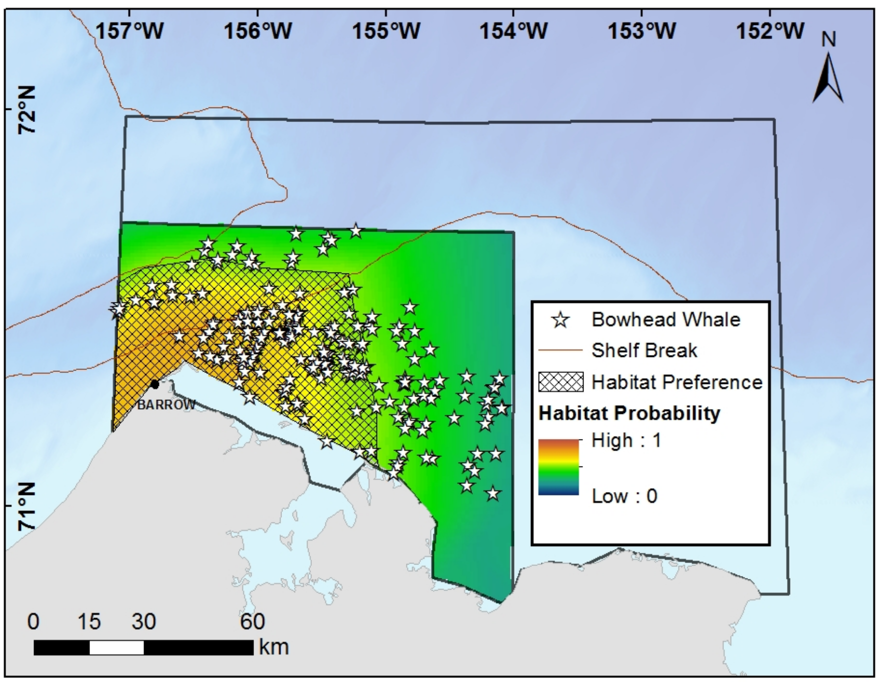


Figure I-18. *Summer habitat probability (low/blue to high/red) and preference (black cross-hatch) of bowhead whales near Barrow, Alaska, based on 2007-2011 sightings (white stars) within the smaller portion of the BOWFEST study area.*

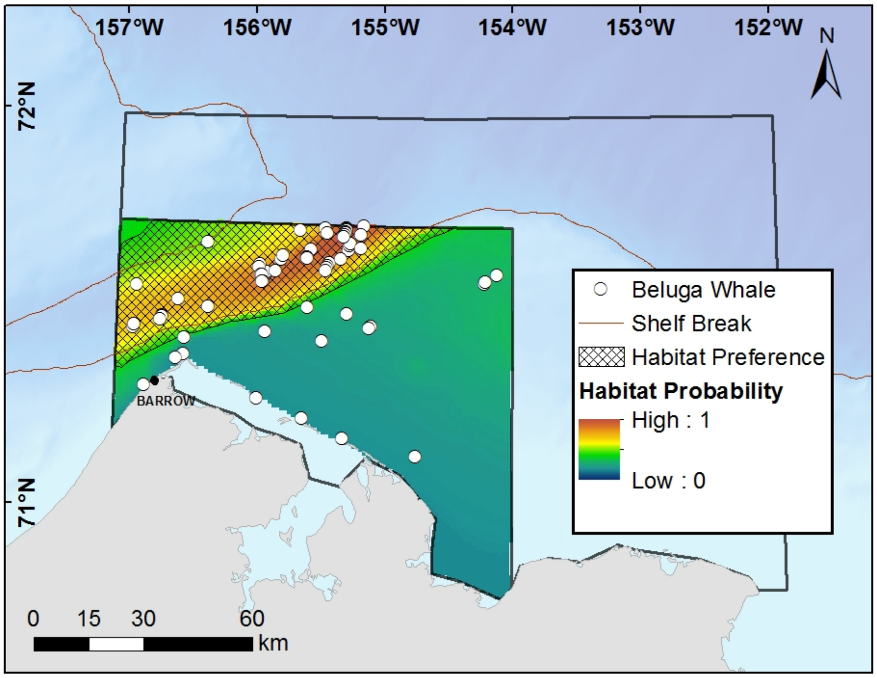


Figure I-19. *Summer habitat probability (low/blue to high/red) and preference (black cross-hatch) of beluga whales near Barrow, Alaska, based on 2007-2011 sightings (white circles) within the smaller portion of the BOWFEST study area.*

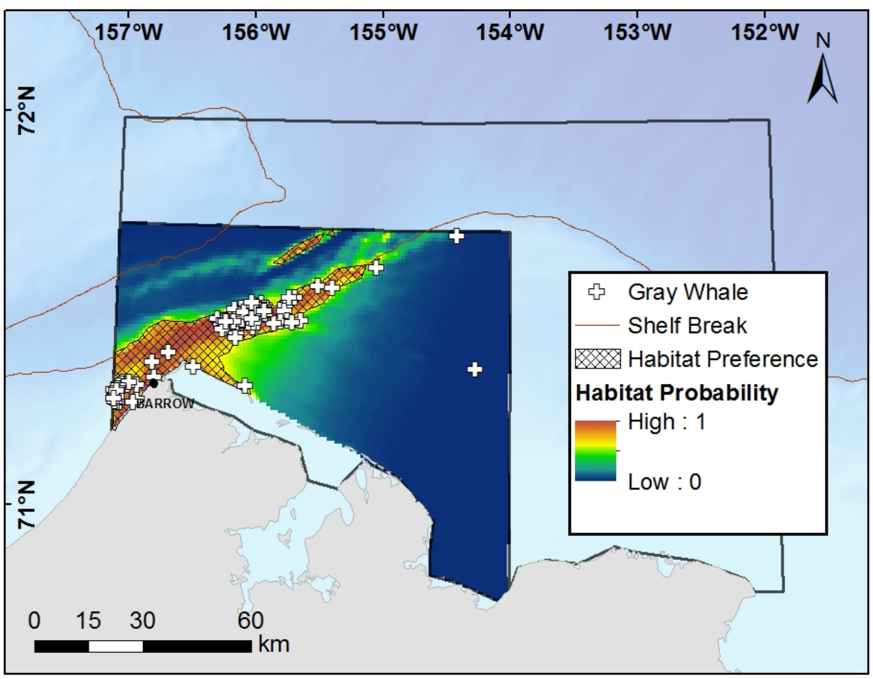


Figure I-20. *Summer habitat probability (low/blue to high/red) and preference (black cross-hatch) of gray whales near Barrow, Alaska, based on 2007-2011 sightings (white crosses) within the smaller portion of the BOWFEST study area.*

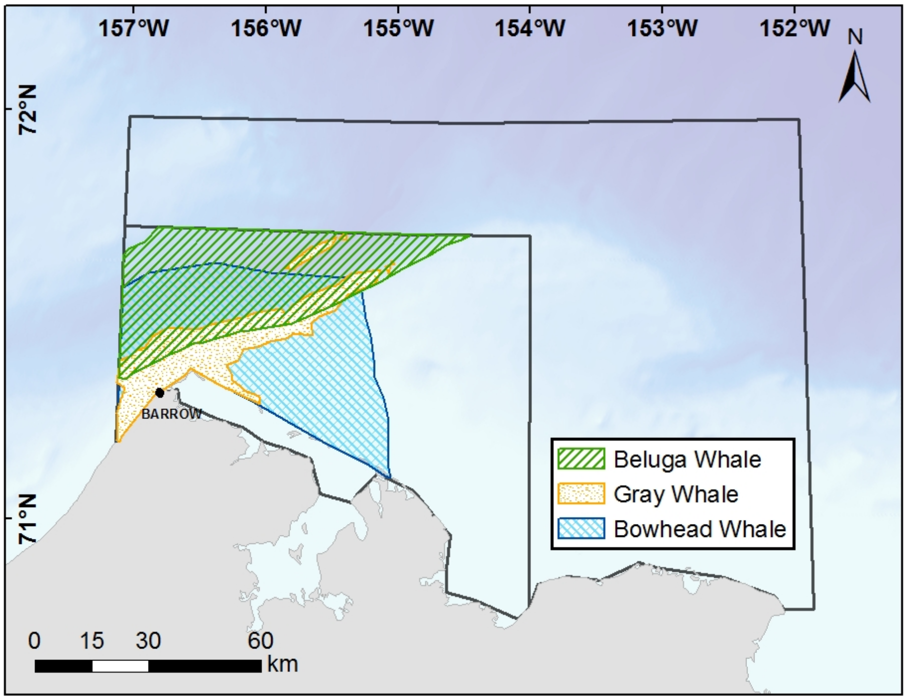


Figure I-21. *2007-2011 summer habitat preference of bowhead (blue crosshatch), beluga (green hatch), and gray (orange speckled) whales within the smaller portion of the BOWFEST study area.*

Behaviors – In general most species were simply swimming or resting at the surface. Observers noted swim direction for bowhead whale sightings when possible. Presumably, if the fall migration was underway, most whales would be travelling in a westerly direction (between 226° and 315°T); however, this was not the case in most years. In 2008 significantly more bowheads traveled in a westerly direction (i.e., about 295°T; [Raleigh uniformity test] probability < 0.05) (Table I-5, Fig. I-18). The sample size in 2007 was too small (n = 2) to test for significance, primarily because most whales appeared to be feeding and not traveling (Table I-6).

Table I-5. *Bowhead whales observed travelling within the BOWFEST aerial survey study area, late August to mid-September 2007-2011. (Note: sample size was too small in 2007).*

Year	Sightings headed westerly (226°-315°)	All sightings	Percent heading westerly	Raleigh uniformity test (KCS, 2012)	Grand mean vector
2007		2	-		-
2008	12	21	57.1%	Z = 7.103, p = 4.82E-4	294.774°
2009	4	8	50.0%	Z = 1.672, p = 0.192	-
2010	16	52	30.8%	Z = 0.414, p = 0.661	-
2011	6	12	50.0%	Z = 1.130, p = 0.33	-
Total	38	93	40.9%		

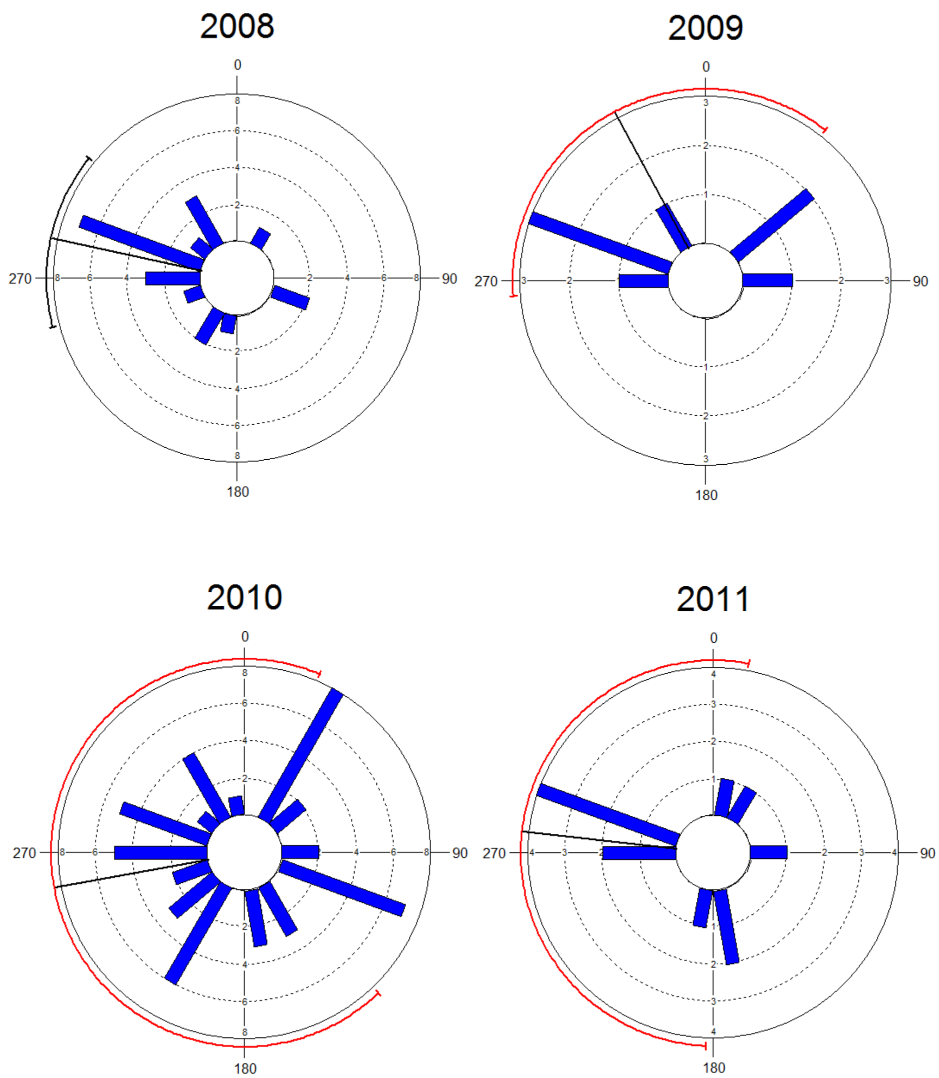


Figure I-18. *Swim directions of bowhead whales observed during BOWFEST aerial surveys, late August to mid-September 2008-2011 (Note: sample size was too small in 2007). Only 2008 showed a significant clustering of sightings in any direction (black line as opposed to red lines in other years)*

The only species, other than bowheads, observed feeding within the study area was gray whales. Large mud plumes were often listed as the sighting cue for gray whales. Bowhead whale behavior was also noted by observers (Table I-6); for most years traveling was reported more often than feeding. Feeding behavior, residency times, and age classes of bowhead whales present within the study area were further explored through the photographic component of BOWFEST.

Table I-6. *Reports of traveling and feeding bowhead whales observed during the BOWFEST aerial survey, late August to mid-September 2007-2011.*

Aerial Observations	2007	2008	2009	2010	2011	Total
Number of traveling sightings	2 (12.5%)	23 (41.1%)	9 (31.0%)	53 (52.0%)	12 (66.7%)	99 (44.8%)
Number of feeding sightings	8 (50.0%)	4 (7.1%)	6 (20.7%)	28 (27.5%)	2 (11.1%)	48 (21.7%)
Total bowhead sightings	16	56	29	102	18	221

Photographic Effort

Effort spent in obtaining photographs - Bowhead whales were photographed on 22 survey days across the five field seasons (2 days in 2007, 6 in 2008, 2 in 2009, 7 in 2010, and 5 in 2011). In total, 16.7 hours were spent photographing bowheads, resulting in 1,605 pictures taken when whales were below the aircraft (Table I-7).

Table I-7. *Photographic effort for BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Camera	Method/Lens*	Bowhead Pictures	Bowhead Images**	Calibration Pictures
Nikon D200	PGRAM/55 mm	158	199	9
Nikon D200	PID/180 mm	161	181	20
Canon Mark III 1DS	PGRAM/55 mm	256	418	38
Canon Mark III 1DS	PID/70-200 mm	307	471	37
Canon Mark III 1DS	PGRAM/55 mm	50	53	190
Canon Mark III 1DS	PID/70-200 mm	58	63	107
3 Canon Mark III 1DS	85 mm	352	689	39
3 Canon Mark III 1DS	85 mm	263	313	43
		1,605	**2,387**	**483**

*****PGRAM is the photogrammetry camera; PID is the photo-id camera.
**Total number of individual bowheads counted from all pictures (e.g., one picture may have 2 or more bowhead images). These totals do not reflect resightings found during the matching effort (total number of unique, identifiable animals was 762).

Image quality and identifiability - Quality ratings of bowhead images indicate that 206 (15 %) were of excellent quality in at least one zone on the body (1+ or 1-), 527 (37 %) were good (2+ or 2-) in at least one zone on the body, and 682 (48 %) were not useful (category 3) in all zones on the body. Photos were considered inadequate usually when a whale was too deep in the water, there was too much splash over the whale's dorsal surface, or the whale was not lying prone in the water. Among the 1,415 images used for matching, 33 images (2 %) were highly marked (H+ or H-) in at least one zone on the body, 43 images (3 %) were moderately marked (M+ or M-) in at least one zone on the body, 667 (47 %) were unmarked (U+ or U-) in at least one zone on the body, and 672 (47 %) were useless (X) in all zones on the body.

Matching effort – During the 5-year study, 1,605 photographs were taken containing 2,387 images of bowhead whales (Table I-7). Matching and removing duplicate photos from passes left a working set of 1,415 images from which 762 unique whales were identified.

Calibration targets – In addition to whale images, 5.5 flight hours were spent taking photographs of calibration targets (483 images counting only those on the primary photogrammetric camera, Table I-7). Measured images of the floating targets showed a strong correlation between the digital imagery and true lengths from the targets, indicating that radar altimeter performance does not change significantly whether over land or over water (Mocklin et al. 2010).

Feeding behavior – Bowhead whale images were categorized as feeding when mud was present on the whales' dorsal surface, mouths were open (skim feeding), mud plumes were apparent, or whales defecated (fecal plumes) (Table I-8). Based on multidirectional positioning of whales as well as the presence of mud plumes, half of the bowheads seen in 2007 appeared to be feeding (Table I-6), but only 37% of the photo images confirmed this behavior (Table I-8). In other years, feeding was generally not as obvious during aerial observations; most whales appeared to be traveling. Photographic images documented feeding behavior at higher rates than visual observations in those years (Fig. I-19). The lowest percent feeding observed both visually and photographically occurred in 2008 (Fig. I-19), the only year whale swim direction was predominately westerly (Table I-5, Fig. I-18). When we looked at individual whales that were photographically identified as feeding, 91% of them had been feeding in shelf waters, and the majority of those were clustered around the 20m isobath.

Table I-8. *Photographic evidence of feeding bowhead whales during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Feeding Behavior	2007	2008	2009	2010	2011	Total
Mud on whale	129 (37.0%)	72 (16.3%)	9 (23.1%)	15 (3.4%)	22 (15.3%)	247 (17.5%)
Open mouth	0	0	0	208 (47.1%)	8 (5.6%)	216 (15.3%)
Feces	0	0	0	0	2 (1.4%)	2 (0.1%)
Total photos	349	441	39	442	144	1415

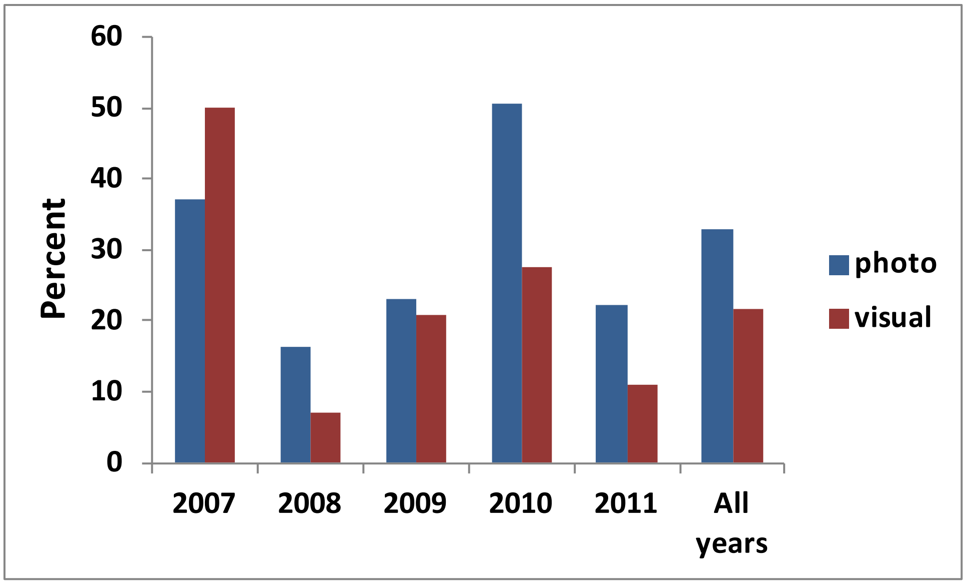


***Figure I-19**. Percent of bowhead whales feeding during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Resightings – Among the 762 unique whale images, there were only three resightings of bowhead whales on different days within a study year (Fig. I-20). Overall, this suggests very low residency times off Barrow (Fig. I-21). These intrayear sightings occurred in 2009 and 2011, years with some of the lowest counts, sighting rates, and percent feeding.
In 2011, the bowhead aerial abundance spring survey (BAASS) flew in the Barrow area photographing whales from April to June (Mocklin et al. 2012). While analyses still continue on this dataset, a spring to fall match between this dataset and BOWFEST included a bowhead whale mother with calf photographed in May and September (Figs. I-21; I-22).

There have been three resightings of bowheads among the five years of BOWFEST (Figs. I-21; I-23). These interyear sightings included a whale photographed in 2007 and 2009, a whale photographed in 2007 and 2011, and a whale photographed in 2008 and 2010 (Fig. I-23).

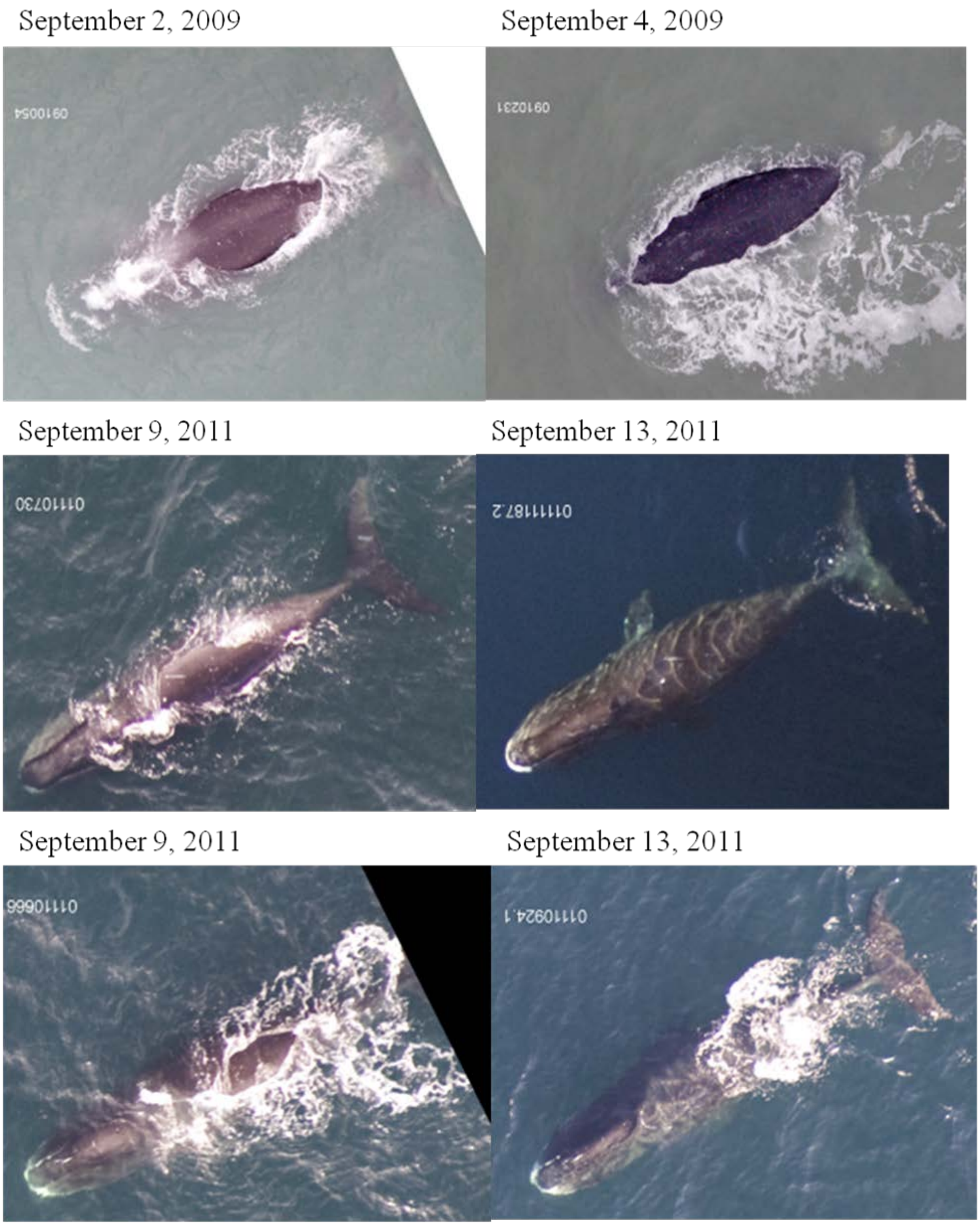


Figure I-20. *Intrayear matches of bowhead whales observed during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

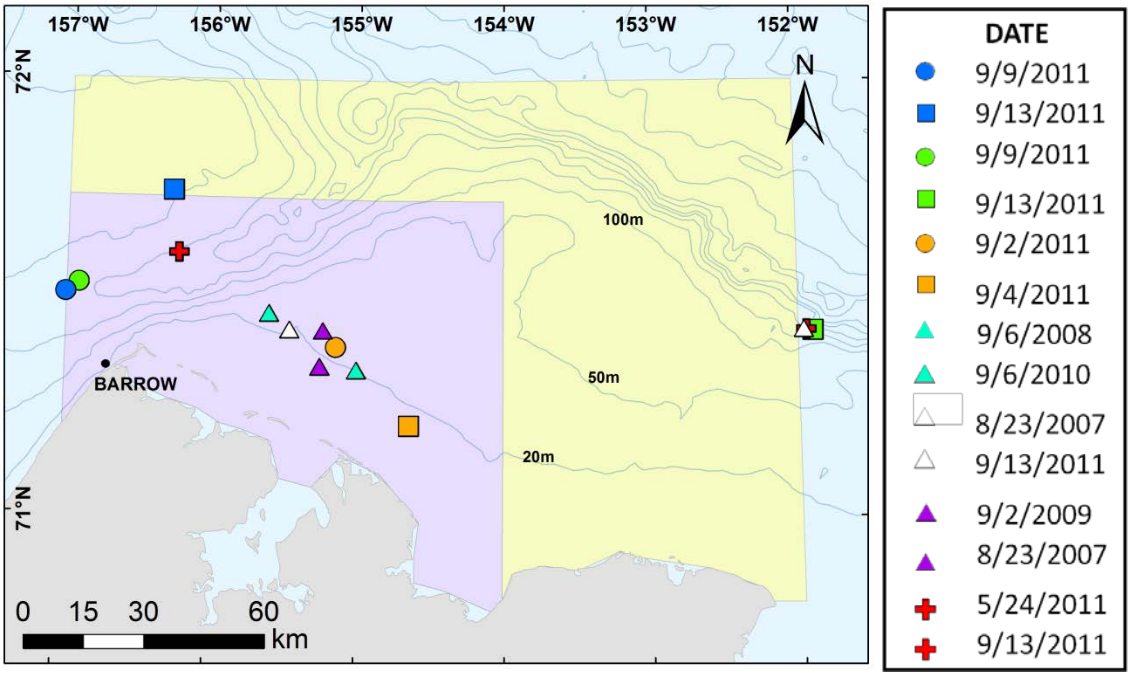


Figure I-21. *Locations of bowhead whales with photographic matches. There were 3 intrayear BOWFEST matches (circle: first sighting; square subsequent), three interyear BOWFEST matches (triangles), and one intrayear match between spring (BAASS survey) to late summer (BOWFEST) (crosses).*

Figure I-22. *Intrayear matches of a bowhead whale mother with calf observed during the BAASS aerial survey April-June 2011 and BOWFEST aerial surveys late August to mid-September 2011. Note the change in calf size relative to the adult.*

Figure I-23. *Interyear matches of bowhead whales observed during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Age classes – Using photogrammetric lengths, bowhead whales were sorted into specific age classes (calf, juvenile, and adult). No clear pattern emerged in terms of age classes using the Barrow area in late summer (Fig. I-24). Of the 803 images of sufficient quality to obtain length measurements (prior to matching), 56% were juveniles (between 6 and 13 m), 44% were adults (>13 m), and 1% were calves (<6 m). There was no statistical difference between juveniles and adults (paired *t*-test; $p = 0.64$).

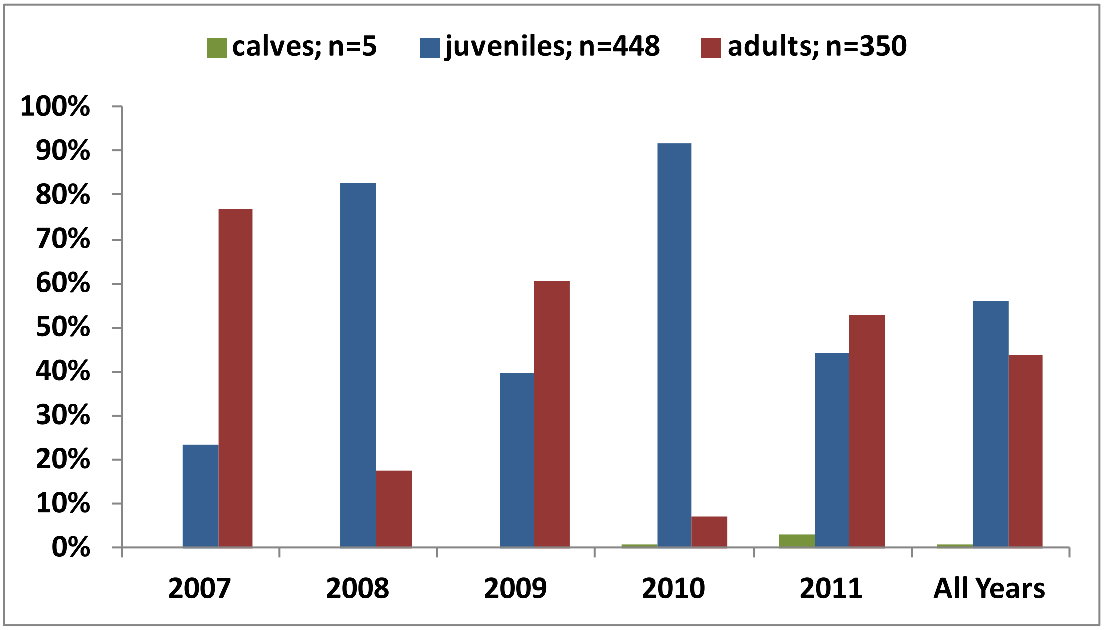


Figure I-24. *Age class distribution of bowhead whales during BOWFEST aerial surveys, late August to mid-September 2007-2011.*

Discussion

The Bowhead Whale Feeding Ecology Study (BOWFEST) goal has been "to facilitate development of future oil and gas development-related mitigation by estimating relationships among bowhead whale prey, oceanographic conditions, and bowhead whale feeding behavior in the western Beaufort Sea." Of the five principal objectives, two have been pertinent to the aerial survey project: "Document patterns and variability in the timing and locations of bowhead whales feeding in the western Beaufort Sea," and "estimate temporal and spatial patterns of habitat use by bowhead whales in the study area." The aerial survey component of BOWFEST has been an excellent platform for answering these two objectives; that is, by documenting the time and location of bowhead occurrence within the study area and recording whale behavior, particularly in regard to feeding activity.

Although bowhead whales are not rare in the Barrow area during the summer, most whales of the Western Arctic Stock are known to spend the summer in the eastern Beaufort Sea (Moore and Reeves 1993). Since the Western Arctic Stock begins migrating westward in early

September, we expected to find more bowheads towards the end of the BOWFEST field season than in the beginning. This trend in sightings was not evident during the BOWFEST sample period; in fact, in 2007 all of our sightings occurred in late August and none in September, perhaps related to this being an unusual year with extreme melting of the polar ice pack (Perovich et al. 2011). The passive acoustic arrays picked up very few bowhead calls in early September, with peak presence occurring from mid-September to the end of October (Berchok et al. Section II: this volume). In the other BOWFEST years, bowheads were seen throughout the survey period (late August to mid-September) with no apparent increase of sightings through the season (Table I-4). This lack of increase may have been because the surveys ended prior to significant numbers of migrants arriving in the Barrow area. However, passive acoustic arrays confirmed our visual observations, detecting peak presence of calling bowheads from late August until mid November for the years 2008-2011 (Berchok et al. Section II: this volume).

The Barrow Shelf is an important area for bowhead whales, and it appears that even during what would be considered the migratory period some whales return to the region after initially heading west into the Chukchi Sea. Quakenbush et al. (2010) performed a kernel density analysis of tagged whale movements that showed, in September, the highest probability of use was the area northeast of Barrow. Their satellite tag data also showed that bowheads do not move across the Beaufort Sea in a continuous stream. Three of the 19 tagged whales left the Barrow area only to return and spend 13-32 days in the waters off Barrow (Quakenbush et al. 2010). It is interesting to note that we found no such evidence of extended residency off the Barrow area during our study period, which ended slightly earlier than the period that the tagged whales lingered off Barrow. However, of the few within year resightings (n = 3) that did occur, none of the whales had moved west of their initial sighting location.

In 2007, most bowheads appeared to be feeding as evidenced by mud plumes, open mouths, the presence of feces and concentrations of whales swimming in multiple directions. However, from 2008 to 2011, bowheads were predominantly recorded as "traveling," that is, whale sightings lacked any remarkable behavior other than that they were swimming. In spite of it being late summer, travel directions did not necessarily indicate a predominately westerly migration (Fig. I-18 & I-21). Only in 2008, was there a significant movement westward. Similarly, whales approached and tagged during the tagging study in 2009-2011 (Baumgartner Section IV: this volume) were predominantly traveling, but not necessarily westward (see Fig. IV-8).

Across all years, observers reported 22% of sightings as evidently feeding; however, photographic examination showed that 33% of the whale images showed evidence of feeding. It seems intuitive that some amount of feeding was occurring that would not be evident from an aerial platform, such as mid-column feeding where neither mud plumes nor open mouths would be visible. Therefore, the percentages of evident feeding reported here can be considered conservative. Prior to and after the BOWFEST survey period (late summer), bowheads are known to feed near Barrow. Past studies (Lowry and Frost 1984, Carroll et al. 1987) concluded that bowheads feed occasionally during the spring migration, and recent research has confirmed that bowheads are feeding during both the spring and fall migrations (Lowry et al. 2004, Mocklin et al. 2012, Sheffield and George Section VB: this volume). During the BOWFEST project years, stomach analyses revealed a higher proportion of animals feeding near Barrow (92%) than at Kaktovik (54%) during the fall, while only 10% were feeding near Barrow in the spring (Sheffield and George Section VB: this volume).

In fall, stomach percent by volume during 2007-2009 was dominated by euphausiid prey (82%) at Barrow (Sheffield and George Section VB: this volume). During 2010, this switched to copepods (88%), while in 2011 a diversity of prey types included isopods, mysids, copepods, amphipods, and fish. Oceanographic sampling found markedly different zooplankton community compositions among the BOWFEST years (Ashjian et al. Section IIIA: this volume). *Pseudocalanus* spp. dominated shelf waters in 2007, and benthic and echinoderm larvae were found in all regions in 2011 (the only year they were observed). The large copepod, *C. glacialis*, was seen consistently only in the offshore region (i.e., the Barrow Canyon). Large euphausiids were in greater numbers on the shelf in 2007, and particularly in 2009, with smaller life stages more dominant during the other BOWFEST years. We plotted locations of feeding bowhead whales and found that 91% of individual bowhead whales showing photographic evidence of feeding were located in shelf waters, predominantly along the 20 m isobath. In most years, nearly all bowhead whale sightings made by BOWFEST aerial observers were located in relatively shallow water over the shelf, except in 2011 when most bowheads were seen in deep water over the Barrow Canyon. In 2008 and 2009, this distribution was somewhat narrow and focused along the 20 m isobath (Fig. I-14 & I-16). In 2010, whales were still on the shelf but more spread out. The abundance of bowhead sightings on the shelf may be the result of animals simply following the coast to take advantage of habitat with suitable concentrations of prey (see Okkonen Section IIIB: this volume). The passive acoustic arrays detected predominantly inshore calling during our surveys in 2008 and 2009, and noted somewhat equal inshore and offshore calling during 2010, and mostly offshore calling occurring during our survey period in 2011 (Berchok et al. Section II: this volume).

To learn more about the consistency of bowhead feeding aggregations seen near Barrow during the summer, photographs collected during the BOWFEST aerial survey were also evaluated for recognizable individuals. The notion that a consistent group of bowheads were utilizing the Barrow area either through the years or within the survey season was not supported by this study. We found only three intrayear resightings and three interyear resightings. None of the whales resighted within a season had moved west of the original sighting; as would be expected during the fall migration; all subsequent sightings were to the east. The photoanalysis yielded no clear pattern explaining bowhead presence off Barrow during our survey period. Age composition varied from year to year but on average was evenly represented by juveniles and adults.

The habitat partitioning in the BOWFEST study area among bowhead, gray, and beluga whales observed by the aerial team (Fig. I-17 & Fig. I-21) was also confirmed for bowhead and gray whales by the small boat surveys conducted by local hunters (George et al. Section VA: this volume). Gray whales were present, and feeding, during every survey year, and sighting numbers were fairly consistent year to year, with the exception of 2010 when their numbers were at their lowest and bowheads at their highest. While there was a large portion of overlap for these species, there was clear spatial separation in their preferred habitat. Bowhead whale preferred habitat was located in the central portion of the study area, stretching south to the shore while beluga whale habitat was stretched from the center to the northern portion of the study area. Gray whale preferred habitat was located at the interface of bowhead shelf and beluga canyon habitat – following the shelf break. Oceanographic sampling also found notable differences in the community composition in four regions among the five BOWFEST years (Ashjian et al. Section IIIB: this volume, see Fig. IIIB-14). The ACC/PW region aligns with our observed gray whale distribution where benthic larvae were present in all years this region was sampled and enumerated (2007, 2010, and 2011). Benthic larvae were also present in smaller quantities in the coastal region (along the 10 m isobath) in 2007 and 2011, and on the shelf (encompassing 20 m to 50 m waters) in most years; and presumably available to the "muddy" bowheads observed those years. Mud may also occur incidental to consuming epibenthic prey, such as *Mysis oculata*, which were the most commonly eaten mysids by bowheads hunted near Barrow, particularly in 2011 (Sheffield and George, Section VB: this volume). The much smaller euphausiid furcilia dominated the shelf in 2010 (Ashjian et al. Section IIIB: this volume), possibly explaining the preponderance of skim feeding (Table I-8) and the echelon formation feeding observed that year (Fish et al. 2013). Fish were generally a minor component of bowhead stomach samples that otherwise contained euphausiids or copepods, except in 2011 (Sheffield and George, Section VB: this volume). The most commonly eaten fish was the Arctic cod (*Boreogadus saida*) – a prey item of beluga whales as well and may explain the increased number of belugas seen in the study area that year. Although most bowhead whales appeared to be traveling (though not necessarily westward), they also took advantage of the diverse prey opportunities off Barrow, particularly in the shelf region along the 20 m isobath.

Acknowledgments

Minerals Management Service (later the Bureau of Ocean Energy Management) funded the BOWFEST program; in particular, Chuck Monnett provided guidance, support, and inspiration to get this large research program underway. NOAA's Aircraft Operation Center provided the aircraft and crew. Our pilots were Jason Mansour, Wally Pierce, and Nicole Cabana in 2007; Nicholas Toth and Jon French in 2008; Nicholas Toth and Chris Daniels in 2009; Brad Fritzler and Rob Mitchell in 2010; and Brad Fritzler and Francisco Fuenmayor in 2011. These pilots filled a critical role in keeping the aircraft at the preferred altitude while flying intricate patterns over moving whales. Dee Allen flew with us one day in 2009 and assisted with video photography of whales. Ron Pauley, Mike Merek, and Rob Miltich provided mechanical support for the aircraft through these years. Wayne Perryman loaned us a radar altimeter and provided technical advice, and Don LeRoi loaned us the FMC mount and assisted with the camera mount installation. Craig George provided the land calibration target. Noah Lawrence-Slavas assisted with the design of a water-borne target used in 2008-2009, and Frederick Brower and Catherine Berchok towed this floating target array within the survey area. Janet Clarke provided the statistics and figure for the bowhead swim direction analysis and Rayleigh test. This study was conducted under MMPA Scientific Research Permits No. 782-1719 and No. 14245. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA. All results in this final report are preliminary; when discrepancies are found between the annual reports and the final report, please defer to the final report.

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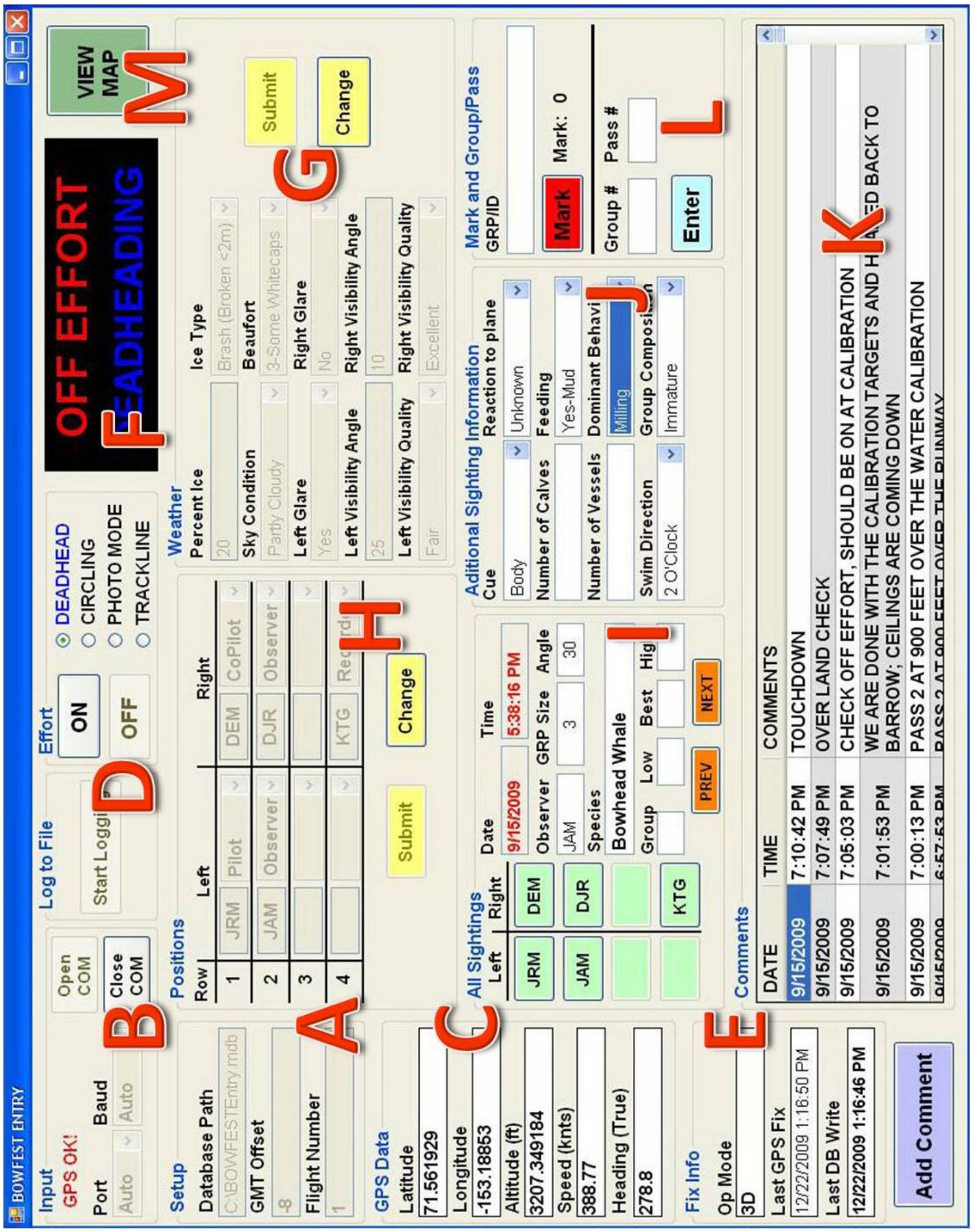
Appendix I-1. *Screen shot of BOWFEST Aerial Survey Program.*



Appendix I-2. *BOWFEST Aerial Survey Program detailed descriptions.*

- Observe the figure showing the layout of the data entry system of the program interface with letters A-L (attached). (Note: the letters are for instructional purposes only and will not appear when the program is opened).
- The following will provide information on the different sections of the program interface in the sequence the tasks should be preformed (this may vary slightly):
  - **A (Setup):** This section contains three fields – Database Path, GMT Offset, and Flight Number. The 'Database Path' is the location of the access database where the data are being recorded; this path location should contain the default value 'C:\BOWFESTEntry' and should not change. The 'GMT offset' needs to be entered in order to record the proper AK time (-8 during Daylight Savings when most of the surveys are conducted or -9 starting in November). Finally, the 'Flight Number' must be filled in or you will not be able to run the program. (Note: once the flight number is added and the program is started, it can not be changed again until the program is stopped).
  - **B (Input):** The Input section contains two fields – Port and Baud Rate. Both fields are defaulted to 'Auto', thereby allowing the program to automatically detect the COM port and Baud rate of the GPS. It is important that the COM port number on the program's interface matches the COM port the GPS is communicating through. If the GpsGate settings are set properly, COM5 should be the correct port. However, if a different COM port was chosen (other than COM5) during the GpsGate setup process, you should use the drop down menu to select that COM number. Also, if you are not using the GpsGate software and using the serial port connection with the GPS, then you need to select the COM number that matches the COM port (see instructions under Setup). The 'Baud Rate' field should stay at 'Auto'. There should be no reason to change this setting. Once these are set, click the "Open Port" button.
  - **C (GPS Data):** There are 5 fields in the GPS Data section – Latitude, Longitude, Altitude, Speed, and Heading. Once the port is opened (see above), these fields should show data from the GPS. (Note: Altitude is recorded in feet and speed in knots). If data does not appear, check to see if the GpsGate icon is green (working properly) and that the COM port number assigned to the GPS matches the COM port selected in the program.
  - **D (Log to File):** There is only one button in the Log File section, Start Logging. Once Data from the GPS appears, the recorder should press the 'Start Logging' button (i.e. recording to the database). Note: you will be not be able to enter anything into the form without pressing the 'Start Logging' button.
  - **E (Fix Info):** The Fix Info section contains three fields –Op Mode, Last GPS Fix and Last DB Write. The Op Mode field shows the accuracy of the GPS. Since we are using the plane's antenna, this field should always show '3D', meaning there are at least three satellites locking the location. The 'Last GPS Fix' field shows the date/time of the last time the computer received a reading from the GPS. The 'Last DB Write'

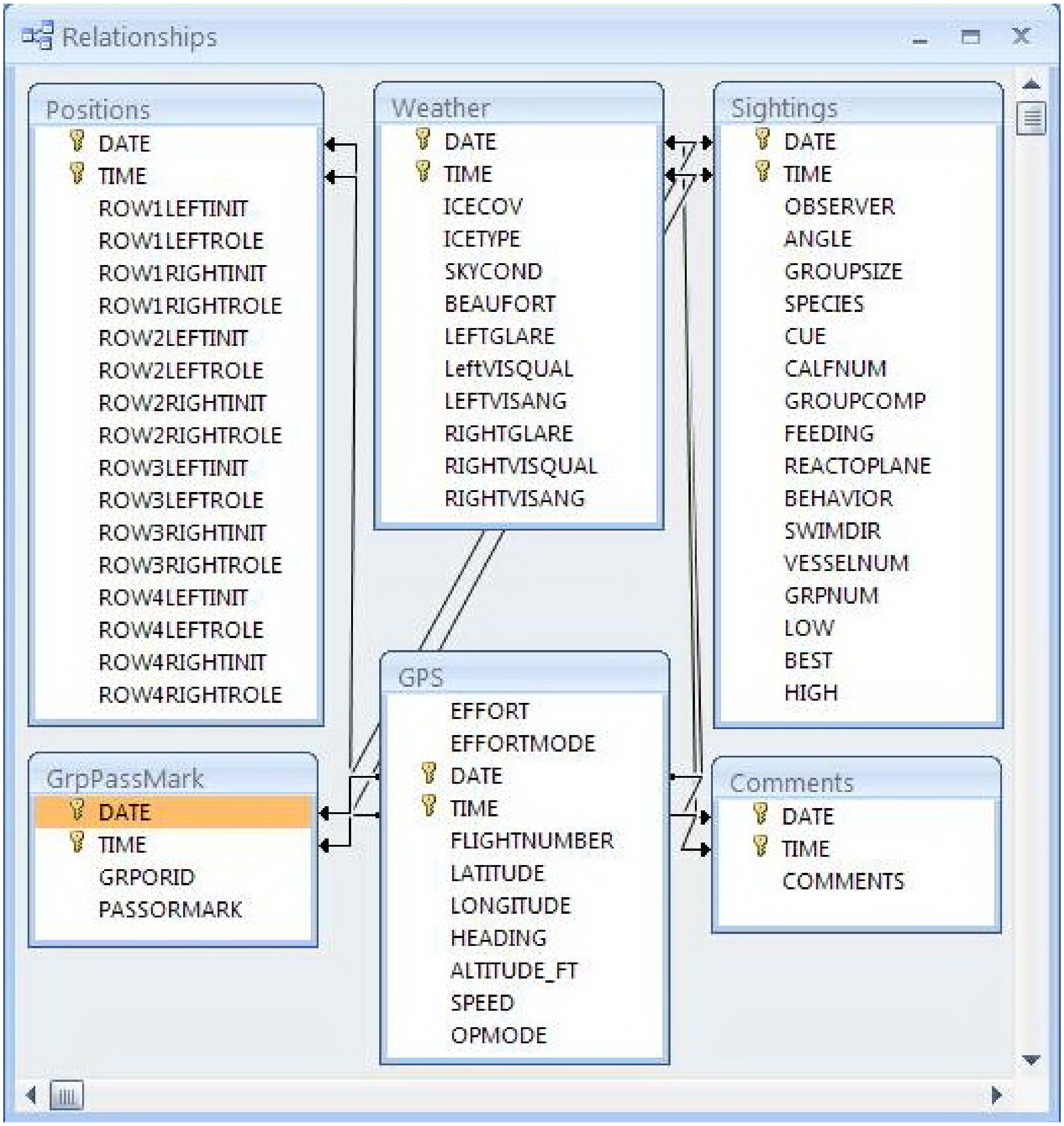
field shows the last time the program wrote to the database. This is usually only a few seconds off from the 'Last GPS Fix' field. (Note: the program is set to record GPS data every 5 seconds as well as the date/time/ lat/long associated with any other info (i.e. weather, position change, etc.) entered into the system between 5-second intervals).

- **F** **(Effort):** This section contains two buttons and four radio buttons. The two buttons, 'ON' and 'OFF', are used to designate the effort status. It is important that the recorder remembers to keep track of the effort status. Once the 'ON' button is selected, an 'ON EFFORT' message will appear in green. When the 'OFF" effort button is pressed, a red, flashing 'OFF EFFORT' message will appear to the right of the button. In addition, the recorder needs to choose one of the four radio buttons to designate effort type. These choices are: 'DEADHEAD', 'CIRCLING', 'PHOTO MODE', or 'TRACKLINE'. By default, when the program is started, the effort is set to 'OFF' and 'DEADHEAD'.
- **G** **(Weather):** The Weather section contains ten fields and two buttons to submit and change entries. The fields record percent ice (0-100), ice type, Beaufort (0-8), and sky condition, as well as glare and visibility (angle and quality) on both sides of the aircraft. Notice that for all the fields other than "Percent Overcast", there are a limited number of choices. Under the drop down menu for 'Beaufort', you will see the following 9 choices: 0 –Mirror, 1 – Ripples, 2 – Small Waves, 3 – Some Whitecaps, 4 – Many Whitecaps, 5 – Whitecaps/Spray 6 – Whitecaps/More Spray, 7 – White Foam Streaks, 8 – Blowing Foam Streaks. 'Yes' and 'No' are the only two options that can be entered into the 'Left Glare' and 'Right Glare' fields. 'Left Visibility Angle' and 'Right Visibility Angle' are numerical values (0-90 degrees) representing the searchable distance out each side of the aircraft as measured by an inclinometer. 'Right Visibility Quality' and 'Left Visibility Quality' are restricted to the following 5 choices: E – Excellent, G – Good, F – Fair, P – Poor, and U –Useless. Note that the recorder can either press the letter or number preceding the selection, or use the mouse to expand the drop-down box to make a selection. For example, to enter a Beaufort of 5, the recorder can press "5" to have to selection appear in the box automatically, or use the mouse to scroll down to the "5 – Whitecaps/Spray" option. Once the fields are filled in, press the "Submit" button. After submitting the data, the fields will become grayed-out and cannot be changed until the change button is pressed. Using this method, the recorder will always be able to see the last submitted data and change when necessary.
- **H** **(Positions):** This section allows the recorder to take note of the location and duties of all personnel in the aircraft. The table is divided into two columns (left and right side of the aircraft) and four rows to accommodate all possible positions in the plane. Each person's 3-letter initials should be placed in the first box under the left and right columns. The second box allows the recorder to select one of five possible duties: P – Pilot, C – Copilot, O – Observer, V – Visitor, R – Recorder, and N – No role. Once again to save time, the recorder can simply type the first letter into the field to have the duty appear automatically. Like the Weather section, all the fields will be grayed out, but still visible, after pressing the "Submit" button until the "Change" button is pressed.
- **I** **(Sightings):** Once the Positions section has been submitted, each person's initials will appear on the boxes under the Sightings section. These boxes represent the planes seating chart. When a sighting is made, the recorder should press the button containing

the initials of the person that made the sighting. For example, if 'DJR' makes a sighting, the recorder will press the button with the initials 'DJR' and the sighting will be recorded to the right with the initials of the observer who made the sightings, in addition to the date and time of the sighting. The 'Angle', 'Species', and 'Group Size' need to be entered manually.

- **J (Additional Sighting Info):** After the 'Angle', 'Species', and 'Group Size' fields are filled in, there is the option of filling out addition information, including 'Cue', 'Reaction to Plane', 'Number of Calves', 'Swim Direction', 'Feeding', 'Number of Vessels', 'Dominant Behavior', 'Swim Direction' and 'Group Compostion'. All fields under the 'Additional Sighting Info' are drop down fields except 'Number of Calves' and 'Number of Vessels' in which a number must be entered manually.
- **K (Comments):** This section is for making any additional comments that may be appropriate during the survey. Press the 'Add Comment' button and type the comment in the space provided. (Note: every time a sighting is made, a line also appears in the comments field with the automatic entry stating 'sighting by' followed by the initials of the person that made the sighting. This is so that the sighting comment has the same time/date stamp as the original sighting.)
- **L (Mark and Group/Pass):**
- **M (View Map):** Pressing the 'View Map' button will bring a map to the front of the data entry form. On the top of the map, you will see the current GPS position in two formats (decimal degree and degree decimal minutes). Also on the top of the screen, is a zoom scroll bar which allows the user to zoom in or out while keeping the screen centered on the position of the plane. To the right of the map, there are two data columns – MAP and SIGHT/MRK. Each time a sighting is made, the group size (if entered) and the species will appear in the SIGHT/MRK column. Whenever a checkbox under the MAP column is checked, the corresponding sighting or marked group will appear on the map. Multiple checkboxes can be checked at any one time. The user may also click on a specific sighting under the SIGHT/MRK column to obtain more information. Clicking a sighting will highlight the entry and the information on the top of the data columns will fill in. The 'Date/Time' and 'Location' of the original sighting or marked group will be displayed as well as the current 'Distance (miles)' and 'Bearing (True)' from the sighting. This allows the user to guide the pilot back to the sighting, if necessary. Only one sighting can be selected at any one time. (Note: The user MUST press the "View Map" button after making a sighting in order to update the sighting information on the map. Toggling between screens without pressing this button will not update the map.)

Appendix I-3. *BOWFEST Aerial Survey Program database structure.*



There are six tables in the Access database:

1. **GPS table**
   a. **DATE**: month/day/year
   b. **TIME**: Alaska Standard Time (-8 GMT)
   c. **EFFORT**
      - ON
      - OFF
   d. **EFFORTMODE** (type of effort)
      - DEADHEAD: surveying while off designated trackline
      - CIRCLING: aircraft has left the trackline to locate a sighting
      - PHOTOMODE: we are over a sighting and photographing
      - TRACKLINE: effort on trackline
   e. **FLIGHTNUMBER**
      - A numeric value representing the flight number for the season
   f. **LATITUDE** (decimal degrees)
   g. **LONGITUDE** (decimal degrees)
   h. **HEADING** (heading of the aircraft - 0 to 359 degrees)
   i. **ALTITUDE** (altitude of the aircraft in feet above sea level)
   j. **SPEED** (speed of the aircraft in knots)
   k. **OPMODE**
      - This column specifies the quality of the GPS location. This should always read '3D' meaning that there were at least 3 satellites used to triangulate the position.

2. **Positions table**
   a. **DATE**: month/day/year
   b. **TIME** : Alaska Standard Time (-8 GMT)
   c. **ROW1LEFTINT** (initials of person in the first row, left side seat)
      - Three letter initials for first, middle, and last name
   d. **ROW1LEFTROLE** (role of person in the first row, left side seat–usually pilot position)
      - P (Pilot)
      - C (CoPilot)
      - O (Observer)
      - V (Visitor)
      - R (Recorder)
      - N (No Role)
   e. **ROW1RIGHTINT** (initials of person in the first row, right side seat)
      - Three letter initials for first, middle, and last name
   f. **ROW1RIGHTROLE** (role of person in the first row, right side seat–usually co-pilot position)
      - P (Pilot)
      - C (CoPilot)
      - O (Observer)

- V (Visitor)
- R (Recorder)
- N (No Role)

g. ROW2LEFTINT (initials of person in the second row, left side seat)
- Three letter initials for first, middle, and last name

h. ROW2LEFTROLE (role of person in the second row, left side seat–usually observer position)
- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

i. ROW2RIGHTINT (initials of person in the second row, right side seat)
- Three letter initials for first, middle, and last name

j. ROW2RIGHTROLE (role of person in the second row, right side seat–usually observer position)
- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

k. ROW3LEFTINT (initials of person in the third row, left side seat)
- Three letter initials for first, middle, and last name

l. ROW3LEFTROLE (role of person in the third row, left side seat)
- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

m. ROW3RIGHTINT (initials of person in the third row, right side seat)
- Three letter initials for first, middle, and last name

n. ROW3RIGHTROLE (role of person in the third row, right side seat–usually recorder position)
- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

o. ROW4LEFTINT (initials of person in the fourth row, left side seat)
- Three letter initials for first, middle, and last name

p. ROW4LEFTROLE (role of person in the fourth row, left side seat)

- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

q. **ROW4RIGHTINT** (initials of person in the fourth row, right side seat)
- Three letter initials for first, middle, and last name

r. **ROW4RIGHTROLE** (role of person in the fourth row, right side seat)
- P (Pilot)
- C (CoPilot)
- O (Observer)
- V (Visitor)
- R (Recorder)
- N (No Role)

3. Weather table

a. **DATE**: month/day/year

b. **TIME** : Alaska Standard Time (-8 GMT)

c. **ICECOV** (percentage of ice cover)
- 0 to 100 percent

d. **ICETYPE** (these codes were taken from the Observers Guide to Sea Ice http://archive.orr.noaa.gov/book_shelf/695_seaice.pdf)
- No Ice
- New Ice
- Brash (Broken <2m)
- Pancake (30cm-3m)
- Ice Cake (3-20m)
- Small Floe (20-100m)
- Medium Floe (100-500m)
- Big Floe (500m-2km)
- Vast Floe (2-10km)
- Giant Floe (>10km)
- Belt (1-100km)
- Strip (<1km)
- Fast Ice
- Pack Ice

e. **SKYCOND** (sky condition)
- Clear
- Partly Cloudy
- Overcast
- Light Fog
- Heavy Fog
- Precipitation
- Fog & Precipitation

- Low Ceiling
- Haze

f. BEAUFORT (sea state)
- 0 (Mirror)
- 1 (Ripples)
- 2 (Small Waves)
- 3 (Some Whitecaps)
- 4 (Many Whitecaps)
- 5 (Whitecaps/Spray)
- 6 (Whitecaps/More Spray)
- 7 (White Foam Streaks)
- 8 (Blowing Foam Streaks)

g. LEFTGLARE (glare is present and affecting viewing conditions on the left side of the aircraft)
- Y (Yes)
- N (No)

h. LEFTVISQUAL (visibility quality on the left side of the aircraft)
- E (Excellent)
- G (Good)
- F (Fair)
- P (Poor)
- U (Useless)

i. LEFTVISANG (inclinometer angle given for how far out the left observer can see, typically regarding a restriction due to glare or sea state quality)
- Values range from 0 to 90

j. RIGHTGLARE (glare is present and affecting viewing conditions on the right side of the aircraft)
- Y (Yes)
- N (No)

k. RIGHTVISQUAL (visibility quality on the right side of the aircraft)
- E (Excellent)
- G (Good)
- F (Fair)
- P (Poor)
- U (Useless)

l. RIGHTVISANG (inclinometer angle given for how far out the right observer can see, typically regarding a restriction due to glare or seastate quality)
- Values range from 0 to 90

4. Sightings table

a. DATE: month/day/year

b. TIME : Alaska Standard Time (-8 GMT)

c. OBSERVER (initials of person making the sighting)
- Three letter initials for first, middle, and last name

d. ANGLE (inclinometer angle of the sighting when perpendicular to the aircraft)

- An inclimometer angle ranging from 0° (horizontal) to 90° (straight down)

e. **GROUPSIZE** (group size of the sighting)
  - Numerical value representing the initial group size of the sighting

f. **SPECIES**
  - Bowhead Whale
  - Beluga Whale
  - Narwhal
  - Gray Whale
  - Bearded Seal
  - Ringed Seal
  - Polar Bear
  - Walrus
  - Unidentified Small Cetacean
  - Unidentified Large Cetacean
  - Unidentified Pinniped
  - Unidentified Seal
  - Unidentified Object
  - Vessel
  - Harbor Porpoise
  - Dalls Porpoise
  - Killer Whale
  - Humpback Whale
  - Minke Whale
  - Fin Whale
  - Sea Otter
  - Sea Lion
  - Harbor Seal
  - Spotted Seal

g. **CUE** (what alerted the observer to the sighting)
  - Blow
  - Body
  - Splash
  - Mud Plume

h. **CALFNUM** (calf number)
  - Numerical value representing the number of calves associated with the sighting

i. **GROUPCOMP** (group composition)
  - Calf Only
  - Cow/Calf
  - Immature
  - Adult
  - Large Adult

j. **FEEDING** (whether or not the bowhead was feeding)
  - Probable
  - Yes-Mud
  - Yes-Open Mouth

- Yes-Mud & Open Mouth
- Yes-Feces
- Unknown
- No

k. REACTOPLANE (reaction to the aircraft, it any)

- None
- Unknown
- Abrupt Dive
- Course Change
- Stop Behavior (this should have a comment associated with it explaining what the behavior was and how it changed)

l. BEHAVIOR (the predominant behavior of the animals in a particular sighting)

- Travel (directional swimming)
- Breaching (animal launches part to most of the body out of the water)
- Diving (animal dives under the water; sometimes presenting flukes)
- Flipper Slapping (whale on side slapping water with pectoral flipper)
- Fluke Slapping (whale slapping water surface with tail)
- Resting (animal floating at surface with no movement)
- Rolling (animal rotating on longitudinal axis)
- Spy Hopping (head extended vertically out of water without lunging)
- Thrashing (rapid flexure or gyration in water)
- Milling (swimming slowly at surface, directions variable)
- Log Playing (animal is associating with log in water)
- Mating (usually in a group, associated with rolling, ventral-ventral orientation of whales, often with penis visible)
- Hurt (animal appears injured)
- Dead (carcass seen floating or stranded)

m. SWIMDIR (the animals swim direction relative to the plane – the nose of the plane = 12 O'Clock)

- 12 O'Clock
- 1 O'Clock
- 2 O'Clock
- 3 O'Clock
- 4 O'Clock
- 5 O'Clock
- 6 O'Clock
- 7 O'Clock
- 8 O'Clock
- 9 O'Clock
- 10 O'Clock
- 11 O'Clock

n. VESSELNUM

- Number of vessels in the area where the sighting was made

o. GRPNUM (group number)

- A numerical value assigned to bowhead whale sightings – usually only used to keep track of bowheads after breaking trackline for circling or photography.

p. LOW

- The lowest estimated number of animals in a sighting – typically only used for walrus or bowhead whales after breaking trackline for circling or photography – added during the 2009 field season.

q. BEST

- The best estimated number of animals in a sighting – typically only used for walrus or bowhead whales after breaking trackline for circling or photography – added during the 2009 field season.

r. HIGH

- The highest estimated number of animals in a sighting – typically only used for walrus or bowhead whales after breaking trackline for circling or photography – added during the 2009 field season.

5. GrpPassMark table (group, pass, mark table)

This table has been evolving year to year. In 2007, we attempted to mark the location where photos were taken but found that linking the camera time to the gps time gave a more reliable and accurate location of the photograph.

a. DATE: month/day/year

b. TIME: Alaska Standard Time (-8 GMT)

c. GRPORID (group number or ID)

- The group number or 3 letter ID associated with the pass or mark (below)

d. PASSORMARK (pass number or mark)

- A number given each time we make a photographic pass or take a gps "mark" over a sighting

6. Comments table

a. DATE: month/day/year

b. TIME: Alaska Standard Time (-8 GMT)

c. COMMENTS

- Miscellaneous information that is not collected on a routine basis. All sightings are automatically linked to a comment with the same date/time stamp.

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SECTION II - PASSIVE ACOUSTIC MONITORING

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Abstract

This study examined the spatio-temporal distribution of bowhead whales (*Balaena mysticetus*) in the BOWFEST study area off Barrow, Alaska, from August 2007 through August 2012 using passive acoustic monitoring. Long-term (year-long) autonomous passive acoustic recorders were deployed on subsurface moorings along the 100 m isobath from Point Barrow to Cape Halkett in all years. These long-term recorders had a sampling rate of 8192 Hz and were run on a 20-45% duty cycle. They were also equipped with a built-in temperature sensor which sampled one near-bottom temperature measurement per recording period. Short-term (week to month-long) autonomous passive acoustic recorders were deployed closer inshore and in shallower water (~20 m) from 2008 to 2012, and ran on a higher duty cycle and sampling rate (80-90% and 12.5 kHz to 40 kHz, respectively). Over the course of the BOWFEST study period, 6,056 days of data were collected from the long-term moorings and 366 days from the short-term moorings (3.72 TB of data in total). In addition to the vocalization and temperature data, ice data were obtained from the NOAA CoastWatch, Aqua AMSR-E, Near Real Time, Global (1 Day Composite) ice coverage dataset.

Here, we show the use of passive acoustic recorder moorings is an effective tool for monitoring not only the spring and fall migrations of bowhead whales through the BOWFEST study area, but also the presence of bowheads in this area throughout the summer. The spring migration was detected from 2009 through 2012 (earliest onset in 2011, latest in 2012). In all four years, a sudden and near-simultaneous onset of calling was observed at the long-term sites around the beginning of April. The peak in this calling occurred under 100% ice cover, most likely because the spatial resolution of the satellite ice data is not of a fine enough scale to capture the leads through which the bowheads were migrating. Small temperature peaks seen prior to the spring calling peak in all years may be indicative of leads forming at those times. Fall migration was detected in all five years of the study. The main pulse of the fall migration, however, had a lower peak and was much more compressed in time than the spring migration peak. The end of the main pulse of calling for the fall migration varied between early November (2007) to mid-November (2008 to 2011). The decrease in calling was inversely proportional to the percentage of ice coverage (and the simultaneous dip in water temperature) in all years. The strongest correlation between temperature and calling was seen in 2007, suggesting that bowheads may use temperature as a cue to start migration. Differences in detection timing among the recorders suggest there were different fall migratory paths taken among the years.

These paths (inshore vs. offshore) broadly agree with the findings from the aerial survey team. The most interesting result from the long-term passive acoustic recordings was the continual presence of bowheads in the study area throughout the summer, and not solely during the spring and fall migrations. This can be seen clearly in 2009 and 2011, where peak or near-peak presence continued between the migrations. Although acoustic data do not provide the means to determine if feeding was occurring, these data reinforce past evidence (Braham et al. 1979, George and Carroll 1989, Moore 1992, George et al. 2006, Moore et. al. 2010a) that bowheads are using the BOWFEST area as a feeding ground and not just as a migratory corridor.

Introduction

With the western Arctic climate rapidly changing, risks to marine mammals are rising. The extended open water season caused by the severe retreat in sea ice allows not only for a longer oil and gas exploration period each year, but a greater range expansion among marine mammals, and an increase in shipping traffic. In order to better understand these risks, an in-depth year-round knowledge of marine mammal distribution is needed.

Passive acoustic sub-surface moorings provide a long-term means of collecting data on the seasonal occurrence of marine mammals (Mellinger et al. 2007, Stafford et al. 2007, MacIntyre et al. 2013, Moore et al. 2006), and the ambient noise conditions they encounter in their environment. Unlike visual observations, recordings can be made at night, under low visibility conditions, and in all sea states. Passive acoustic moorings also allow monitoring to occur during long periods when ice covers the region. Such measurements are virtually impossible to obtain from shipboard and aerial surveys, because of the relatively short duration of cruises/flights and severe limitations in the availability of ships able to work in ice-covered seas. Furthermore, this method is low in impact to the marine mammals and their environment as only a half-hour per year is required to service each mooring. Upfront costs are on par with the cost of one day at sea, and turnaround costs are minimal.

Previous acoustic studies of the bowhead whale within the Western Beaufort Sea date back to the 1970s, however they were mostly limited to the spring migration period of April-May and used sonobuoys or short-term autonomous recorders (Clark and Johnson 1984; Clark et al. 1996, Ljungblad et al. 1982, Cummings and Holliday 1987, George et al. 2004). The majority of these studies were aimed at supporting the spring visual census of bowhead whales as they passed Barrow, Alaska. Würsig and Clark (1993) summarize the acoustic behavior of bowhead whales and provide a nice outline of the bowhead whale vocal repertoire. One study collected recordings outside of the spring migration period: Moore et al. (2010b) deployed three autonomous recorders northeast of Barrow, Alaska, for the 2003-2004 winter, recording vocalizations from both the fall and spring migrations of the Bering-Chukchi-Beaufort stock of bowhead whales.

Other studies of bowhead acoustics in the Arctic include the arrays of Directional Autonomous Seafloor Acoustic Recorders (DASARs) maintained between Harrison Bay and Kaktovik, Alaska, during autumn (Blackwell et al. 2007, 2012), and a vast network of AURAL (Autonomous Underwater Recorder for Acoustic Listening, Multi-Électronique, Rimouski, QC, Canada) and AMAR (Autonomous Multi-Channel Acoustic Recorders, JASCO) arrays in the Chukchi Sea since the fall of 2007. Delarue et al. (2009) summarizes the different bowhead songs present in the Chukchi Sea from these arrays in the fall of 2007 and spring of 2008. In addition, recorders located off Barrow from Scripps Institution of Oceanography (Roth et al.

2011), and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and recorders located off Tuktoyaktuk from Cornell University, have been making acoustic recordings of bowheads, although these bowhead data have not yet been published.

The following report details the passive acoustic monitoring of bowhead whales during the period of time from August 2007 through August 2012, when passive acoustic recorders were collecting data in the BOWFEST study area (Fig. II-1).

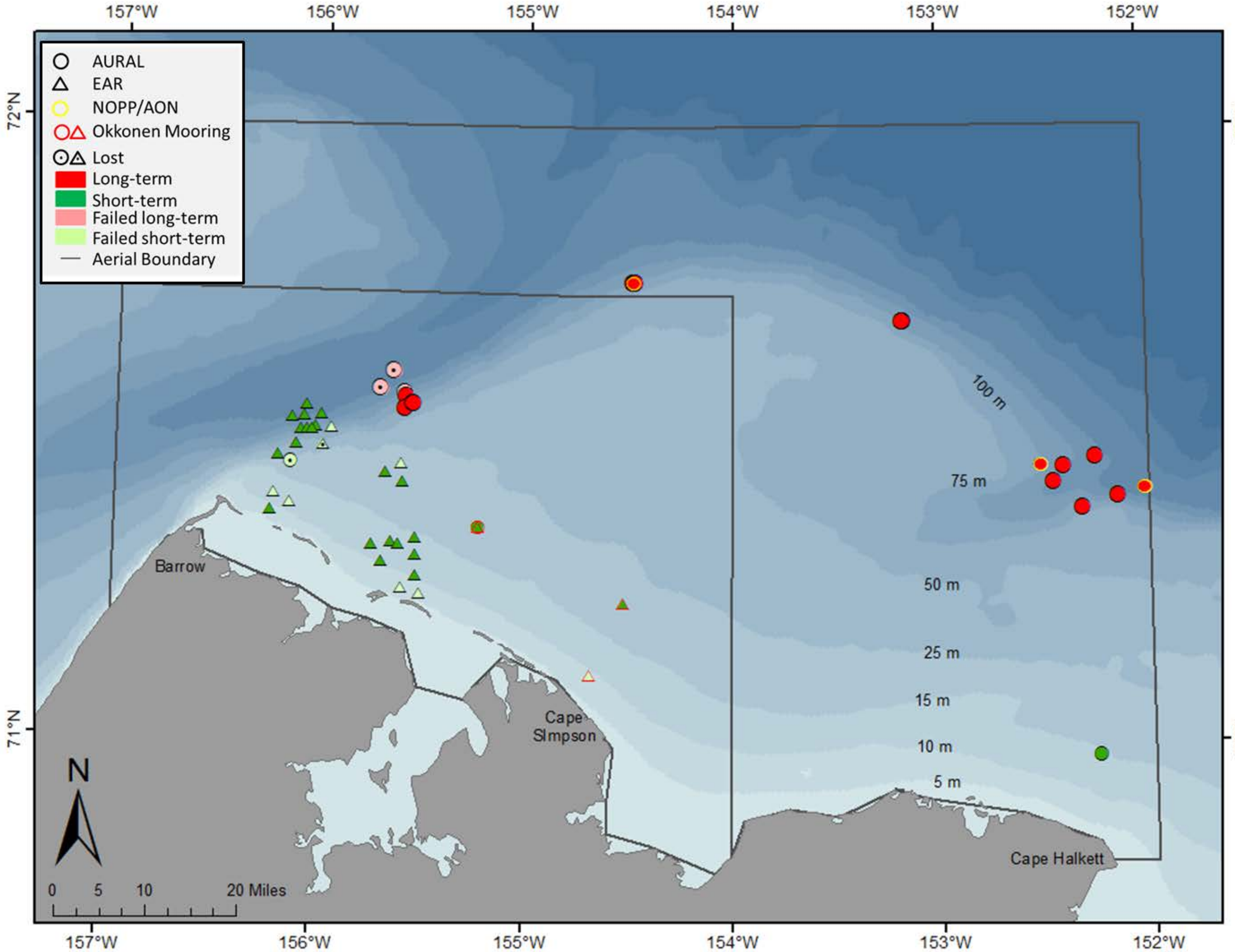

Figure II-1. *Recorder locations for the BOWFEST study, August 2007 through August 2012.*

Methods

Equipment

Two types of autonomous passive acoustic recorders were used during the BOWFEST study period (Fig. II-2): AURALs (Autonomous Underwater Recorder for Acoustic Listening, Multi-Électronique, Rimouski, QC, Canada), and EARs (Ecological Acoustic Recorder, Oceanwide Science Institute, Honolulu, HI). AURAL recorders were used as long-term recorders in all five years (Table II-1) and were deployed with two different configurations over the study period. The AURALs were also equipped with a built-in temperature sensor which sampled one temperature measurement per recording period. From 2007-2009, AURALs were deployed on a subsurface mooring consisting of seven 14” round plastic floats in varying arrangements, an acoustic release, and an anchor. From 2010-2012, the AURAL moorings were simplified to one 30” steel float, an acoustic release, and an anchor (Fig. II-3). These moorings were deployed along the 100m isobath recording at 8 kHz on various duty cycles (23-45%: Table II-1). In 2007, AURALs were deployed at two inshore locations as short-term moorings. These moorings recorded continuously at 8 kHz. Due to the large size and weight of the AURALs, the short-term moorings were switched to EARs. From 2008-2011, EARs were deployed at a variety of inshore locations and on two different types of moorings (Fig. II-4). Because of their small size, a hand-deployable sub-surface mooring configuration was designed for the EARs (Fig. II-4, left) so that they could be easily relocated by a small boat during the field season if whale movements required a shift in the array location. Because of this portability, deployment locations of the EARs varied within and between seasons, recording at 40 kHz on a 79% duty cycle (Table II-2). Additionally, an EAR was deployed on a University of Alaska at Fairbanks (UAF Okkonen: see also Okkonen Section IIIB: this volume) mooring frame during each field season from 2008-2011, which recorded at 12.5 kHz on a 92% duty cycle. Because of software problems with the EAR recorders, we switched to a short-chassis AURAL in 2012 that was deployed on the UAF mooring and recorded at 16 kHz on a 77% duty cycle. The UAF mooring was a cage designed to sit on the ocean floor and housed multiple oceanographic instruments (Fig. II-4: right panel).

Figure II-2. *The two types of recorders used during the BOWFEST study. Left = AURAL. Right = EAR.*

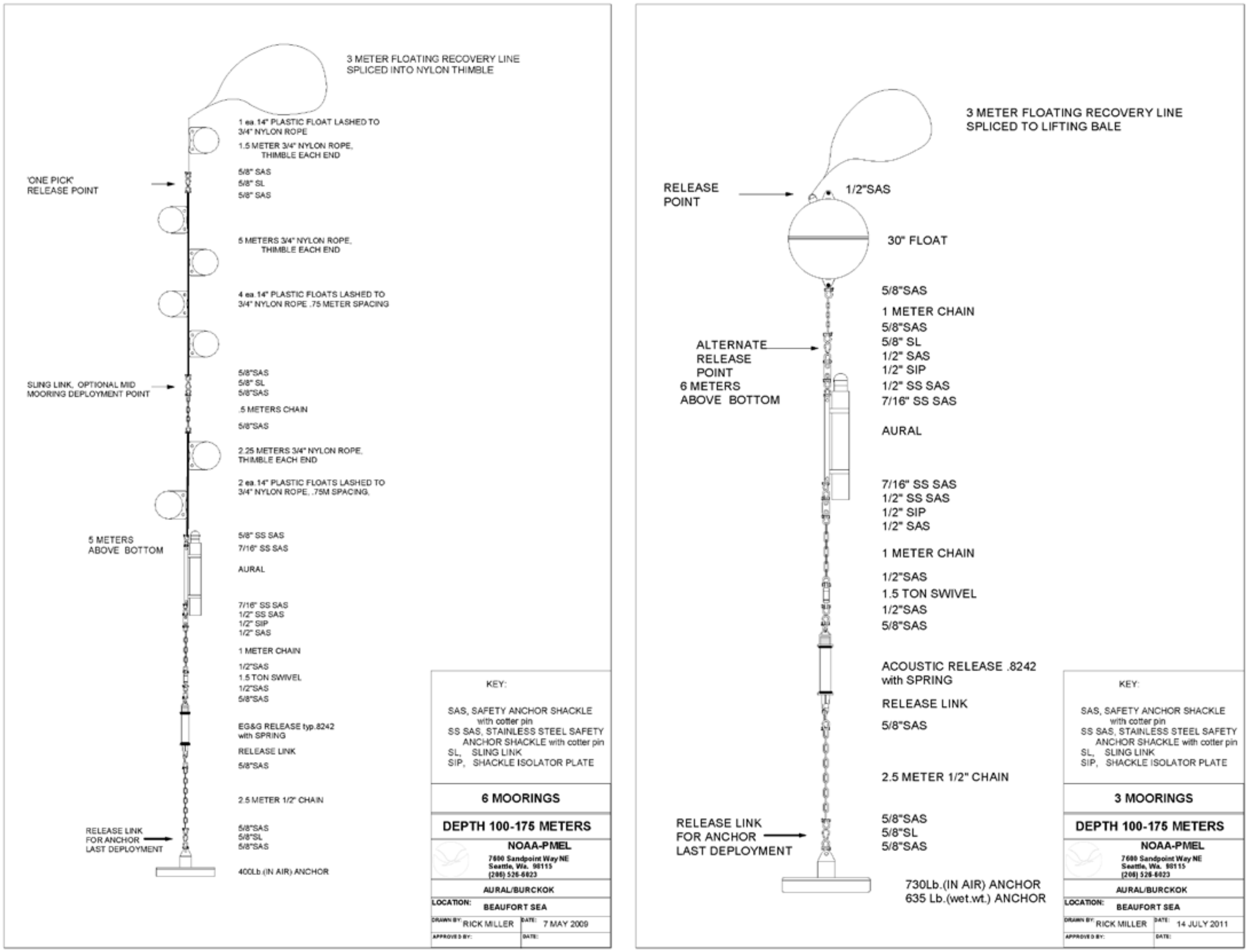

Figure II-3. *Long-term mooring configurations. Left = 2007-2009 deployments. Right = 2010-2012 deployments.*

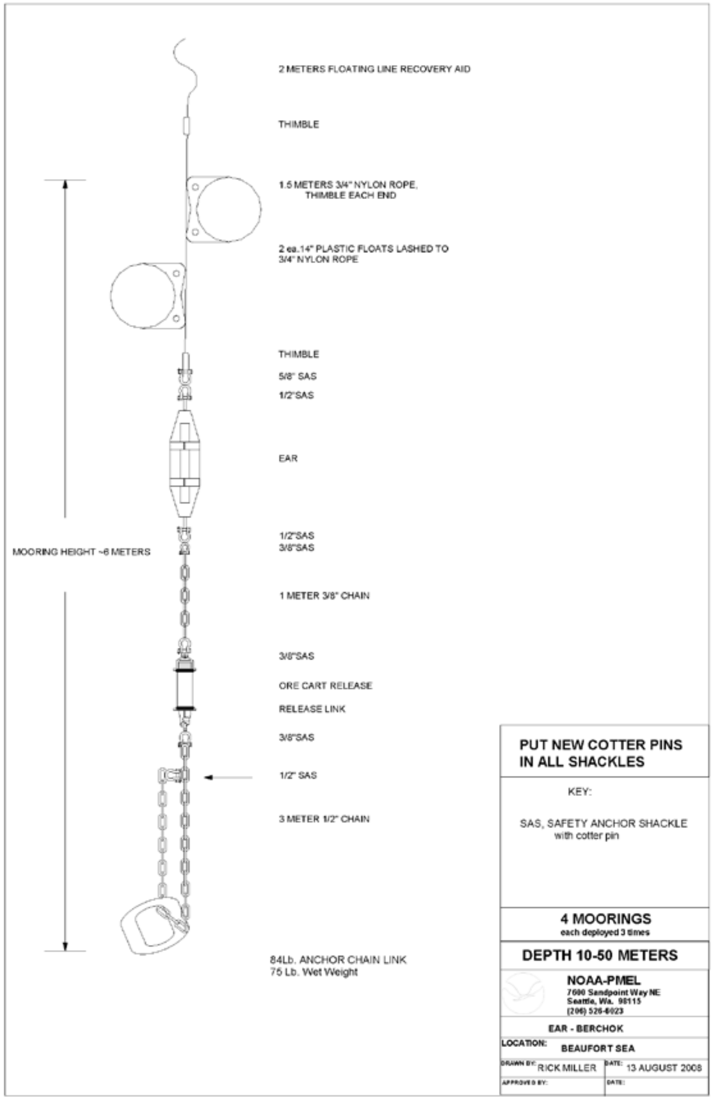

Figure II-4. *Short-term mooring configurations. Left = movable EAR. Right = Okkonen mooring (green arrow shows EAR attached to the frame).*

Table II-1. *Long-term recorder locations and recording parameters.*

Mooring	Mooring Cluster	Latitude	Longitude	Water depth (m)	Recorder Start Date	Recorder End Date	Number of Days with Data	Sampling Rate (Hz)	Duty Cycle (min on/ min off)	Deployment Date	Retrieval Date	Recorder Type	Comments
BF07_AU_02	M2	71.5616	-155.5882	110	20-Aug-07	18-Mar-08	211	8192	10/20	16-Aug-07	8-Aug-08	AURAL	
BF07_AU_03	M3	71.7512	-154.4906	100	20-Aug-07	18-Mar-08	211	8192	10/20	16-Aug-07	8-Aug-08	AURAL	
BF07_AU_04	M4	71.6886	-153.1742	104	20-Aug-07	18-Mar-08	211	8192	10/20	16-Aug-07	12-Aug-08	AURAL	
BF07_AU_05	M5	71.3997	-152.1375	108	20-Aug-07	18-Mar-08	211	8192	10/20	16-Aug-07	9-Aug-08	AURAL	
BF08_AU_01	M2	71.5749	-155.7104	110	-	-	-	8192	9/20	8-Aug-08	-	AURAL	On side in mud
BF08_AU_02	M2	71.6032	-155.6469	173	-	-	-	8192	9/20	8-Aug-08	-	AURAL	Lost
BF08_AU_03	M2	71.5681	-155.5878	118	-	-	-	8192	9/20	13-Aug-08	-	AURAL	Lost
BF08_AU_05	M5	71.3825	-152.3098	92	15-Aug-08	19-Oct-08	65	8192	9/20	9-Aug-08	2-Aug-09	AURAL	
BF08_AU_06	M5	71.4635	-152.2460	134	15-Aug-08	2-Aug-09	353	8192	9/20	9-Aug-08	2-Aug-09	AURAL	
NP08_AU_A1*	M3	71.75033	-154.48267	100	16-Aug-08	27-Jul-09	345	8192	9/21	9-Aug-08	27-Jul-09	AURAL	
NP08_AU_A2*	M5	71.45217	-152.50533	98	16-Aug-08	29-Jul-09	347	8192	9/21	9-Aug-08	2-Aug-09	AURAL	
BF09_AU_01	M2	71.5417	-155.5919	66	7-Aug-09	18-Mar-10	223	8192	9/11	5-Aug-09	8-Sep-10	AURAL	
BF09_AU_05	M5	71.4250	-152.4501	137	4-Aug-09	4-Aug-10	365	8192	9/11	3-Aug-09	13-Sep-10	AURAL	
BF09_AU_06	M5	71.4500	-152.4001	125	4-Aug-09	8-Apr-10	247	8192	9/11	3-Aug-09	13-Sep-10	AURAL	
NP09_AU_A1*	M3	71.7506	-154.4826	102	1-Aug-09	15-Aug-10	379	8192	9/30	29-Jul-09	12-Sep-10	AURAL	
NP09_AU_A2*	M5	71.4522	-152.5053	95	4-Aug-09	11-Aug-10	372	8192	9/30	2-Aug-09	12-Sep-10	AURAL	
BF10_AU_01	M2	71.5504	-155.5585	70	9-Sep-10	2-Aug-11	327	8192	9/11	8-Sep-10	28-Aug-11	AURAL	
BF10_AU_02[1]	M3	71.7505	-154.4830	100	20-Sep-10	5-Mar-11	166	8192	9/11	12-Sep-10	29-Aug-11	AURAL	
BF10_AU_03[2]	M4	71.6880	-153.1740	105	20-Sep-10	22-Aug-11	336	8192	9/11	12-Sep-10	29-Aug-11	AURAL	
AO10_AU_01*	M5	71.4120	-152.0065	105	25-Sep-10	29-Aug-11	339	8192	9/21	15-Sep-10	29-Aug-11	AURAL	
BF11_AU_01	M2	71.5513	-155.5512	73	1-Sep-11	30-Jul-12	333	8192	6/14	28-Aug-11	27-Aug-12	AURAL	
BF11_AU_02	M3	71.7512	-154.4800	104	1-Sep-11	29-Jul-12	332	8192	6/14	29-Aug-11	27-Aug-12	AURAL	
BF11_AU_03	M4	71.6887	-153.1753	108	29-Aug-11	15-Jul-12	321	8192	6/14	29-Aug-11	27-Aug-12	AURAL	
AO11_AU_01*	M5	71.4120	-152.0112	179	1-Sep-11	28-Aug-12	362	8192	9/21	29-Aug-11	28-Aug-12	AURAL	

[1]Due to a software problem, starting on 3/15/2011, BF10_AU_02 recorded only 35 minutes of data per day with no temperature measurements saved.
[2]Due to another software problem, no temperature measurements on BF10_AU_03 were saved after 10/25/2010.
*Kate Stafford's moorings deployed as part of her National Ocean Partnership Program (NP08-09) and National Science Foundation (AON 10-11) grants.

Table II-2. *Short-term recorder locations and recording parameters.*

Mooring	Mooring Cluster	Latitude	Longitude	Water depth (m)	Recording Start Date	Recording End Date	Number of Days with Data	Sampling Rate (Hz)	Duty Cycle (min on/ min off)	Deployment Date	Retrieval Date	Recorder Type	Comments
BF07_AU_01	-	71.4521	-156.1331	15.2	-	-	-	8192	Continuous	17-Aug-07	-	AURAL	Lost
BF07_AU_06	O	70.9813	-152.2507	15.1	15-Aug-07	11-Sep-07	28	8192	Continuous	15-Aug-07	11-Sep-07	AURAL	
BF08_EA_M01a	A	71.4631	-156.2025	17.6	29-Aug-08	10-Sep-08	13	40000	30/8	28-Aug-08	10-Sep-08	EAR	Movable array #1
BF08_EA_M01b	B	71.5065	-156.0911	100	6-Sep-08	13-Sep-08	8	40000	30/8	6-Sep-08	13-Sep-08	EAR	Movable array #2
BF08_EA_M02b	B	71.5114	-156.0221	100	6-Sep-08	13-Sep-08	8	40000	30/8	6-Sep-08	13-Sep-08	EAR	Movable array #2
BF08_EA_M03b	B	71.5282	-156.0768	115	6-Sep-08	13-Sep-08	8	40000	30/8	6-Sep-08	13-Sep-08	EAR	Movable array #2
BF08_EA_O01	O	71.1138	-154.6887	9.57	-	-	-	12500	60/5	19-Aug-08	10-Sep-08	EAR	Okkonen Mooring/Failed
BF08_EA_O02	O	71.2292	-154.5258	18.75	21-Aug-08	11-Sep-08	22	12500	60/5	19-Aug-08	10-Sep-08	EAR	Okkonen mooring
BF09_EA_M01a	A	71.5076	-156.0651	9	26-Aug-09	7-Sep-09	13	40000	30/8	26-Aug-09	7-Sep-09	EAR	Movable array #1
BF09_EA_M02a	A	71.5307	-155.9978	20	26-Aug-09	7-Sep-09	13	40000	30/8	26-Aug-09	7-Sep-09	EAR	Movable array #1
BF09_EA_M03a	A	71.5255	-156.1401	9	26-Aug-09	7-Sep-09	13	40000	30/8	26-Aug-09	7-Sep-09	EAR	Movable array #1
BF09_EA_M04a	B	71.5460	-156.0683	13	26-Aug-09	7-Sep-09	13	40000	30/8	26-Aug-09	7-Sep-09	EAR	Movable array #1
BF09_EA_M01b	B	71.4395	-155.6833	20	11-Sep-09	6-Oct-09	26	40000	30/8	11-Sep-09	12-Oct-09	EAR	Movable array #2
BF09_EA_M02b	B	71.4239	-155.5994	20	11-Sep-09	5-Oct-09	25	40000	30/8	11-Sep-09	12-Oct-09	EAR	Movable array #2
BF09_EA_M03b	B	71.4535	-155.6024	21	-	-	-	40000	30/8	11-Sep-09	12-Oct-09	EAR	Movable array #2/Failed
BF09_EA_O01	O	71.3516	-155.2296	18.7	21-Aug-09	15-Sep-09	26	12500	60/5	21-Aug-09	15-Sep-09	EAR	Okkonen mooring
BF10_EA_M01a	A	71.3220	-155.7410	15	24-Aug-10	8-Sep-10	16	40000	30/8	24-Aug-10	8-Sep-10	EAR	Movable array #1
BF10_EA_M02a[1]	A	71.2955	-155.6944	15	24-Aug-10	8-Sep-10	16	40000	30/8	24-Aug-10	8-Sep-10	EAR	Movable array #1
BF10_EA_M03a	A	71.3264	-155.6476	15	24-Aug-10	8-Sep-10	16	40000	30/8	24-Aug-10	8-Sep-10	EAR	Movable array #1
BF10_EA_M01b	B	71.2526	-155.5950	15	-	-	-	40000	30/8	13-Sep-10	17-Sep-10	EAR	Movable array #2/Failed
BF10_EA_M02b	B	71.2726	-155.5254	15	13-Sep-10	17-Sep-10	5	40000	30/8	13-Sep-10	17-Sep-10	EAR	Movable array #2
BF10_EA_M03b	B	71.2424	-155.5104	15	-	-	-	40000	30/8	13-Sep-10	17-Sep-10	EAR	Movable array #2/Failed
BF10_EA_M01c	C	71.4023	-156.2204	15	-	-	-	40000	30/8	17-Sep-10	23-Sep-10	EAR	Movable array #3/Failed
BF10_EA_M02c	C	71.3736	-156.2328	15	17-Sep-10	23-Sep-10	7	40000	30/8	17-Sep-10	23-Sep-10	EAR	Movable array #3
BF10_EA_M03c	C	71.3863	-156.1439	15	-	-	-	40000	30/8	17-Sep-10	23-Sep-10	EAR	Movable array #3/Failed
BF10_EA_O01	O	71.3514	-155.2291	18.7	19-Aug-10	28-Aug-10	10	12500	60/5	19-Aug-10	16-Sep-10	EAR	Okkonen mooring
BF11_EA_M01a*	A	71.3221	-155.6111	N/A	29-Aug-11	12-Sep-11	15	40000	30/8	29-Aug-11	12-Sep-11	EAR	Movable array #1
BF11_EA_M02a*	A	71.3342	-155.5314	N/A	29-Aug-11	12-Sep-11	15	40000	30/8	29-Aug-11	12-Sep-11	EAR	Movable array #1
BF11_EA_M03a*	A	71.3051	-155.5327	N/A	29-Aug-11	12-Sep-11	15	40000	30/8	29-Aug-11	12-Sep-11	EAR	Movable array #1
BF11_EA_M01b*	B	71.4826	-156.1169	N/A	14-Sep-11	24-Sep-11	11	40000	30/8	14-Sep-11	29-Sep-11	EAR	Movable array #2
BF11_EA_M02b*	B	71.5066	-156.0391	N/A	16-Sep-11	24-Sep-11	9	40000	30/8	14-Sep-11	29-Sep-11	EAR	Movable array #2
BF11_EA_M03b*	B	71.5091	-155.9469	N/A	-	-	-	40000	30/8	14-Sep-11	29-Sep-11	EAR	Movable array #2/Failed
BF11_EA_M04b*	B	71.4822	-155.4888	N/A	-	-	-	40000	30/8	14-Sep-11	29-Sep-11	EAR	Movable array #2/Lost
BF11_EA_O01	O	71.3512	-155.2292	19	18-Aug-11	22-Aug-11	5	12500	60/5	18-Aug-11	30-Sep-11	EAR	Okkonen mooring
BF12_AU_O01	O	71.3505	-155.2261	19	23-Aug-12	11-Sep-12	20	16384	85/25	23-Aug-12	11-Sep-12	AURAL	Okkonen mooring

[1]Mooring not completely analyzed due to excessive masking

*Unknown which mooring was deployed at which location within each array.

Field Methods

2007

On August 16th and 17th, 2007, six AURAL recorders were deployed from the R/V *Annika Marie* (Fig. II-1, Table II-1). Moorings BF07_AU_02-05 were deployed along the 100 m isobath for a period of one year. Moorings BF07_AU_01&06 were deployed inshore in 20 m of water (Table II-2). The latter two moorings were to be deployed for a one month period; however BF07_AU_01 was not able to be retrieved due to the start of whaling season and an early onset of ice, and subsequently was lost over the winter.

2008

Long-term moorings

In 2008, all AURAL recorders BF08_AU_01-03&05-06 (Figure II-1) were deployed along the 100 m isobath from the USCGC *Healy*. BF08_AU_04 was not deployed due to lack of time. All 2007 moorings (BF07_AU_02-05) were retrieved on this cruise.

In addition to these BOWFEST moorings, two identically programmed AURAL moorings were deployed for the NOPP funded project. The configuration of AURAL recorders was a triad array (BF08_AU_01-03, spaced ~ 3-4 km apart) at the M2 cluster location, a single mooring to the north (NP08_AU_A1) at M3, and a triad array (BF08_AU_05-06 and NP08_AU_A2, spaced ~9-10 km apart) at M5 (Fig. II-1). Lack of ship time prevented the fourth overwintering unit to be redeployed at M4. All BOWFEST moorings used the same deployment configuration as in 2007 (Fig. II-3).

Short-term moorings

Because of the AURALs unwieldy size (6 ft long, 150 lbs), EAR recorders were introduced as our short-term recorders starting in the 2008 field season. Two units were sent to Prudhoe Bay to be hand-deployed during the R/V *Annika Marie's* transit from Prudhoe Bay to Barrow. These recorders were deployed in shallow water on UAF mooring frames (Okkonen; Fig. II-1) on August 19th and were retrieved on September 10th, 2008. After opening the units to download data, it was discovered that the computer chip in the inshore unit (BF08_EA_O01) had been knocked out of its socket en route to Prudhoe Bay from Seattle. A quick scan of the hard drive revealed that no data were recorded on this unit during its deployment.

The remaining four EAR recorders were hand-deployed on movable moorings (Fig. II-1) as a single mooring and a triad array. All units were deployed from the M/V *Iipuk* and the M/V *Little Whaler*. The M/V *Little Whaler* was used to retrieve all the moorings at the end of the season.

2009

Long-term moorings

As in 2008, all AURAL recorders (Fig. II-1) were again deployed and retrieved along the 100 m isobath from the USCGC *Healy*. The plan for 2009 was to recover the five AURALs deployed in 2008 and redeploy them in addition to adding a sixth mooring. However, several unsuccessful attempts were made to recover the triad deployed at the M2 cluster. Attempts have been made every summer since 2009 to retrieve these moorings. To date, only one mooring of the triad is still responding but appears to be lying on its side in the mud, thus leading us to believe something catastrophic such as a mudslide must have happened. During the same year, a Japanese research group lead by Takashi Kikuchi lost 3 double-release moorings in the same area. Because of this loss only one mooring (BF09_AU_01) was deployed at the M2 location. All other moorings were retrieved and redeployed successfully with NP09_AU_01 again occupying the M3 location and NP09_AU_02 and BF09_AU_05-06 deployed as a triad spaced 3.6 km apart at the M5 cluster (Fig. II-1, Table II-1).

Short-term moorings

A single EAR recorder (Fig. II-1, Table II-2) was sent to Prudhoe Bay to be hand-deployed during the R/V *Annika Marie's* transit from Prudhoe Bay to Barrow. This recorder was deployed in 18.7 m of water on a UAF mooring frame (Fig. II-4: right panel) on August 21st and was retrieved on September 11th, 2009.

The remaining four EARs were hand-deployed on the movable moorings (Fig. II-1). All deployments and retrievals were done from the M/V *Little Whaler*. The movable array was successfully deployed and retrieved twice: once as a four-element array, and once as a triad (Table II-2).

2010

Long-term moorings

Due to time constraints aboard the USCGC *Healy*, the F/V *Alaskan Enterprise* was also used to aid in deployment of the 2010 moorings and retrieval of the 2009 moorings.

From the USCGC *Healy*, BOWFEST-funded moorings BF10_AU_02 (M3 location) and BF10_AU_03 (M4 location) were deployed, while moorings BF09_AU_05 and BF09_AU_06 were retrieved from the M5 location (Fig. II-1, Table II-1). Stafford's NOPP and new NSF (Arctic Observing Network, AON) funded AURAL recorders, whose data will complement the National Marine Mammal Laboratory (NMML) data set, were also turned around on the USCGC *Healy*.

Mooring work on the F/V *Alaskan Enterprise* included the turn-around of the BOWFEST mooring at the M2 location (BF09_AU_01 to BF10_AU_01), as well as recovery attempts (dragging) on the BOWFEST triad array (BF08_AU_01-03) lost off Barrow Canyon during the 08-09 season (Fig. II-1, Table II-1).

Short-term moorings

As in previous years, an EAR recorder (BF10_EA_O01) was hand-deployed from the R/V *Annika Marie* during its transit from Prudhoe Bay to Barrow. The recorder was deployed on the UAF mooring frame (Okkonen) from August 19th until September 16th, 2010 (Fig. II-1, Table II-2).

Again the movable mooring operations were conducted from the M/V *Little Whaler*. Over the course of the season, three deployments of a three-unit array (Fig. II-1, Table II-2) were made. A change to the anchor system (gravel-filled burlap sacks) was made this year in order to reduce the exorbitant costs of shipping 80 pound anchors to Barrow. The new system worked well except the bag broke open on one mooring. Luckily, the mooring was found adrift by Brower and recovered.

2011

Long-term moorings

In 2011, the long-term mooring work was completed entirely aboard the F/V *Mystery Bay*. Two days of sea time were paid for by BOWFEST to accomplish these mooring operations as well as to try another unsuccessful dragging attempt on the 2008 M2 triad. The three BOWFEST-funded AURALs (BF11_AU_01-03) and the Stafford NSF-funded AON AURAL (AO11_AU_01) moorings were all successfully retrieved and new moorings redeployed at the same four locations (Fig. II-1, Table II-1).

Short-term moorings

As in previous years, an EAR recorder (BF10_EA_O01) was hand-deployed from the R/V *Annika Marie* during its transit from Prudhoe Bay to Barrow. The recorder was deployed on the UAF mooring frame (Okkonen) from August 18th through September 30th, 2011 (Fig. II-1, Table II-2).

Once again the movable mooring operations were conducted from the M/V *Little Whaler*. This year one deployment of a three-unit array and one deployment of a four-unit array were made (Fig. II-1, Table II-2). The rock-filled burlap sacks were again used in place of the 80 pound chain link anchor to save on shipping costs. Unfortunately, one of the recorders in the four-unit array broke free from its anchor and was not recovered.

2012

Long-term moorings

In 2012, long-term mooring work was completed entirely aboard the R/V *Aquila*. A single day of sea time was paid for by BOWFEST to accomplish the mooring operations and to attempt to drag for the lost 2008 triad array.

All BOWFEST (BF11_AU_01-03) and Stafford NSP AON (AO11_AU_01) funded AURALs deployed in 2011 were successfully retrieved and new moorings were redeployed at the same four locations (Fig. II-1, Table II-1). These were the final retrievals for the BOWFEST project; however, because the turnaround costs are minimal, we plan to continue this valuable long-term time series. Of the AURALs that were redeployed in 2012, three are part of the BOEM-funded Arctic Whale Ecology Study known as ARCWEST (AW12_AU_01-03) and one remains part of Stafford's NSP AON project (AO12_AU_01).

Short-term mooring

Because of software issues with the EARs, and their higher annual cost, in 2012 we replaced the EAR recorder with an AURAL recorder housed in a smaller sized (64 instead of 128 battery-cell) chassis. The smaller-sized AURAL (BF12_AU_O01) was still much heavier than the EAR, however it was again hand deployed and attached to a UAF mooring frame. The recorder was deployed from August 23rd through September 11th (Fig. II-1, Table II-2).

Analysis Methods

Data processing

After recorders were retrieved, the hard drives were removed and a backup of the raw data was immediately made onto an external hard drive. The original drives were saved as master copies of the data. The data were then processed in two steps. First the raw sound files were converted into working sound files by converting them to .wav files (EAR data only), dividing them into ten-minute files, and renaming these files with intuitive filenames (including mooring name, date, and time). The working .wav files were then converted into spectrogram image files that were used, with the .wav files, in our SoundChecker Analysis Program (described below).

Temperature data were extracted from the AURAL recordings using the AURAL InfoWav software. An average daily temperature was calculated, and these results were smoothed with a no-phase 7-day moving average. Due to some software problems in a couple of the AURALs, there are sometimes periods where there are acoustic data available, but not temperature measurements.

Ice data were obtained from the Environmental Research Division's Data Access Program website. (http://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=ice, Ice Coverage, Aqua AMSR-E, Near Real Time, Global (1 Day Composite) dataset, NOAA CoastWatch, West Coast Node). A 10 mile radius around each M cluster was used and a daily average of all points within that area was calculated for ice coverage. Daily averages were smoothed with a no-phase 7-day moving average.

Data analysis

An in-house, Matlab-based analysis program, SoundChecker, was used to analyze all acoustic data. The SoundChecker program was developed in response to the sheer magnitude of passive acoustic data recordings that need to be analyzed, the enormous overlap of the acoustic repertoires of many Alaskan marine mammal species, and the lack of any semblance of a stereotyped call for most species (which results in poor auto-detection performance). The trouble with any spectrogram-based sound analysis program is the amount of computational time needed to generate the spectrograms on the fly. This time increases as the frequency band of interest increases. SoundChecker operates on image files (Portable Network Graphics (PNG) format) that can be generated ahead of time, so no time is wasted waiting for the spectrogram to appear during the analysis sessions.

Figure II-5 shows the interface window for the SoundChecker program. The main action buttons used are the Yes/No/Maybe buttons. Once the analyst decides if a species or call type is present, they select one of those buttons and the program jumps to either the next image file for No or Maybe answers or the first image file of the next time interval for Yes answers. A No-with-noise button was added in 2011 to indicate zero effort, and was used when background noise was so loud that it prevented possible calls from being detected. A three-hour analysis interval was used for the long-term AURAL data, while every image file was reviewed for the EAR and short-term AURAL data. If the analyst needed more detail to help with their decision, zoom and playback buttons provided additional reviewing options.

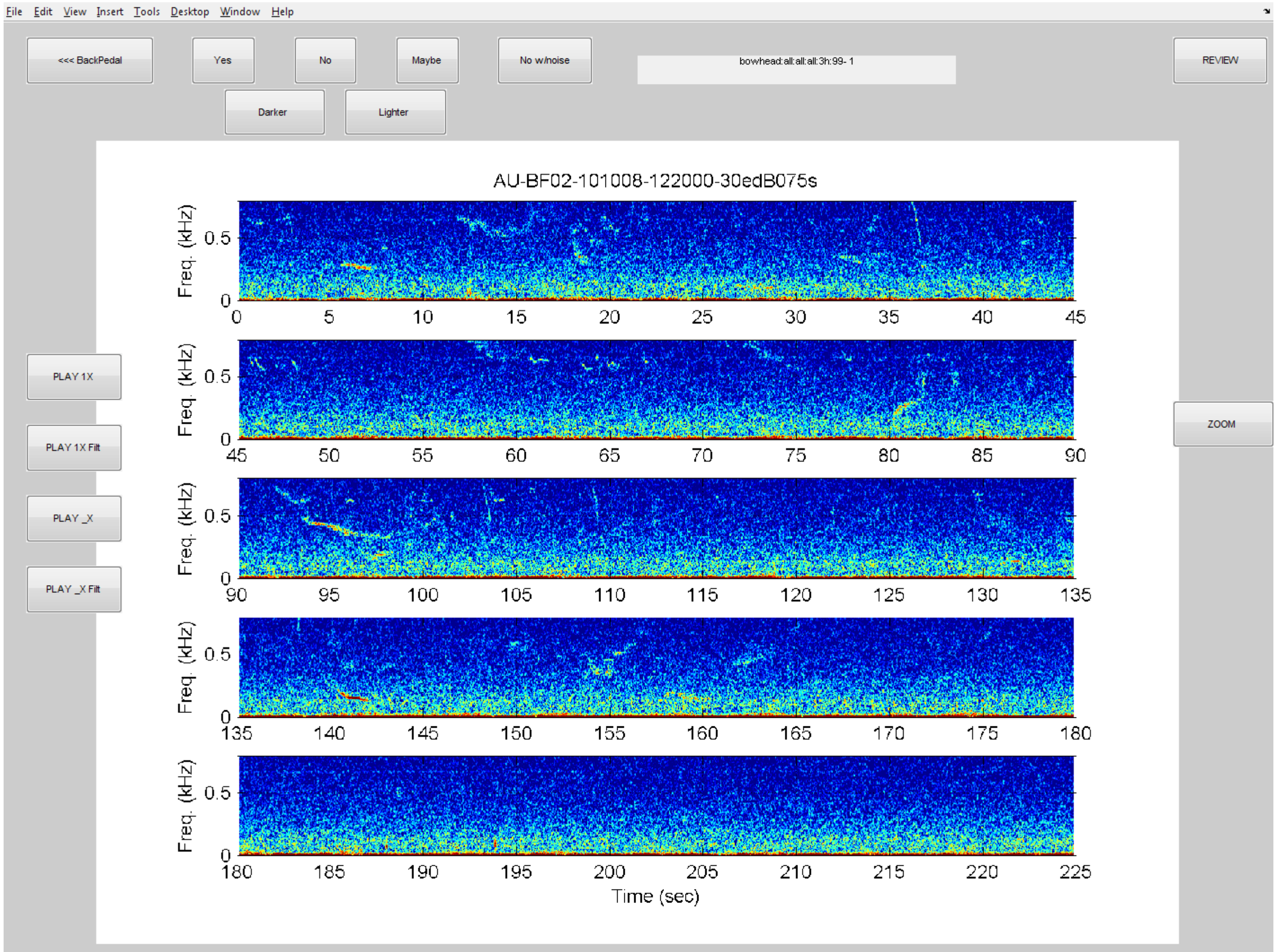

Figure II-5. *SoundChecker analysis interface. Spectrogram shown is for a BOWFEST mooring deployed in 2010 and represents 225s of recordings starting at 12:20:00 UTC on October 8, 2010. The upper information bar shows that this analyst was looking for bowhead whale calls in 3hr analysis intervals and was on the first spectrogram of their analysis session. Present are bowhead whale and ice seal calls.*

The results of the SoundChecker analysis were stored in a matrix, along with a structure array of .png file names and a metadata file. Several additional programs were written to process these results, including converting to a longer analysis interval (e.g., for the EAR results), plotting, and computing data statistics.

Results

[Note: Because deployment locations and array configurations of the AURALs have changed slightly since the beginning of BOWFEST, results are framed in terms of mooring clusters (indicated by the 'M' labels). When more than one mooring was deployed in an area in the same year results are treated as an array and combined into one plot. All long-term graphs, except when noted, use data that are zero-phase moving-averaged by week to allow for easier interpretation. All short-term graphs use data that are zero-phase moving averaged over two days. All numbers given for individual moorings are done with daily averages. For this report peak presence was defined as any day when greater than 50% of time intervals for that day had detections of bowhead calls. All data were converted into 3 hour analysis bins]

Over the course of the BOWFEST study period, 6,056 days of data were collected from the long-term moorings and 366 days from the short-term moorings. Figure II-6 summarizes the data collected on all four long-term mooring clusters from the fall 2007 through spring of 2012. Although it appears that the M3 cluster had the most recording effort, the M5 cluster does have data from Stafford's NSF-funded AON AURAL from August 2010 onward, which was unavailable at the time of this report. The unfortunate loss of the M2 triad in 2008 led to the large gap in data for that mooring, and lack of ship time on the *USCGC Healy* caused the 2.5 year gap for M4. Table II-3 summarizes both the long- and short-term data for all moorings deployed within this 5-year period. For both calling and peak (> 50%) calling, start and end dates, number of days, and percent of days with calling/peak calling are listed. Since recorders were typically deployed from August of one year through August of the next year, data were sorted for this table, and for subsequent yearly plots and summaries that follow below.

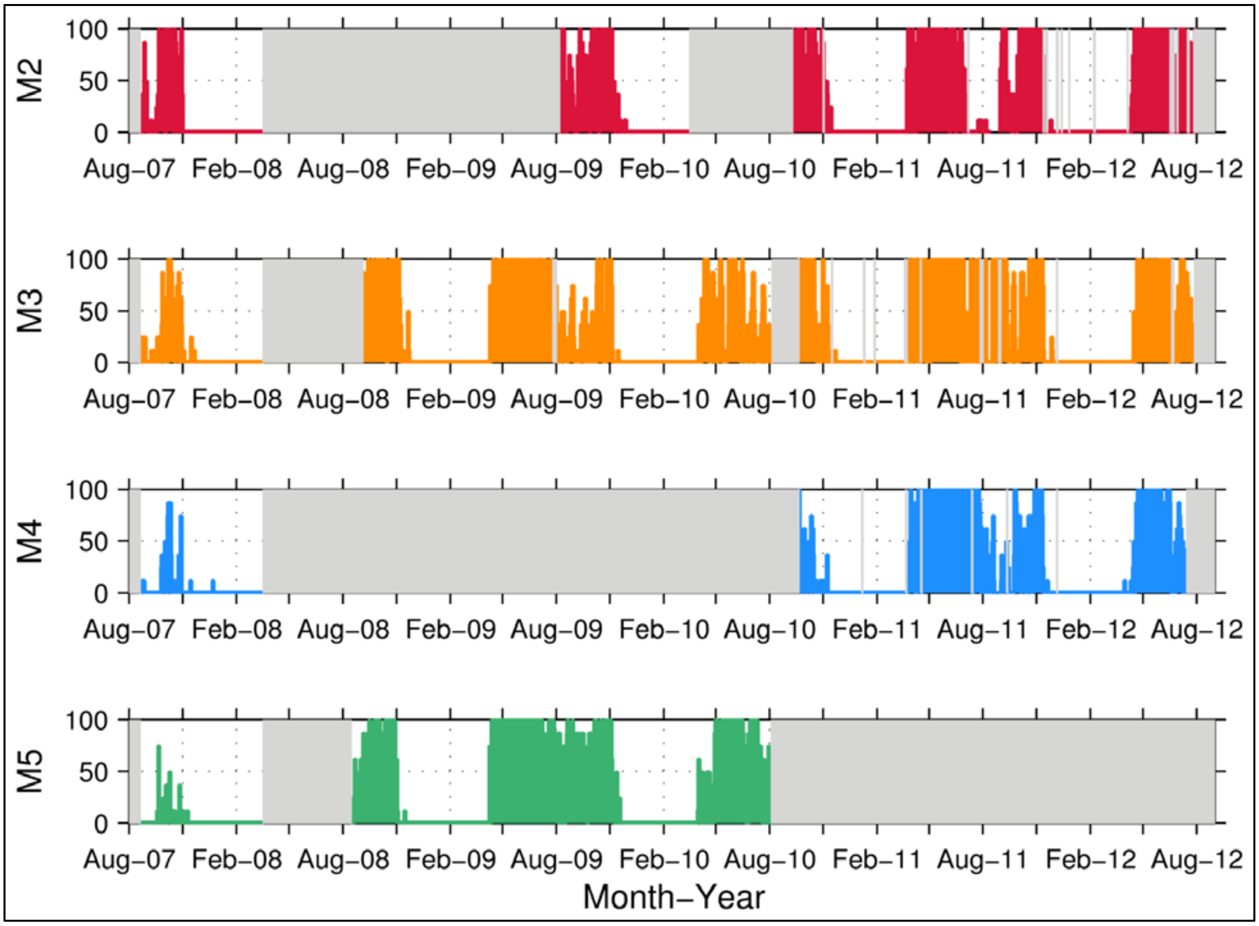

Figure II-6. *Percentage of time with bowhead calls (y-axis) for all long-term moorings over all five years of the BOWFEST study. No moving average was applied. Gray shaded areas were periods with no data. Data at M5 from August 2010-2012 were not available at the time of this report.*

Table II-3. *Summary of results for all long- and short- term mooring clusters including effort, percent calling, percent peak calling, and start and end dates of calling and percent calling for each mooring. When more than one mooring was deployed in an area in the same year results were treated as an array and combined into one plot. Peak calling was when greater than 50% of time intervals per day had calling.*

Cluster	Year	# of days w/data	# of days w/calls	Date of first call detected	Date of last call detected	% of days w/calls	# of days w/peak calling	Start date of peak calling	End date of peak calling	% of days w/calls w/peak calling
M2	2007	134	47	24-Aug-07	31-Oct-07	**35.07**	25	28-Aug-07	30-Oct-07	**53.19**
M3	2007	134	44	22-Aug-07	21-Nov-07	**32.84**	18	28-Sep-07	29-Oct-07	**40.91**
M4	2007	134	23	24-Aug-07	23-Dec-07	**17.16**	7	2-Oct-07	29-Oct-07	**30.43**
M5	2007	134	18	21-Sep-07	9-Nov-07	**13.43**	2	21-Sep-07	10-Oct-07	**11.11**
O	2007	28	1	3-Sep-07	3-Sep-07	**3.57**	0	N/A	N/A	**0.00**
M2	2008	78	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
M3	2008	197	69	4-Sep-08	22-Nov-08	**35.03**	53	6-Sep-08	21-Nov-08	**76.81**
M4	2008	78	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
M5	2008	217	78	16-Aug-08	15-Nov-08	**35.94**	57	22-Aug-08	1-Nov-08	**73.08**
A	2008	13	10	30-Aug-08	9-Sep-08	**76.92**	4	2-Sep-08	8-Sep-08	**40.00**
B	2008	8	8	6-Sep-08	13-Sep-08	**100.00**	8	6-Sep-08	13-Sep-08	**100.00**
O	2008	23	21	21-Aug-08	11-Sep-08	**91.30**	13	21-Aug-08	10-Sep-08	**61.90**
M2	2009	147	91	7-Aug-09	28-Nov-09	**61.90**	55	7-Aug-09	8-Nov-09	**60.44**
M3	2009	362	174	11-Apr-09	15-Nov-09	**48.07**	129	11-Apr-09	4-Nov-09	**74.14**
M4	2009	0	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
M5	2009	365	208	10-Apr-09	18-Nov-09	**56.99**	175	10-Apr-09	13-Nov-09	**84.13**
A	2009	13	13	27-Aug-09	8-Sep-09	**100.00**	10	27-Aug-09	8-Sep-09	**76.92**
B	2009	26	25	11-Sep-09	6-Oct-09	**96.15**	23	11-Sep-09	6-Oct-09	**92.00**
O	2009	26	25	22-Aug-09	15-Sep-09	**96.15**	24	22-Aug-09	15-Sep-09	**96.00**
M2	2010	191	61	10-Sep-10	14-Nov-10	**31.94**	47	10-Sep-10	7-Nov-10	**77.05**
M3	2010	321	129	2-Apr-10	22-Nov-10	**40.19**	75	8-Apr-10	8-Nov-10	**58.14**
M4	2010	103	30	20-Sep-10	8-Nov-10	**29.13**	13	20-Sep-10	14-Oct-10	**43.33**
M5*	2010	217	109	1-Apr-10	5-Aug-10	**50.23**	80	2-Apr-10	5-Aug-10	**73.39**
A	2010	16	8	29-Aug-10	8-Sep-10	**50.00**	3	30-Aug-10	8-Sep-10	**37.50**
B	2010	5	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
C	2010	7	7	17-Sep-10	23-Sep-10	**100.00**	6	17-Sep-10	22-Sep-10	**85.71**
O	2010	10	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
M2	2011	346	165	25-Mar-11	26-Nov-11	**47.69**	128	25-Mar-11	12-Nov-11	**77.58**
M3	2011	365	154	29-Mar-11	28-Nov-11	**42.19**	135	29-Mar-11	12-Nov-11	**87.66**
M4	2011	359	196	27-Mar-11	20-Nov-11	**54.60**	146	28-Mar-11	11-Nov-11	**74.49**
M5*	2011	0	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
A	2011	14	5	31-Aug-11	12-Sep-11	**35.71**	0	N/A	N/A	**0.00**
B	2011	11	11	14-Sep-11	24-Sep-11	**100.00**	11	14-Sep-11	24-Sep-11	**100.00**
O	2011	5	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
M2	2012	212	97	12-Apr-12	30-Jul-12	**45.75**	82	15-Apr-12	30-Jul-12	**84.54**
M3	2012	211	94	16-Apr-12	26-Jul-12	**44.55**	69	16-Apr-12	22-Jul-12	**73.40**
M4	2012	197	84	31-Mar-12	15-Jul-12	**42.64**	62	16-Apr-12	8-Jul-12	**73.81**
M5*	2012	0	0	N/A	N/A	**0.00**	0	N/A	N/A	**0.00**
O	2012	20	20	23-Aug-12	11-Sep-12	**100.00**	18	24-Aug-12	11-Sep-12	**90.00**

*Incomplete data

Annual Results

2007

Long-term moorings

Bowheads were first detected in the BOWFEST study area at M3 on August 22nd and last heard on November 21st at M3 (Figs. II-7 and II-8). The peak presence of bowheads in the BOWFEST study area was from mid-September until the end of October (Table II-3). Very few bowheads were heard in early September. The western portion of the study area had a higher percentage of time intervals with calls.

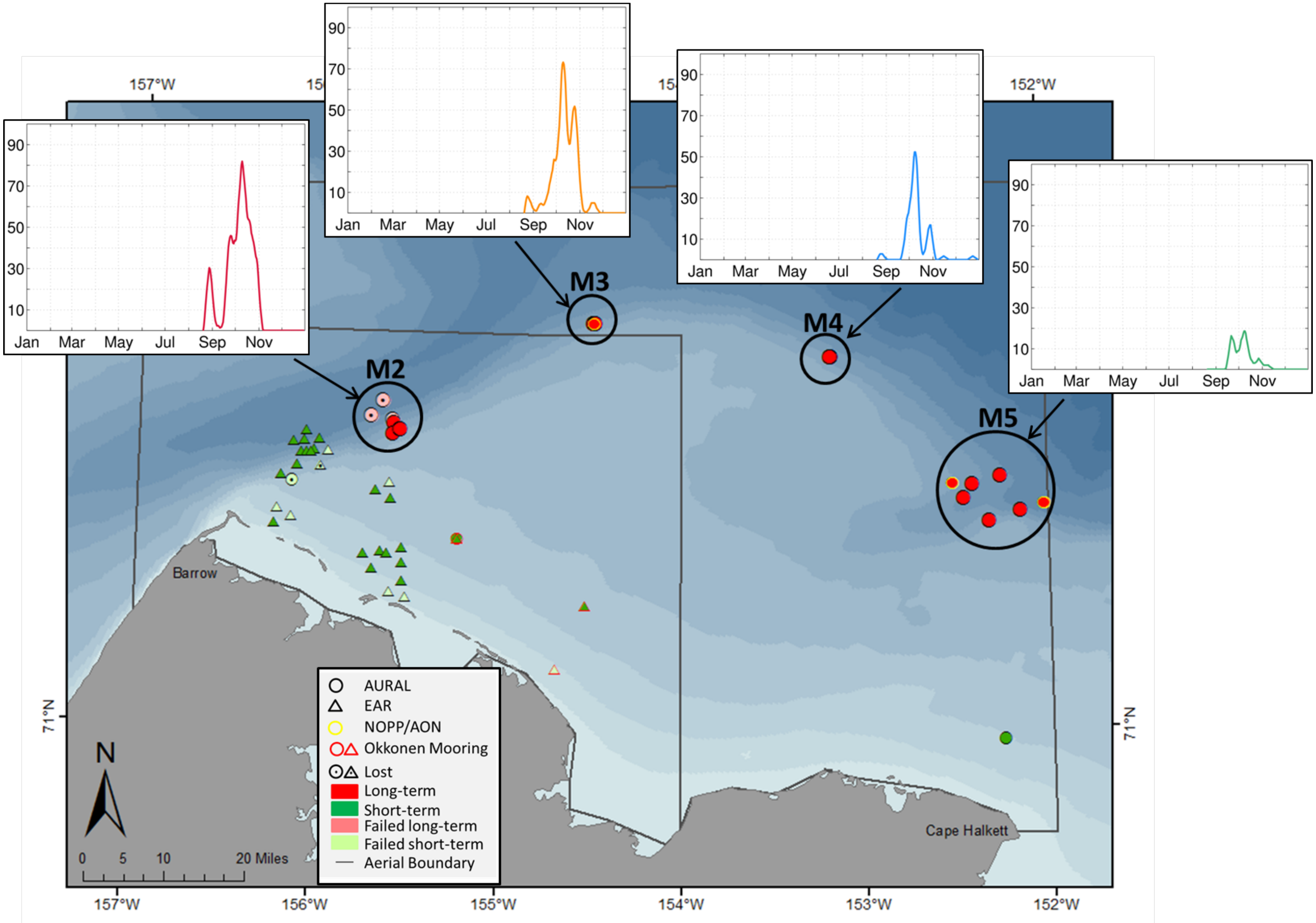

Figure II-7. Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2007. See Figure II-8 for a larger version of the data plots.

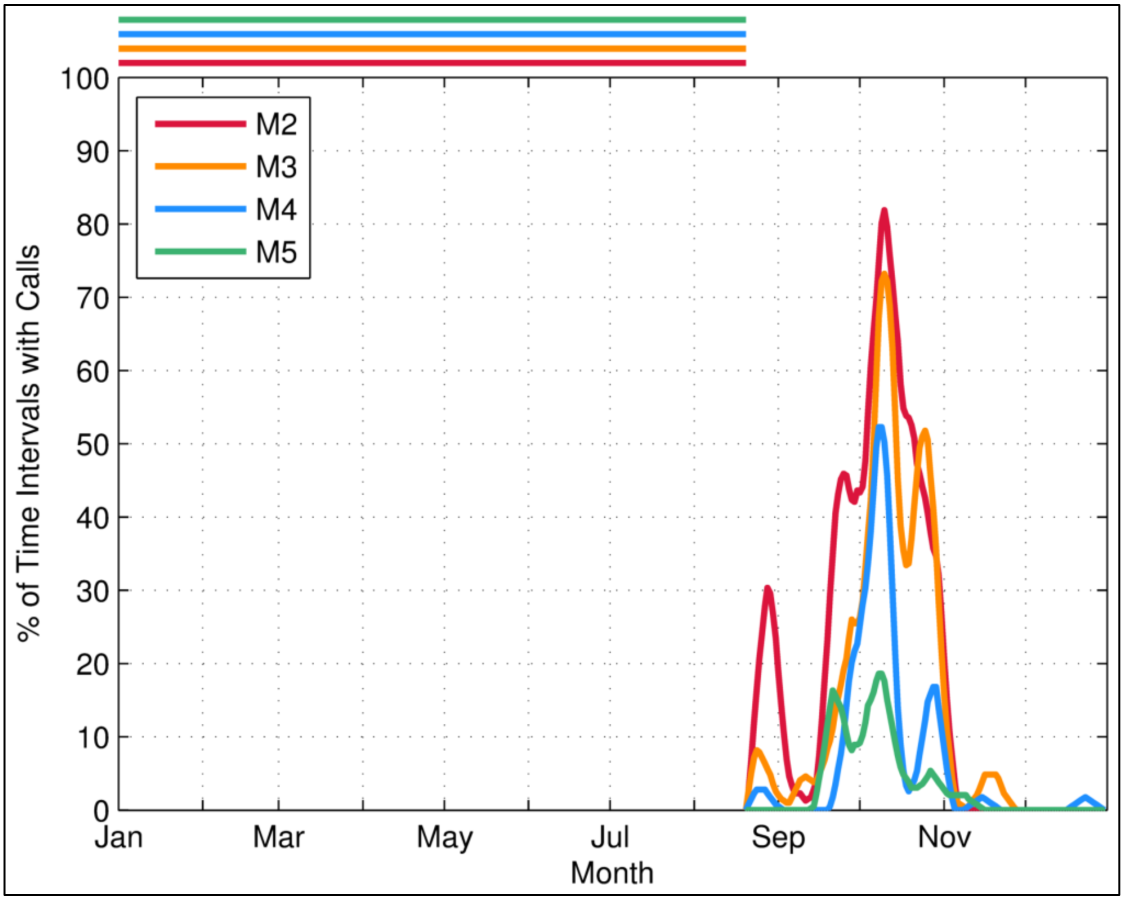

Figure II-8. *Results from all M clusters for 2007. Bars above the plot correspond with periods of no data for those moorings*

<u>Short-term moorings</u>

One mooring was deployed and retrieved successfully as a short-term mooring in 2007 (Fig. II-9). It was deployed and recorded continuously from August 15th until September 11th, 2007. One lone bowhead call was detected on September 3rd. This corresponds with the lack of calls detected at the M5 location during the same time period (Fig. II-10).

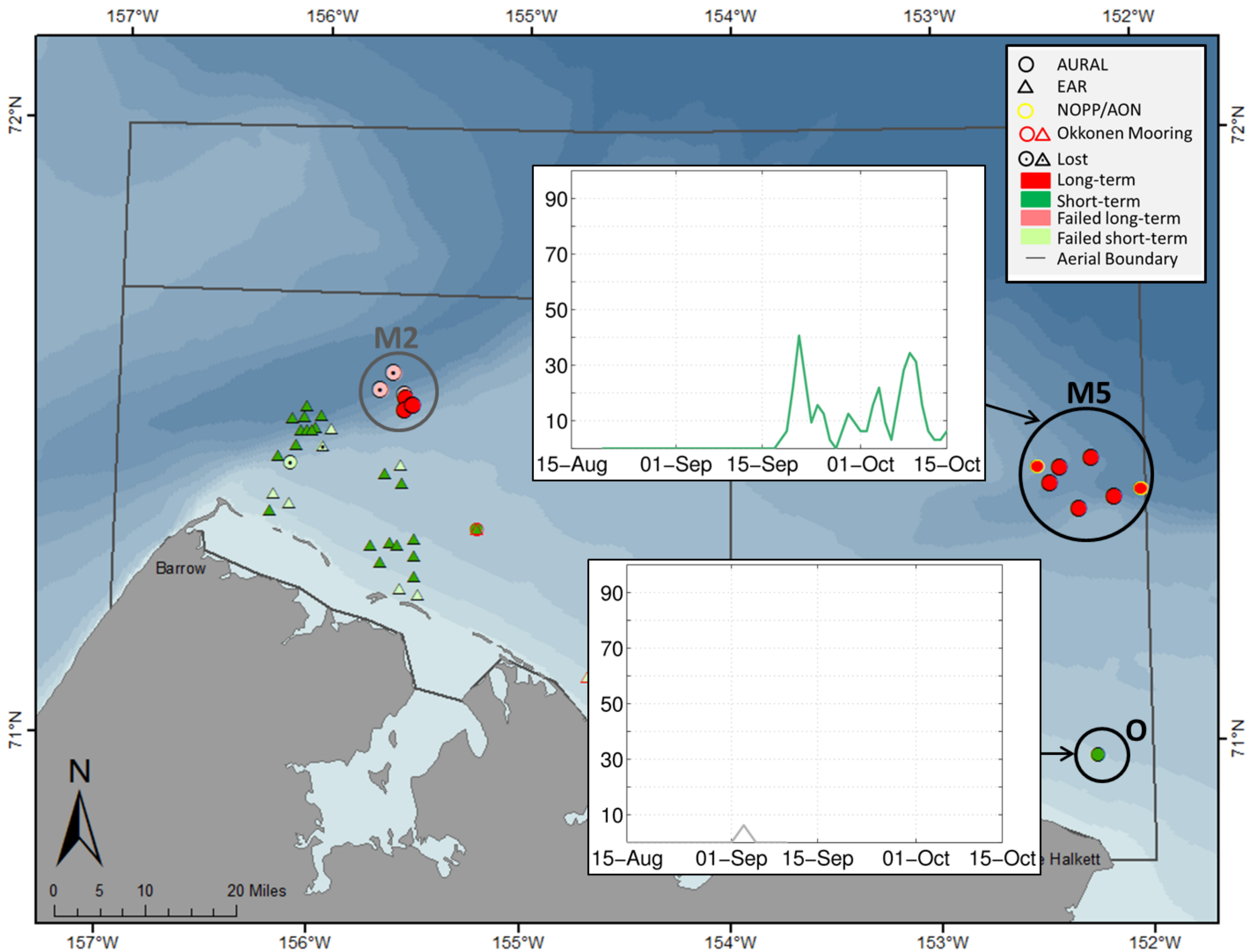

Figure II-9. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, as well as M5, August 15th through October 15th, 2007. See Figure II-10 for a larger version of the data plots.*

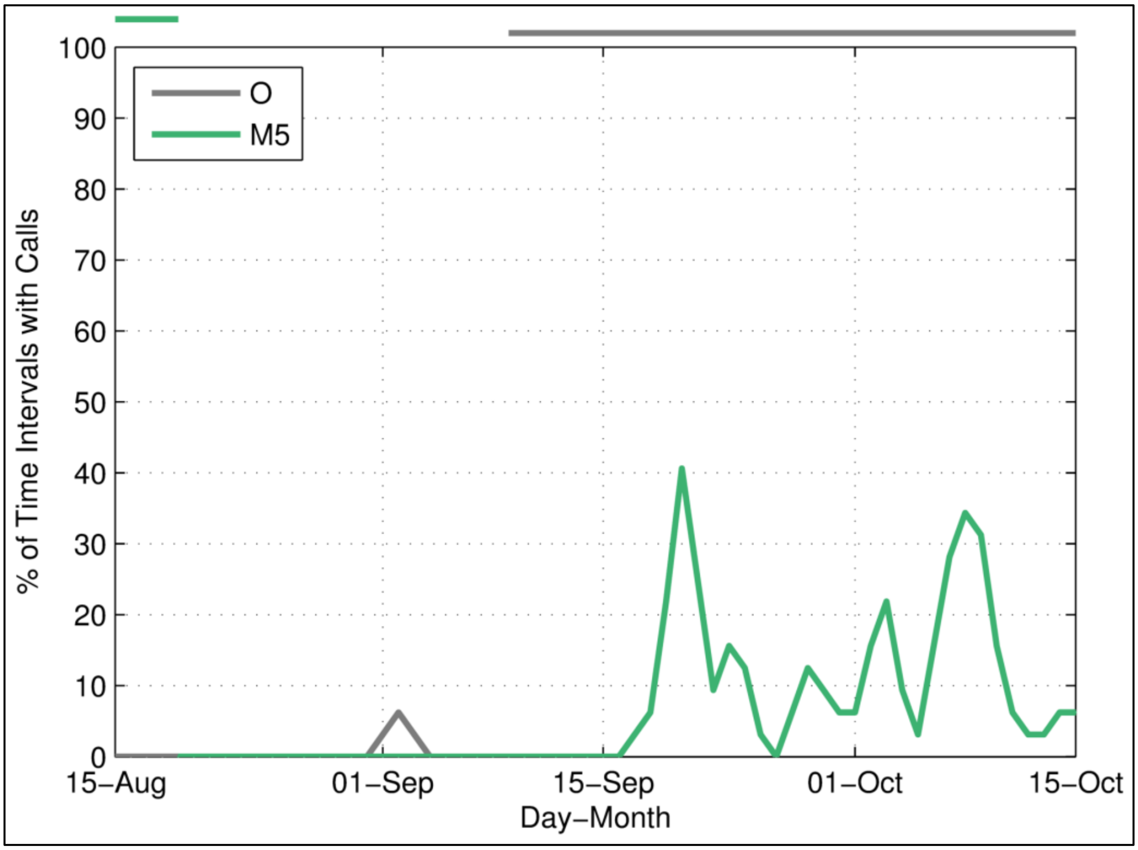

Figure II-10. *Results from the short-term O mooring and the M5 mooring location for 2007. Bars above the plot correspond with periods of no data for those moorings*

2008

<u>Long-term recorders</u>

Due to an error in the 2007 version of the AURAL programming software, all four of the 2007-deployed recorders stopped recording after 8 months, just short of the 2008 spring migration Figs. II-11 and II-12). The loss of the 2008 M2 cluster, and the lack of time to deploy the M4 mooring during the *USCGC Healy* cruise, resulted in no fall data being available at those two mooring cluster locations. During the fall migration, bowheads were first detected at M5 on August 16th and last heard November 22nd on M3. Peak presence was reached in late August and lasted until late November (Table II-3). The westward migration of bowheads out of the BOWFEST area can be seen as the last call detected on M5 occurred seven days before the last call detected on M3.

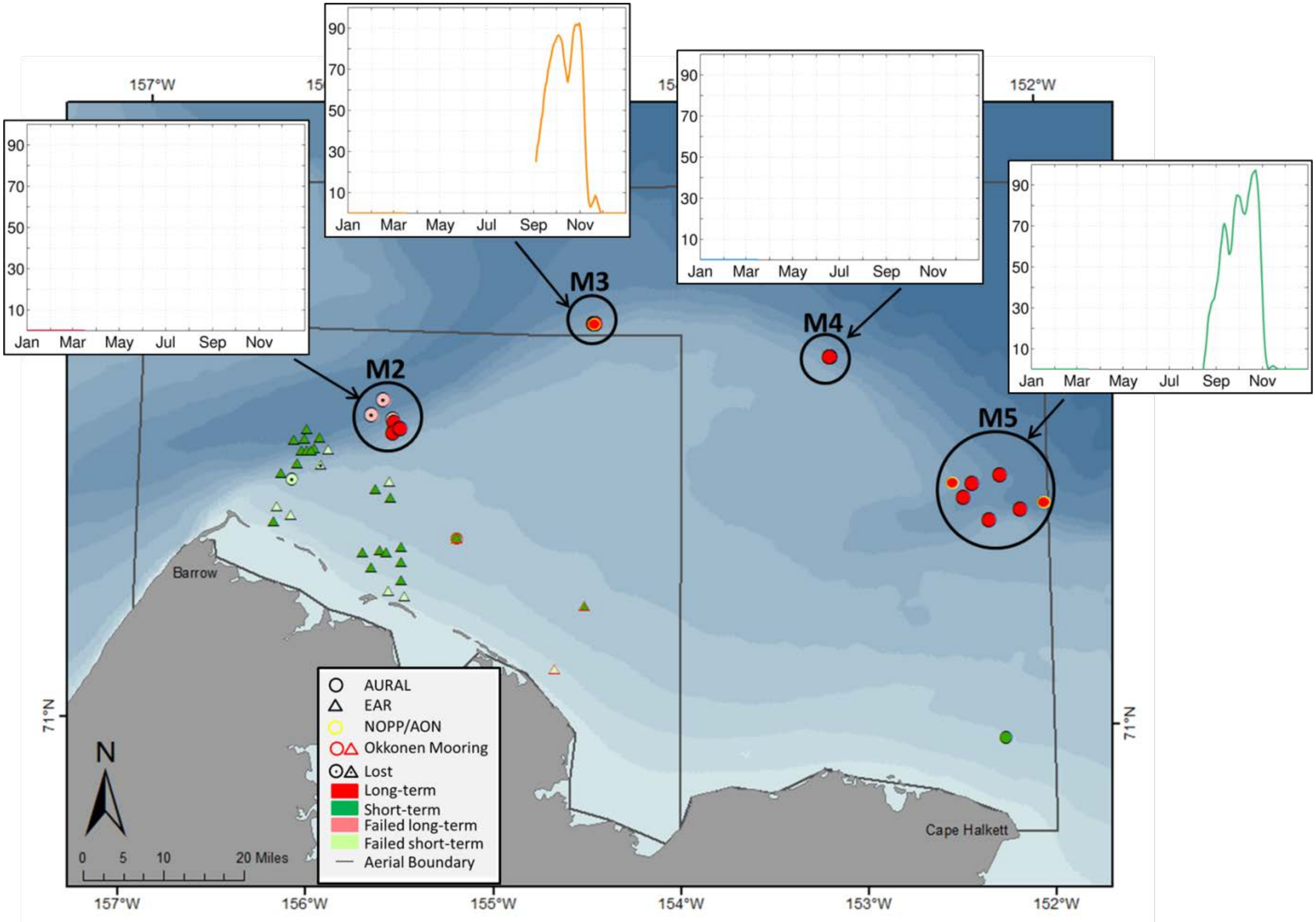

Figure II-11. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2008. See Figure II-12 for a larger version of the data plots. For 2008, the M2 recorders were lost at sea and the M4 recorder was not deployed*

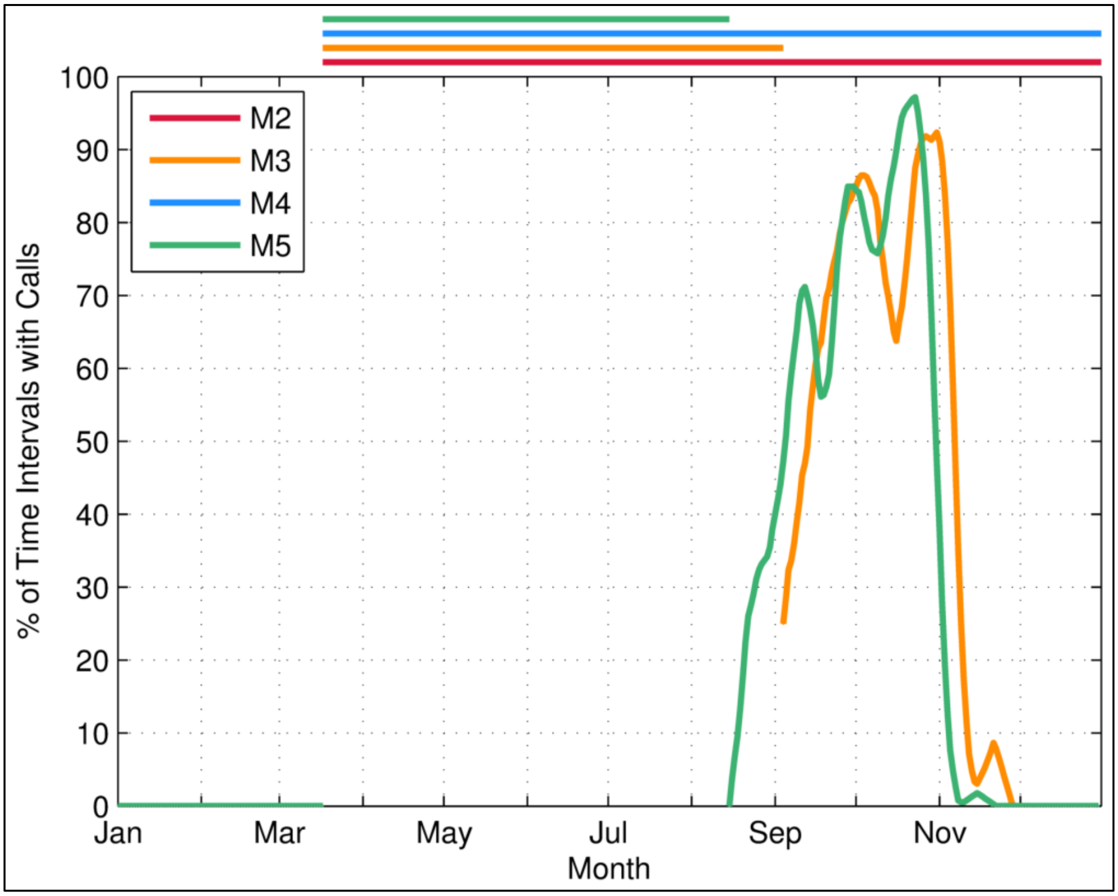

Figure II-12. *Results from all M clusters for 2008. Bars above the plot correspond with periods of no data for those moorings*

<u>Short-term recorders</u>

The short-term moorings for 2008 were deployed from August 19th until September 13th at three locations, two which were the movable arrays (clusters A and B) plus one on the UAF Okkonen mooring (O cluster) frame (Fig. II-13). The first call detected was at the O cluster on August 21st and calls were still being detected on September 13th on the B cluster when it was retrieved. The deployment location of clusters A and B were inshore of the long-term M2 location site. Unfortunately, due to our loss of the triad in 2008 there are no data for M2; however, clusters A and B show a stark contrast to each other with the B cluster recording a much higher percentage of time with calls than the A cluster (Fig. II-14). In 2008 the Okkonen mooring was deployed further to the east off of Cape Simpson and was used for an inshore/offshore comparison with the long-term M3 location. As seen in Figure II-15, for the period of time with recording overlap at the two mooring locations, the percentage of time with calls was inversely correlated between the two sites. However, there was 25% higher overall percentage of time with calls at the Okkonen mooring location than at the M5 cluster.

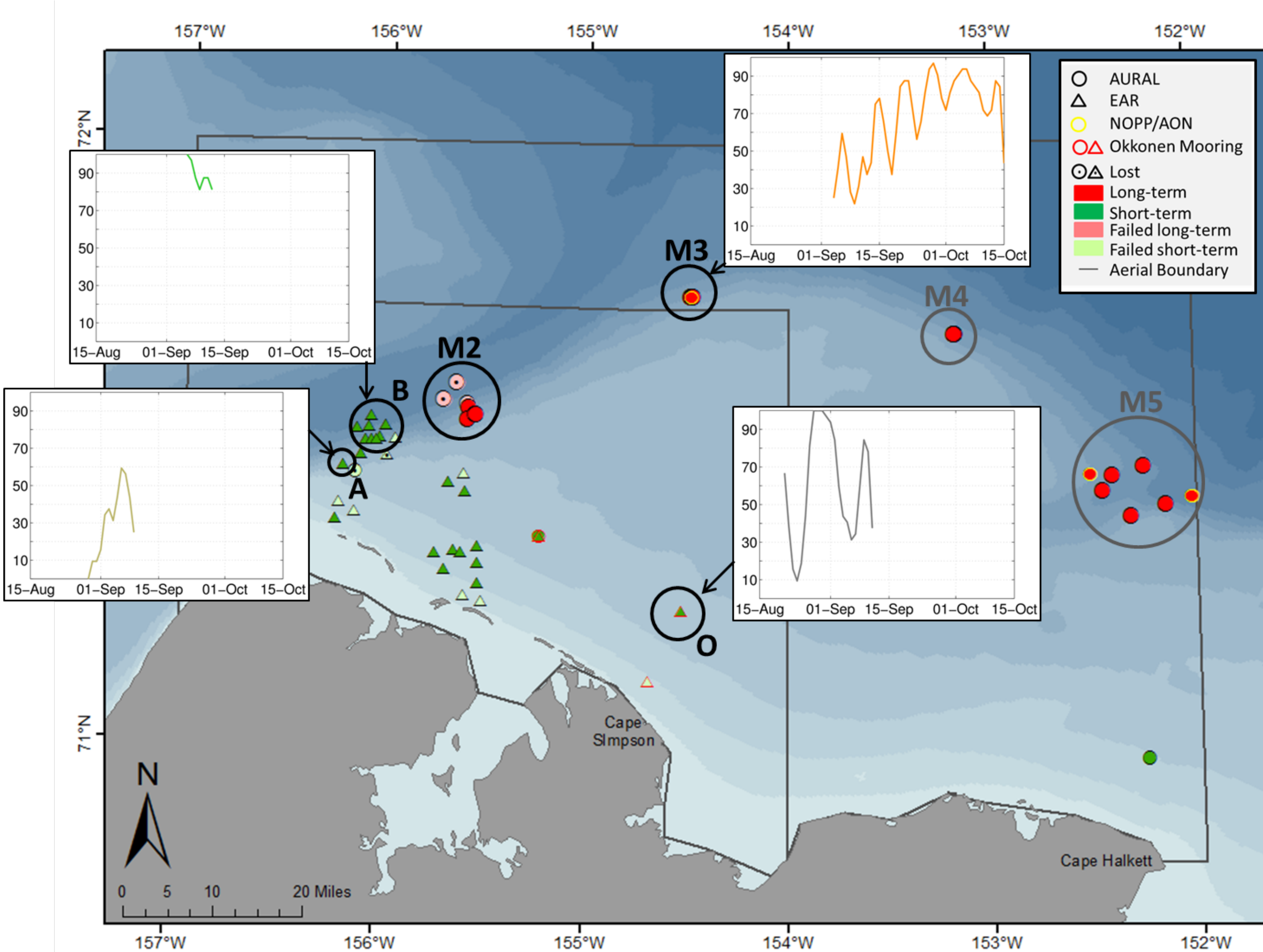

Figure II-13. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, as well as M3, August 15th through October 15th, 2008. See Figures II-14 & II-15 for a larger version of the data plots.*

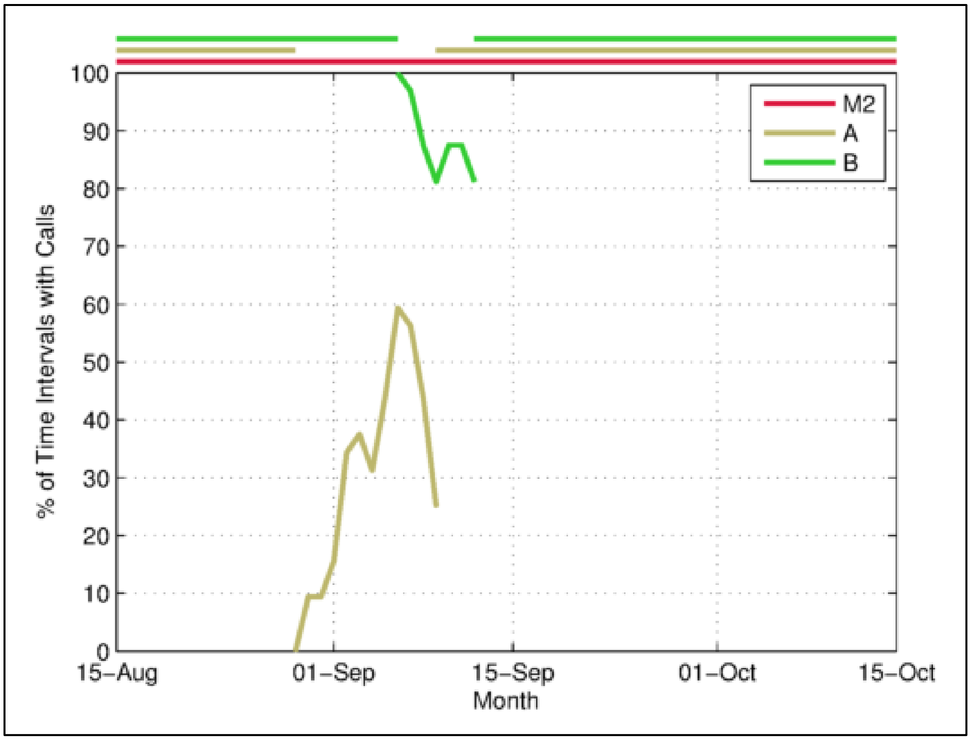

Figure II-14. *Comparison of results from the movable A and B short-term mooring clusters for 2008 with M2 data from the same time period. Bars above the plot correspond with periods of no data for those moorings.*

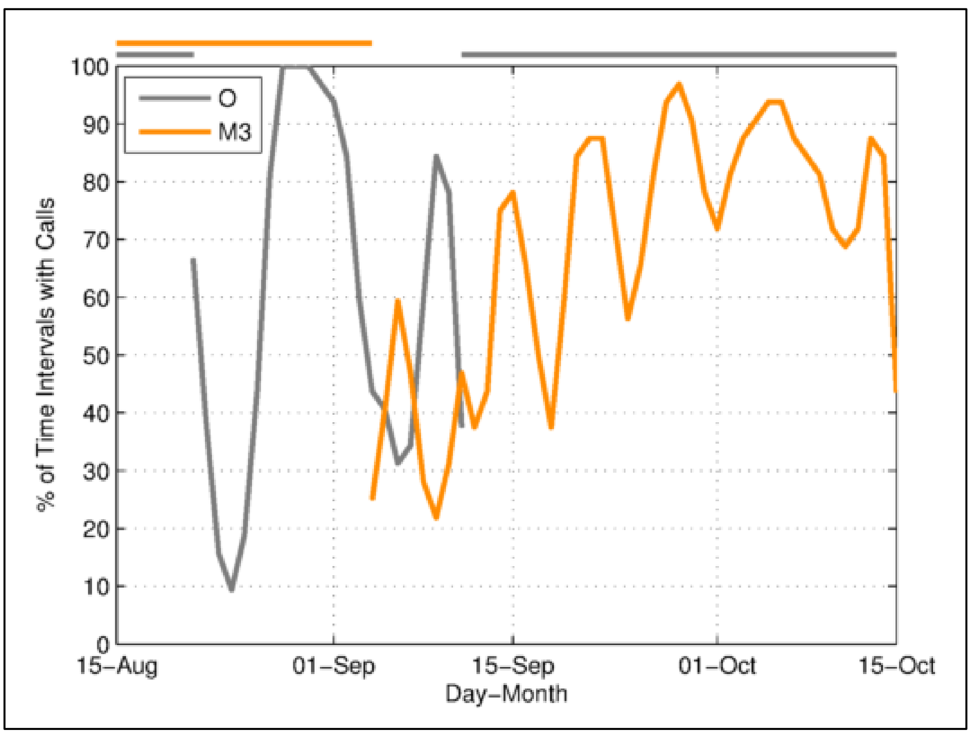

Figure II-15. *Comparison of results from the Okkonen (O cluster) and the M3 mooring clusters for 2008. Bars above the plot correspond with periods of no data for those moorings.*

2009

Long-term moorings

Because the 2008 M2 recorder array was lost and the 2008 M4 recorder was not deployed, there were no spring data from these locations. However, for the other two cluster locations, bowheads were first detected on their spring migration on April 10th and 11th (M5 and M3 respectively) and immediately reached peak presence (Figs. II-16 and II-17). During this calling period, M5 was at peak presence 84% of the days and M3 for 74% (Table II-3). When a replacement recorder was deployed at M2 in the fall, it immediately hit peak presence before decreasing during late August and early September. The last call in the BOWFEST area was heard on November 28th at M2. While the highest and most extensive peak in calling occurred during the spring, M5 also showed a strong presence of bowheads throughout the months of August and September.

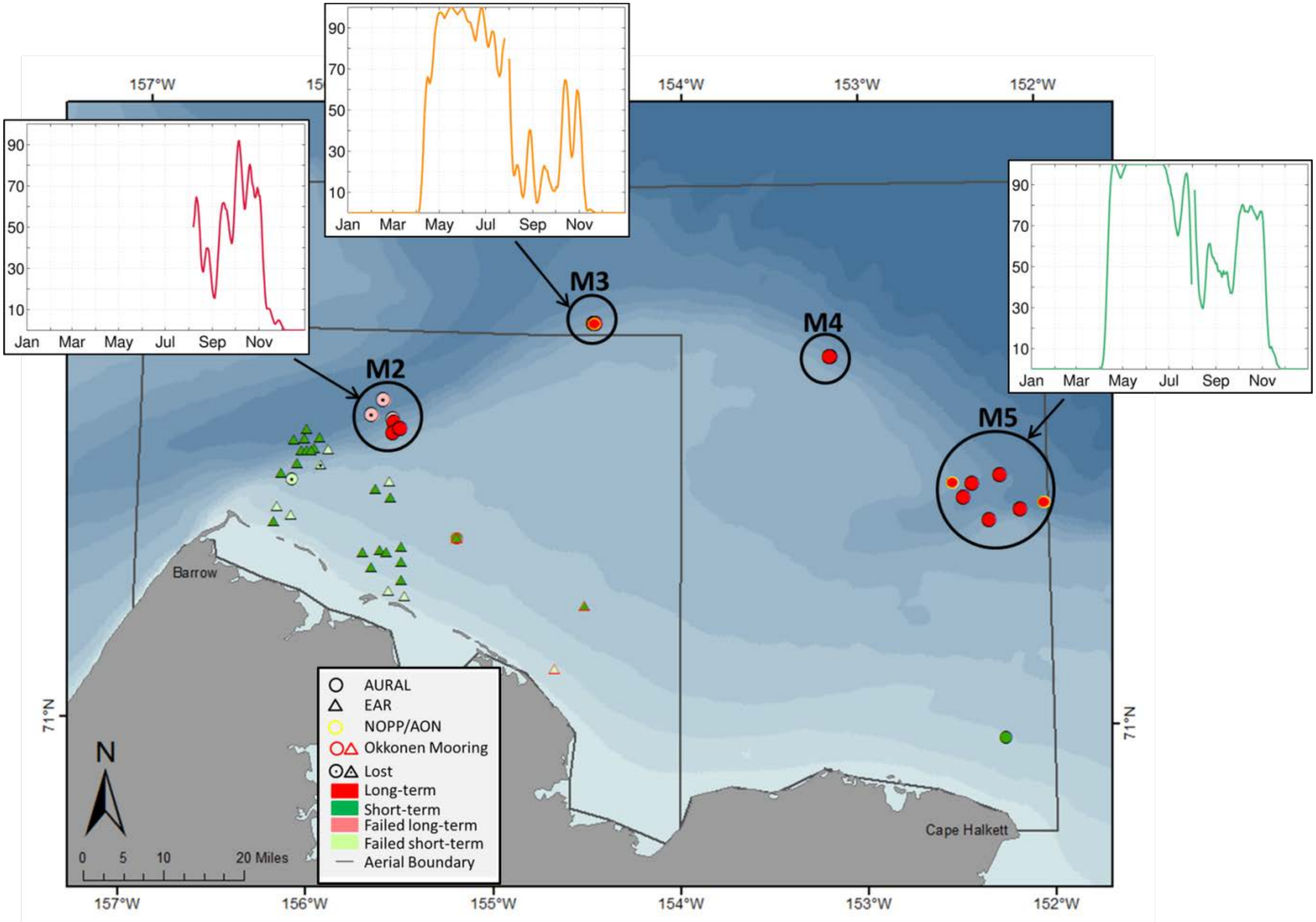

Figure II-16. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2009. See Figure II-17 for a larger version of the data plots. The triad array at M2 was lost, so no spring 2009 data exist, and M4 was not deployed during 2009.*

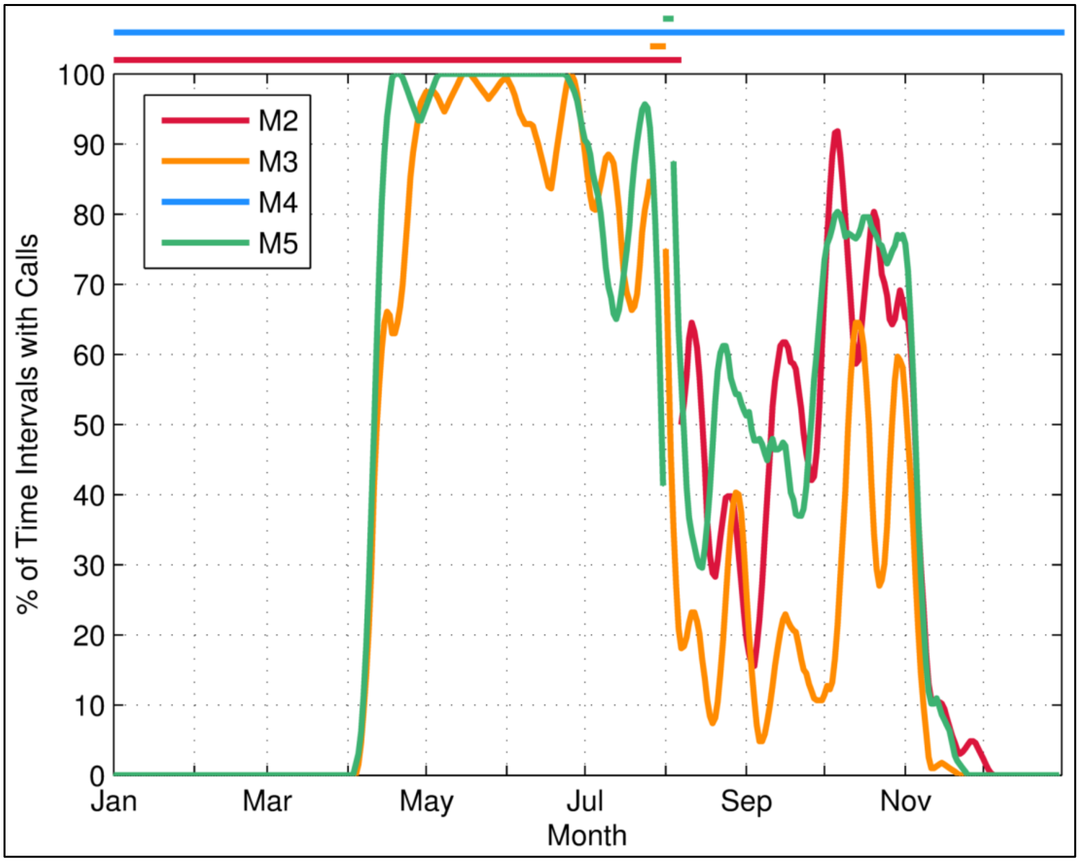

Figure II-17. *Results from all M clusters for 2009. Bars above the plot correspond with periods of no data for those moorings. M4 was not deployed during 2009.*

<u>Short-term moorings</u>

The short-term moorings for 2009 were deployed from August 21st until October 12th at three locations, two on movable arrays (clusters A and B) and the other on the UAF Okkonen mooring (O cluster) frame (Fig. II-18). The first call detected was at the O cluster on August 22nd and calls were detected until October 6th when the last recorder in the B cluster stopped recording. The deployment locations for all three clusters (A, B, and O) in 2009 were inshore of the long-term M2 location site. All four moorings were plotted in comparison in Figure II-19 where it can clearly be seen that the short-term moorings detected a higher percent of time intervals with calls than M2 up until the beginning of October.

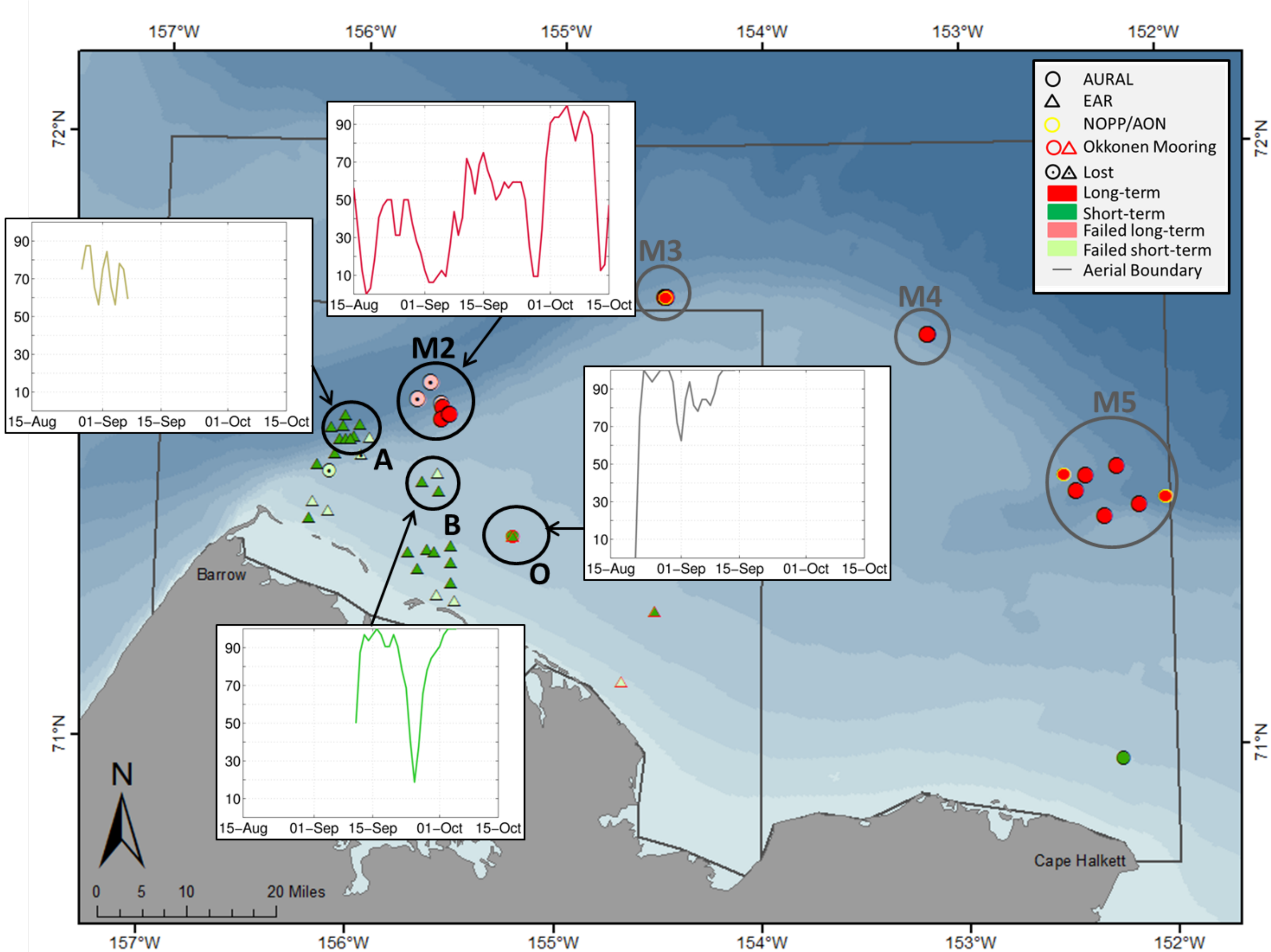

Figure II-18. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, as well as M2, August 15th through October 15th, 2009. See Figure II-19 for a larger version of the data plots.*

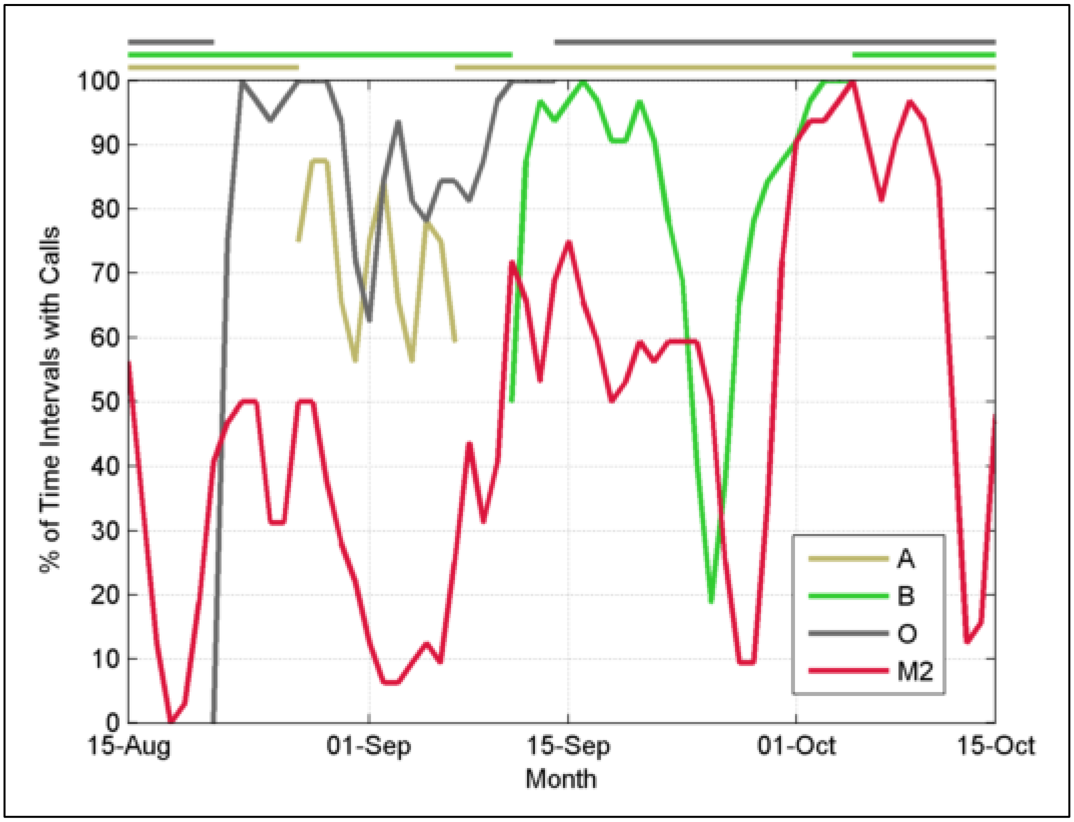

Figure II-19. *Comparison of results from the short-term and M2 mooring clusters for 2009. Bars above the plot correspond with periods of no data for those moorings.*

2010

<u>Long-term moorings</u>

In 2010, bowheads were detected on their spring migration starting April 1st (M5) and were last detected November 22nd on M3 (Figs. II-20 and II-21). Peak presence was reached in early April and ended for the east (M4) in mid-October (note that data for the AON mooring deployed at M5 were unavailable at the time of this report) and for the west (M2 and M3) in early November (Table II-3). Due to recorder failure, the presence of bowheads in August at the long-term moorings was unknown.

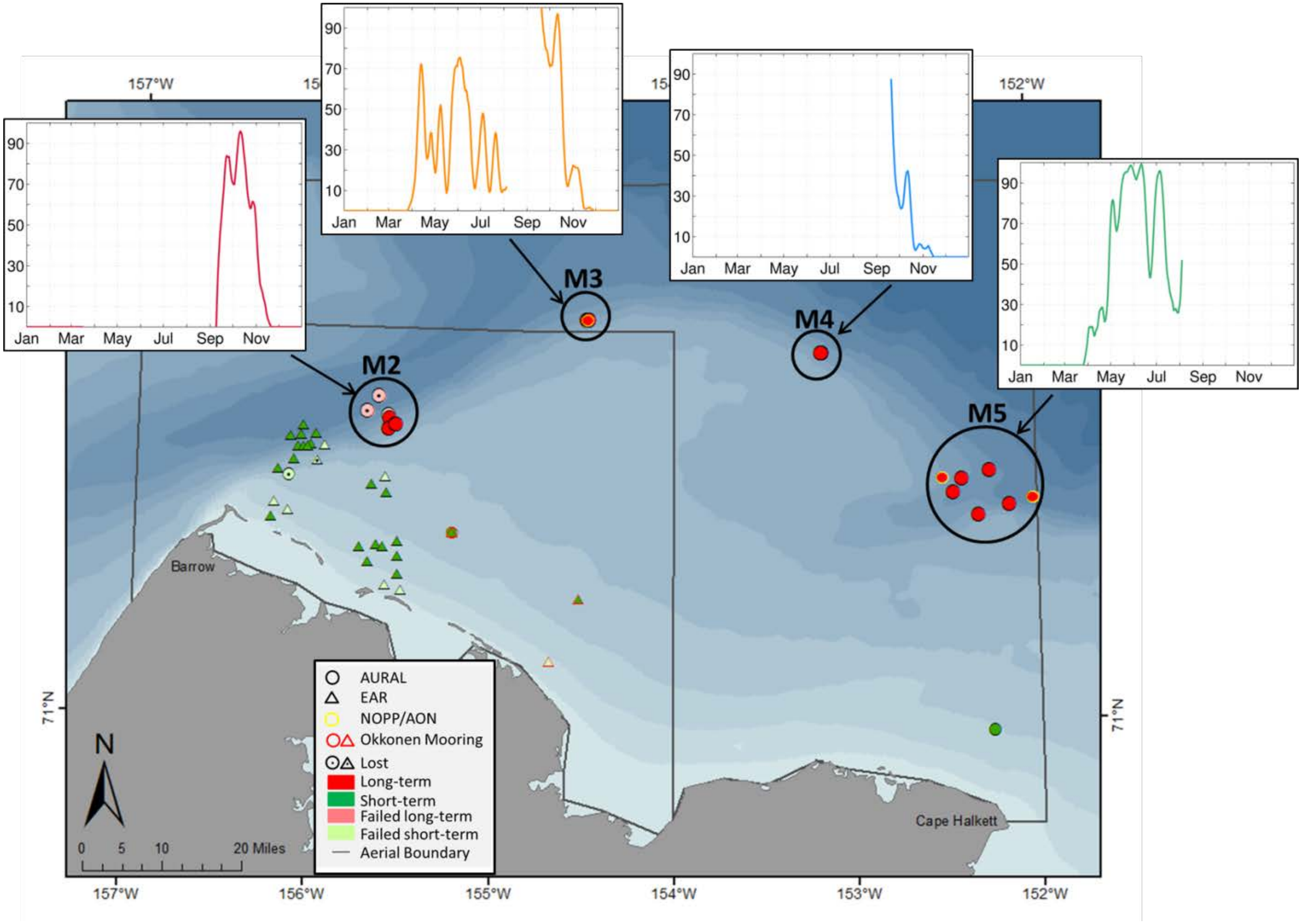

Figure II-20. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2010. See Figure II-21 for a larger version of the data plots. Data for the AON mooring deployed at M5 are unavailable at the time of this report.*

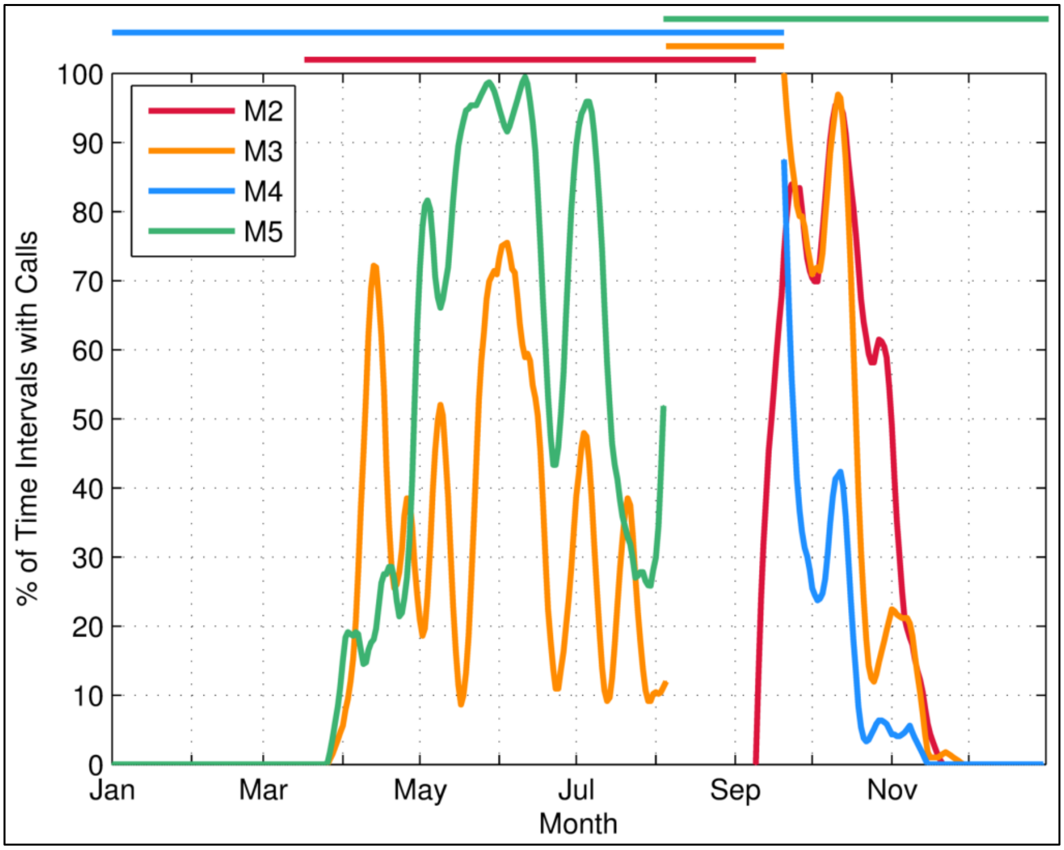

Figure II-21. *Results from all M clusters for 2010. Bars above the plot correspond with periods of no data for those moorings. Data for the AON mooring deployed in 2010 at M5 were unavailable at the time of this report.*

<u>Short-term moorings</u>

The short-term moorings for 2010 were deployed from August 19th until September 23rd at four locations, three of which were the movable arrays (clusters A, B, and C) and the other which was on the UAF Okkonen mooring (O cluster) frame (Fig. II-22). The first call detected was at the A cluster on August 29th and calls were still being detected on September 23rd when the C cluster was retrieved. Two of the mooring clusters deployed (B and O) had no calls detected. The deployment locations for all four clusters (A, B, C, and O) in 2010 were inshore of the long-term M2 location site. Figure II-23 superimposes all five moorings for comparison. Only mooring cluster C had recordings that overlapped with recordings made at M2. These recordings show a higher percentage of time intervals with calls for cluster C around mid-September. However, before cluster C was recovered, its percentage of time intervals with calls had decreased slightly below that at M2. Although mooring cluster A's recording did not overlap with those at M2, detections made at cluster A show that bowheads were present inshore in late August and early September.

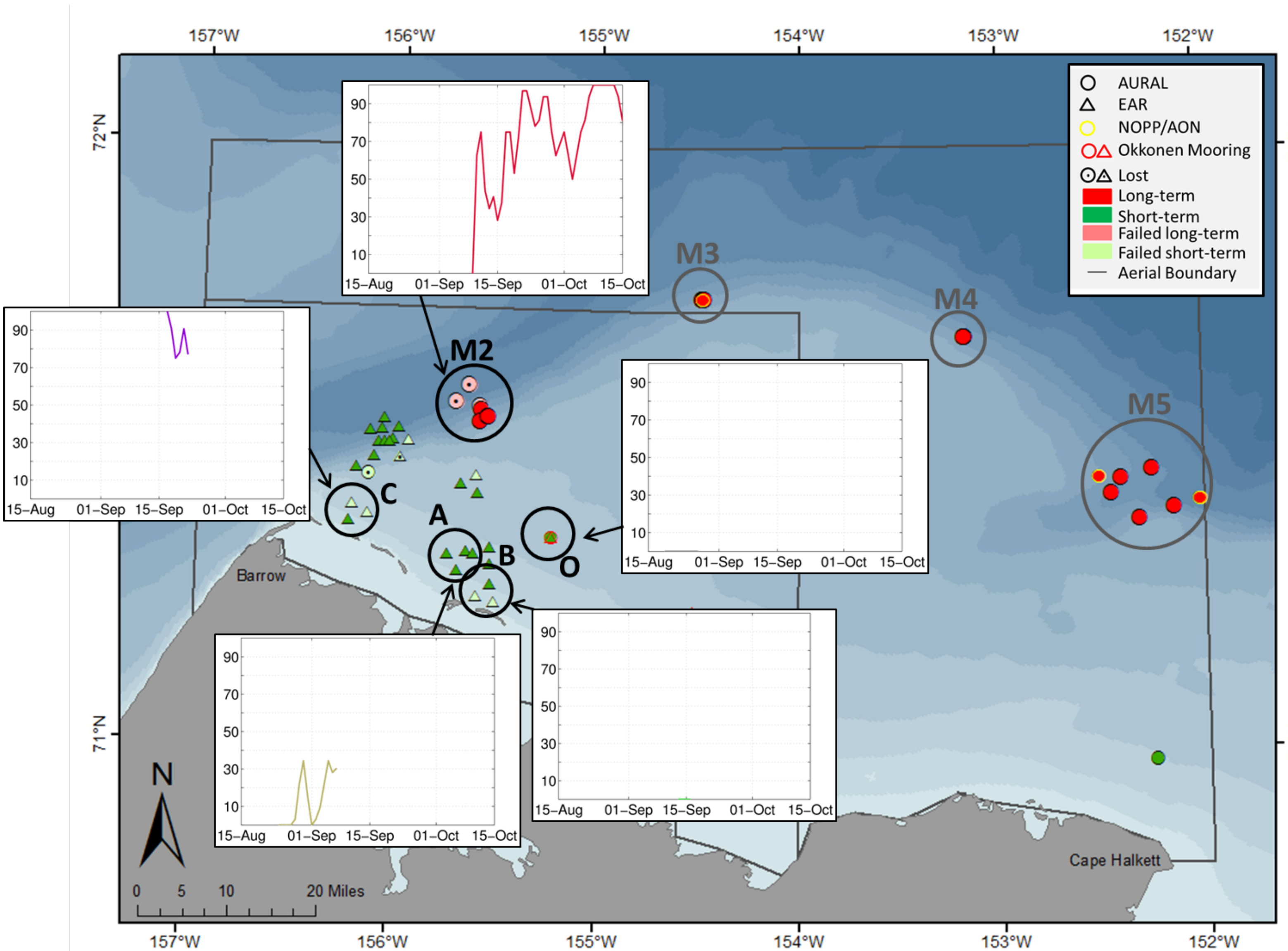

Figure II-22. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, as well as M2, August 15th through October 15th, 2010. See Figure II-23 for a larger version of the data plots.*

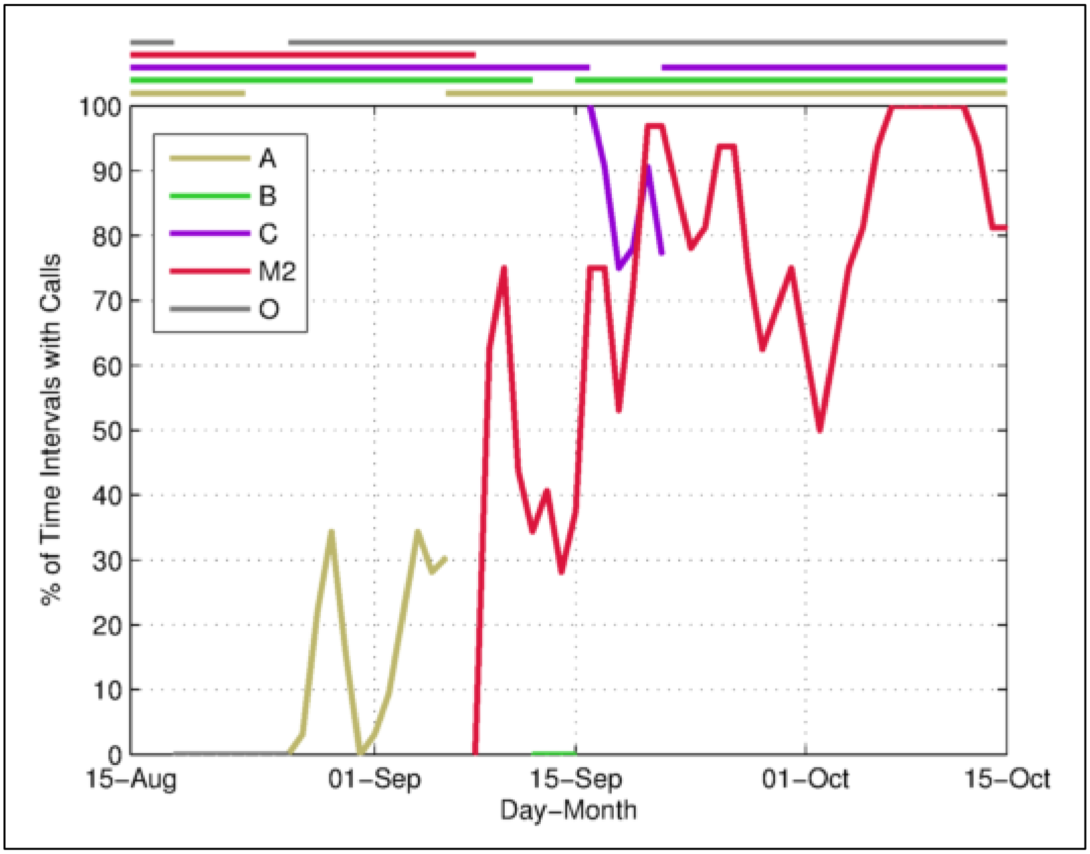

Figure II-23. *Comparison of results from the short-term and M2 mooring clusters for 2010. Bars above the plot correspond with periods of no data for those moorings.*

2011

Long-term moorings

The first bowhead call detection occurred on March 25th (M2) during the 2011 spring migration (Figs. II-24 and II-25). This was the earliest migration recorded during the BOWFEST study period. As in 2009, all three moorings immediately reached peak presence in the spring and maintained it for the majority of the time until mid-November (Table II-3). The last call detected was on November 28th at M3 (Figs. II-24 and II-25). This year was noteworthy in that it had the most recording effort as well as, within the period with calling, the most days with peak presence of all five years, with % peak calling values ranging from 74% at M4 to 88% at M3. Data from the AON mooring deployed at M5 were unavailable at the time of this report.

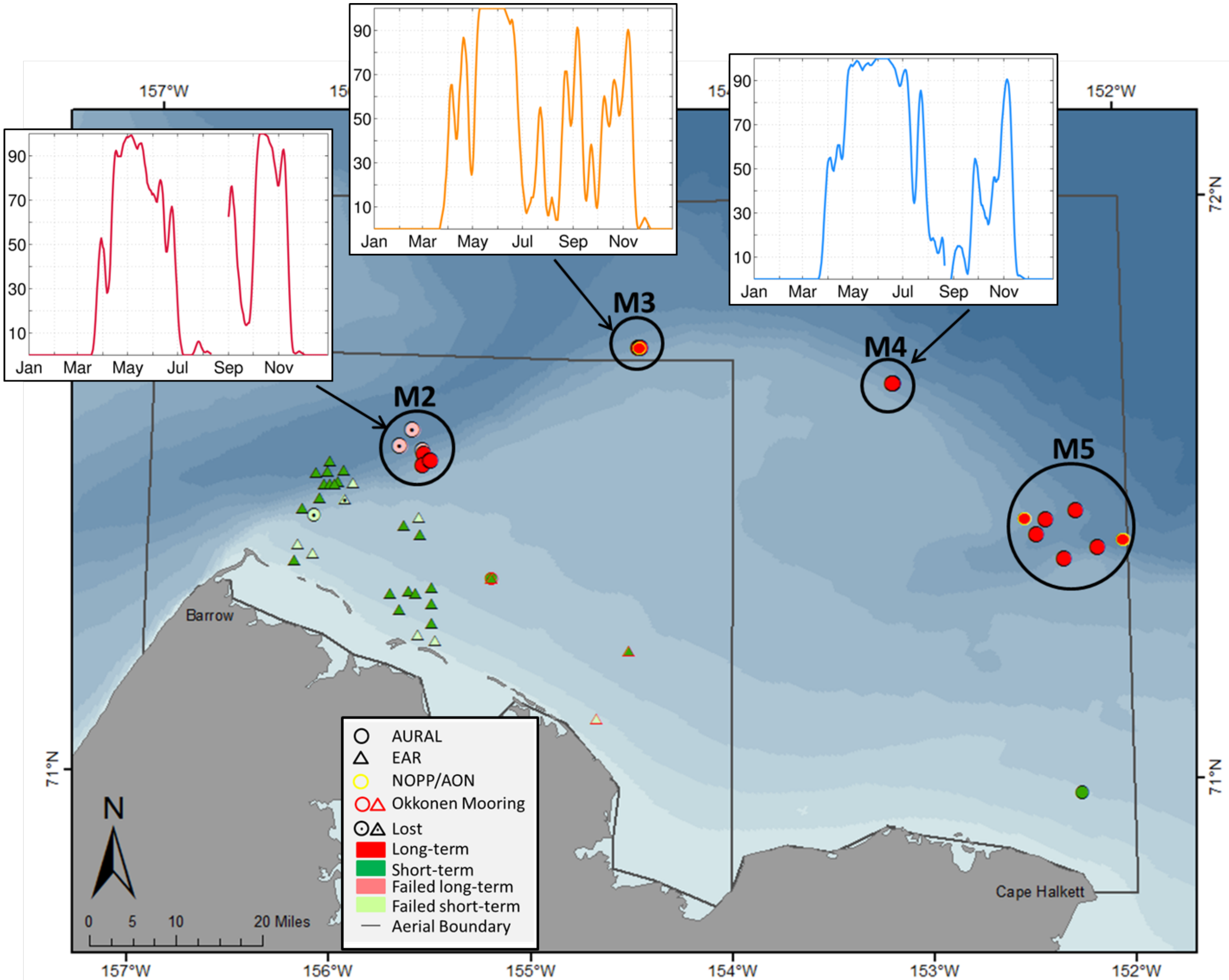

Figure II-24. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2011. See Figure II-25 for a larger version of the data plots. Data for the AON mooring deployed at M5 are unavailable at the time of this report.*

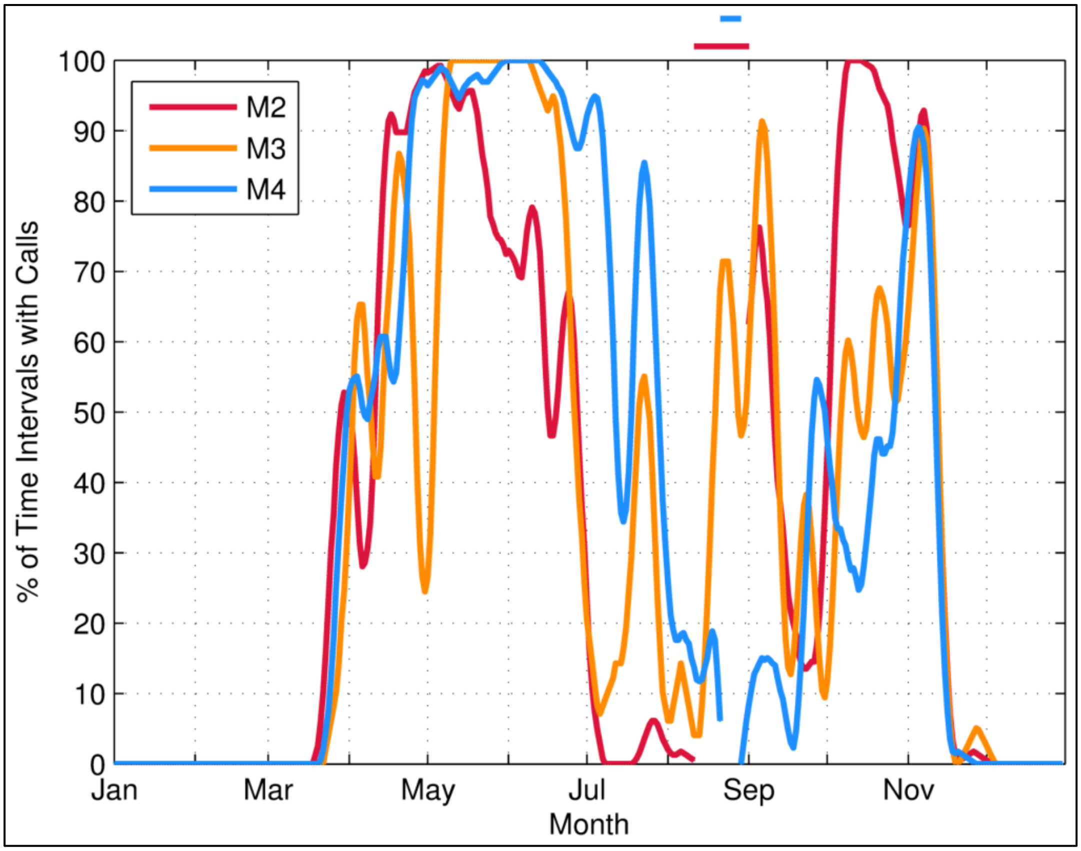

Figure II-25. *Results from all M clusters for 2011. Bars above the plot correspond with periods of no data. Data from M5 were unavailable at the time of this report.*

Short-term moorings

The short-term moorings for 2011 were deployed from August 18th until September 30th at three locations, two of which were the movable arrays (clusters A and B) and the other which was on the UAF Okkonen mooring (O cluster) frame (Fig. II-26). The first call detected was at the A cluster on August 31st and calls were still being detected on September 24th when the B cluster stopped recording. Unfortunately, the O mooring had no call detections and failed five days into its month long deployment. The deployment locations for all three clusters (A, B, and O) in 2011 were inshore of the long-term M2 location site. Comparison of these four clusters (Fig. II-27) showed that in the first half of September when the A cluster was deployed, a lower percentage of time with calls was seen on M2 versus A, and in the second half of September when the B cluster was deployed, a high percentage of time with calls was seen on B versus M2.

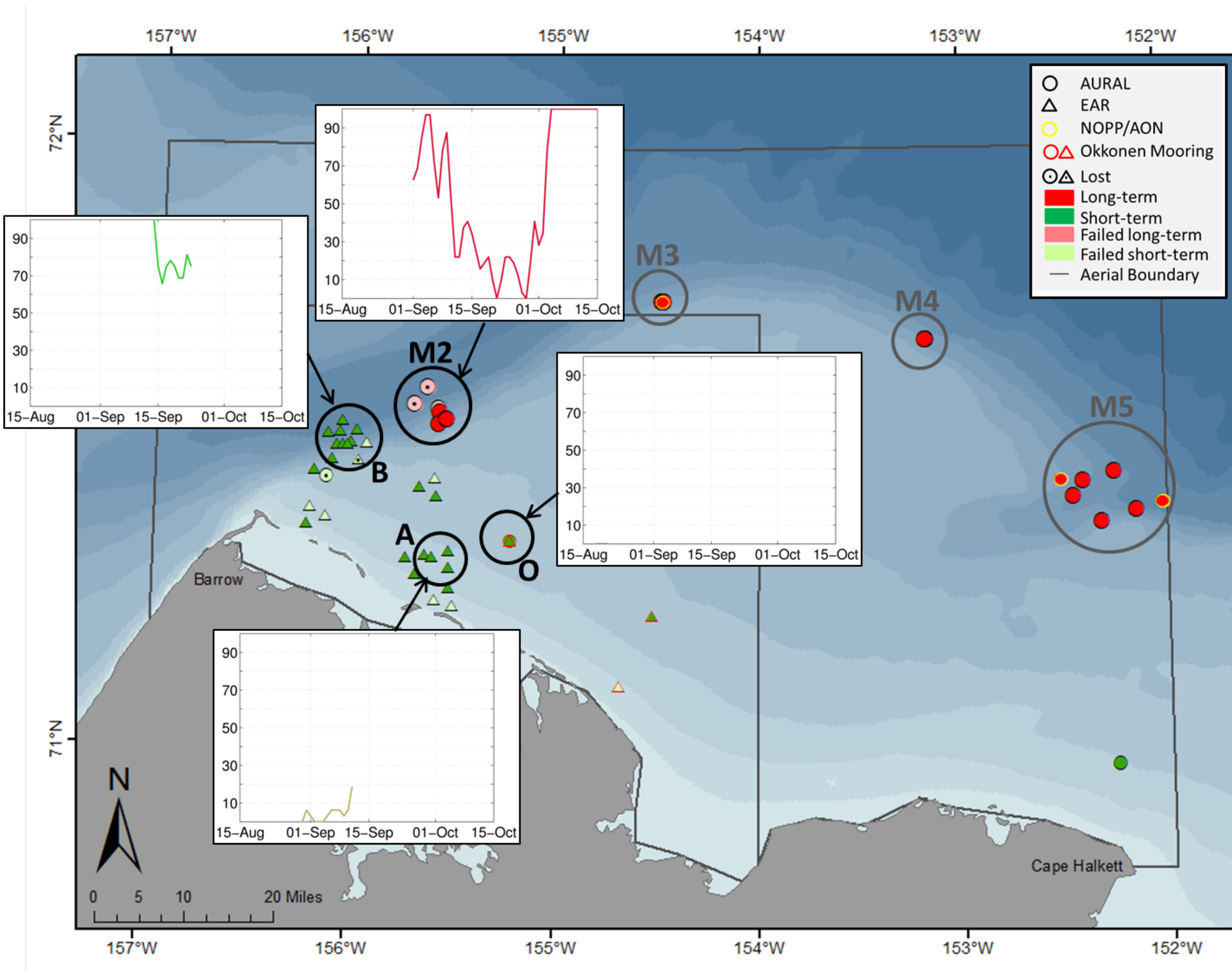

Figure II-26. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, as well as M2, August 15th through October 15th, 2011. See Figure II-27 for a larger version of the data plots.*

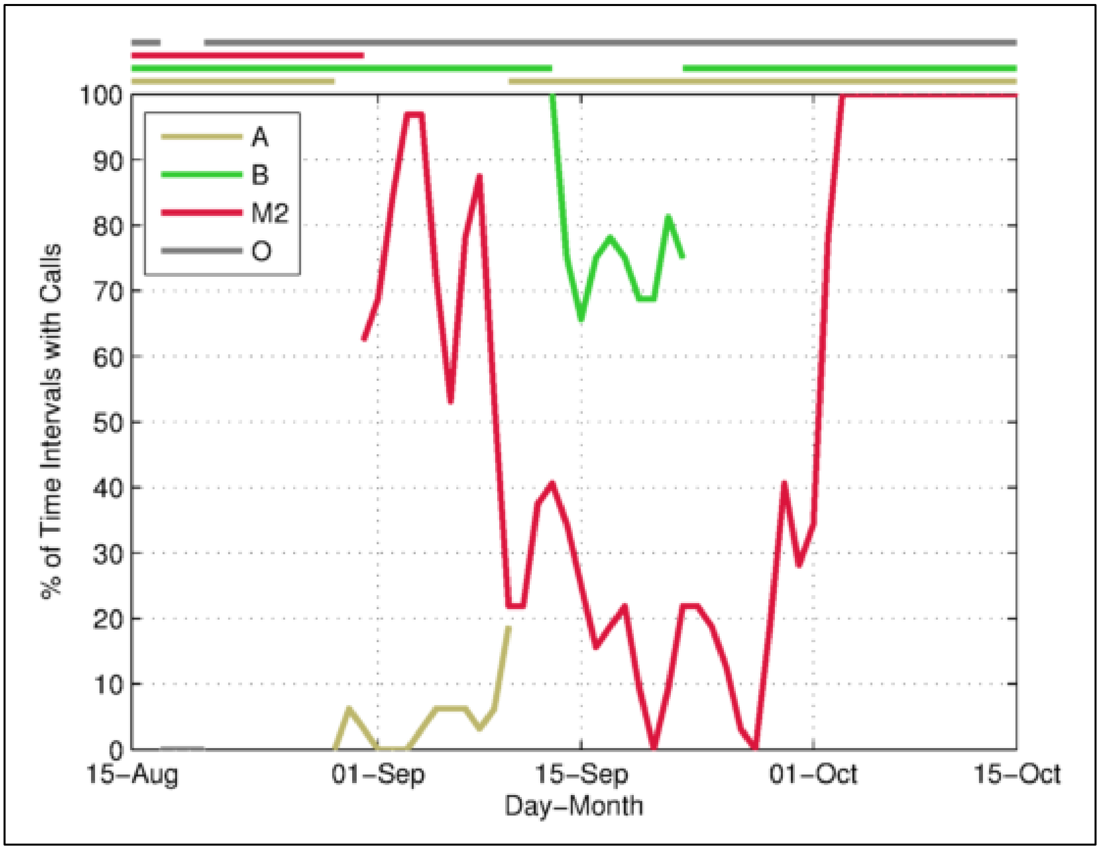

Figure II-27. *Comparison of results from the short-term and M2 mooring clusters for 2011. Bars above the plot correspond with periods of no data for those moorings.*

2012

Long-term data

Like 2009 and 2011, the spring migration of 2012 shows a quick arrival of bowheads into the area with peak presence being reached by April 16th on all moorings (Fig. II-28). Although a lone call was detected in the BOWFEST study area on March 31st at M5, the migration really appeared to begin with the detections at M2 on April 12th. Peak presence for all three locations lasted until July when the moorings stopped recording (Table II-3). However, in late June a large drop in time intervals with calls occurred at all three moorings at the same time (Fig. II-29). Investigation of this dip reveals that masking of the recordings by noise did not contribute to this simultaneous drop in calling. Data from the AON mooring deployed at M5 were unavailable at the time of this report.

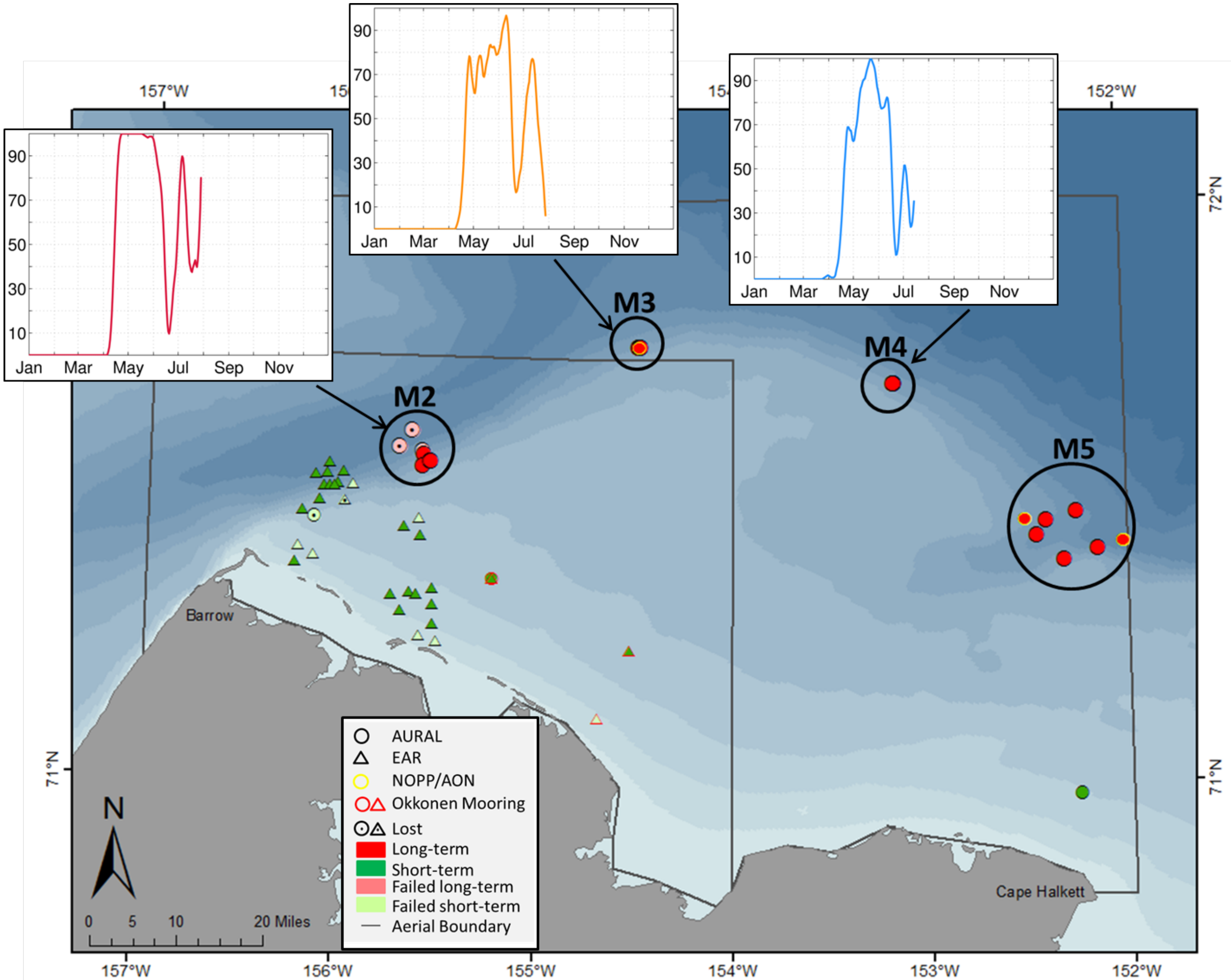

Figure II-28. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the long-term mooring clusters, January through December 2012. See Figure II-29 for a larger version of the data plots. Data for the AON mooring deployed at M5 are unavailable at the time of this report.*

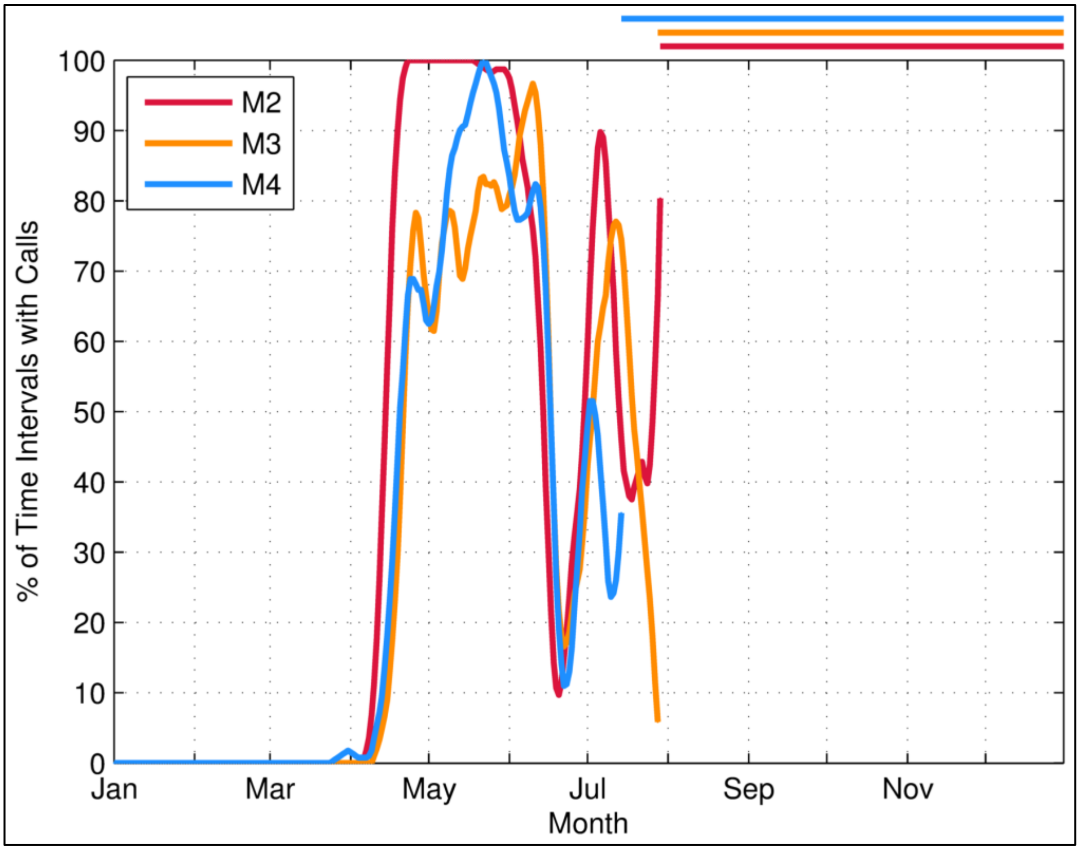

Figure II-29. *Results from all M clusters for 2012. Bars above the plot correspond with periods of no data. Data from M5 were unavailable at the time of this report.*

<u>Short-term moorings</u>

The short-term mooring effort in 2012 was scaled back to a single recorder deployed on a UAF Okkonen frame from August 23rd until September 11th (Fig. II-30). This mooring recorded bowhead calls on every day of the deployment and was at peak presence for 90% of that time (Table II-3). This mooring was deployed in the same location as the previous years and will be compared to M2; however, at the time of this report, the M2 mooring for this time period was still deployed (Fig. II-31).

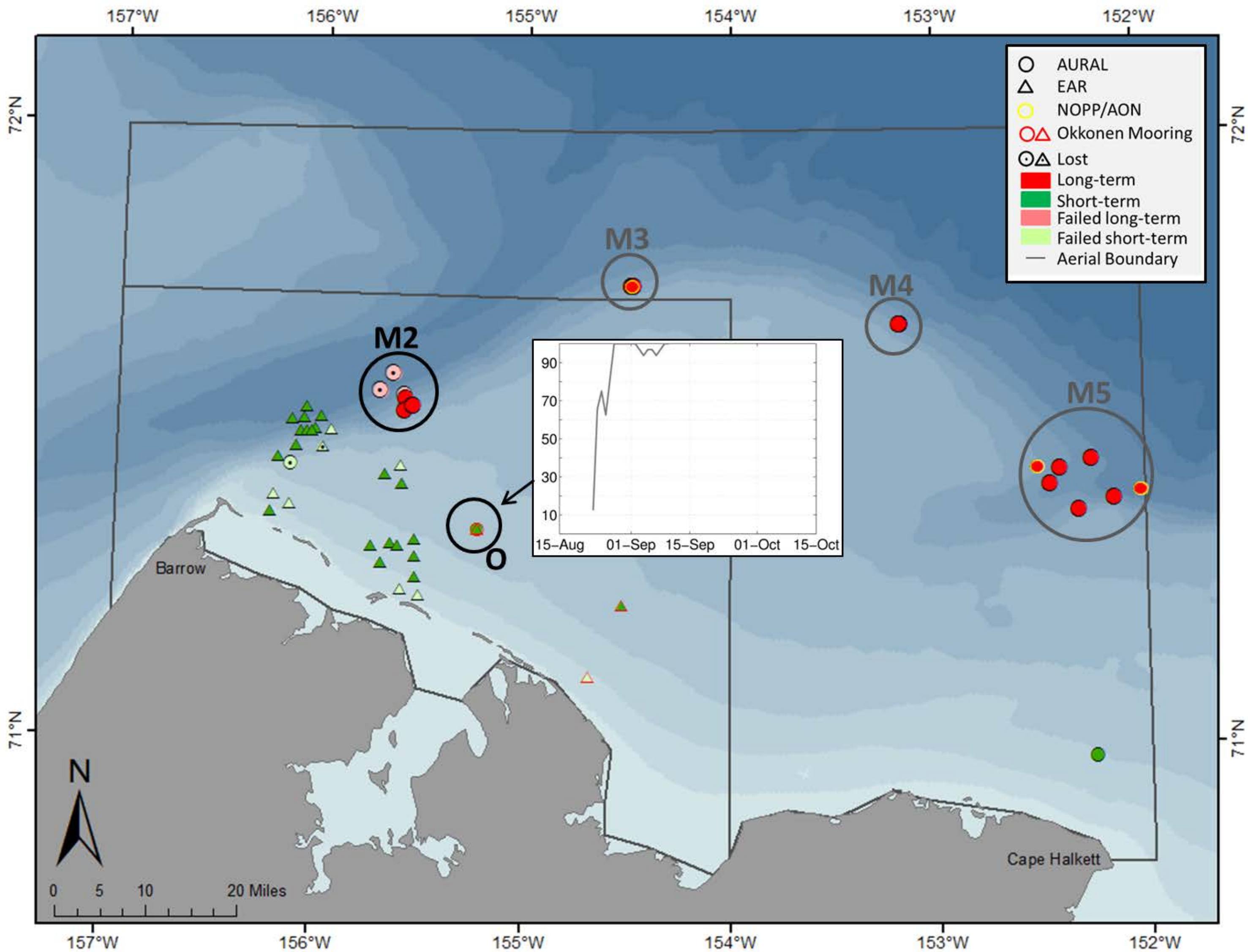

Figure II-30. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term mooring, August 15th through October 15th, 2012. See Figure II-31 for a larger version of the data plots.*

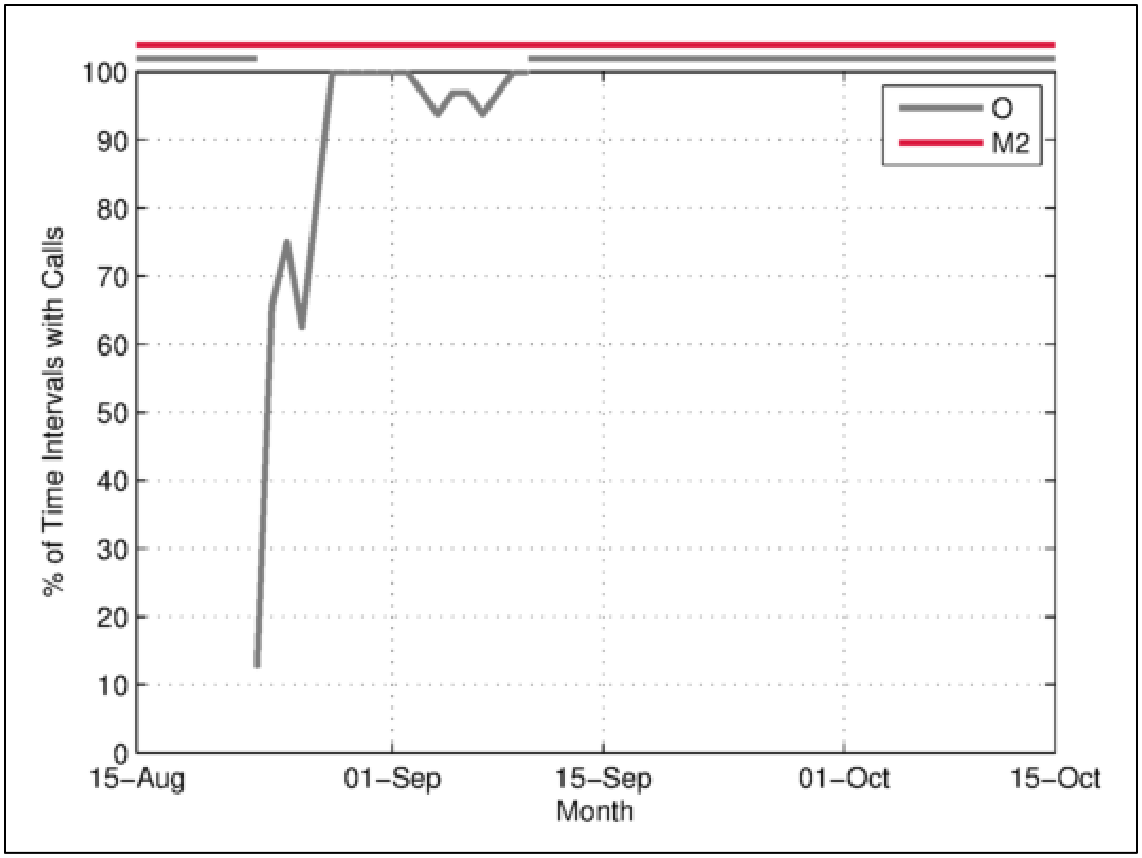

Figure II-31. *Results from the short-term mooring in 2012. Results from the M2 cluster were not available at the time of this report. Bars above the plot correspond with periods of no data for those moorings.*

Inter-Annual Results

Long-term

For all M clusters (Figs. II-32 through II-35), the first detections of bowhead whales in the BOWFEST area in the spring occurred the earliest in 2011 and the latest in 2012. In 2011, we also saw the latest detections in the area during the fall months, and thus had the longest occupation of bowheads heard during the BOWFEST study for a particular year (Figs. II-32 through II-35). The earliest departure of bowheads from the study area occurred in fall of 2007 (Figs. II-32 through II-35), and M5 from this year also recorded a very low percentage of time with calls, when compared with the M5 mooring detections during other years (Fig. II-35). In general, calling was much lower in 2007 than in any other year of the BOWFEST study. It is possible that this is due to a less experienced analyst, combined with an earlier version of SoundChecker that did not allow user control of contrast. However, spot checks suggest that increasing the 2007 results by 25% would be a conservative solution until these data can be reanalyzed. Even with a 25% increase, the percentage of time with calling for all M clusters in 2007 was still far lower than in the other years of the BOWFEST study.

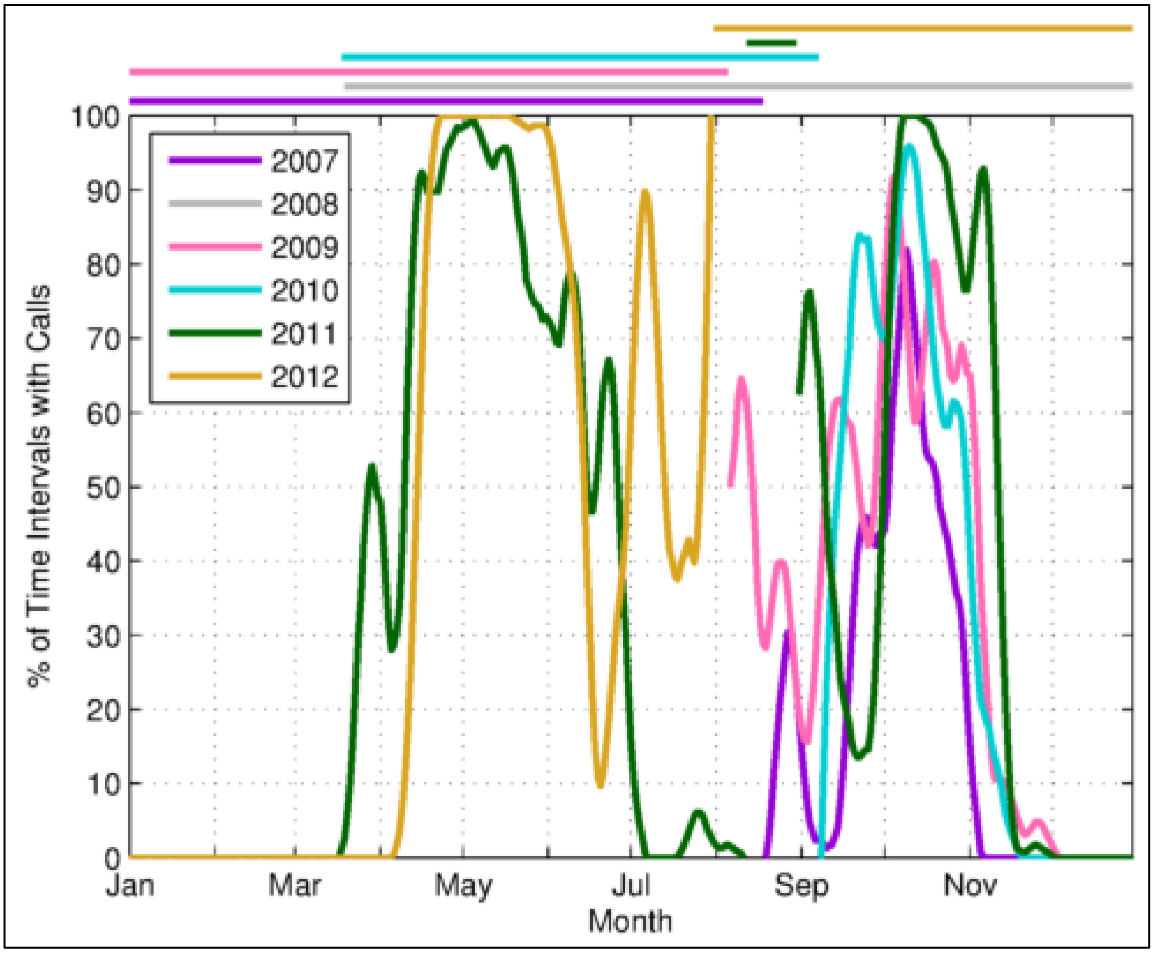

Figure II-32. *All moorings deployed at the M2 cluster location during the duration of the BOWFEST study. Bars above the plot correspond with periods of no data for those moorings.*

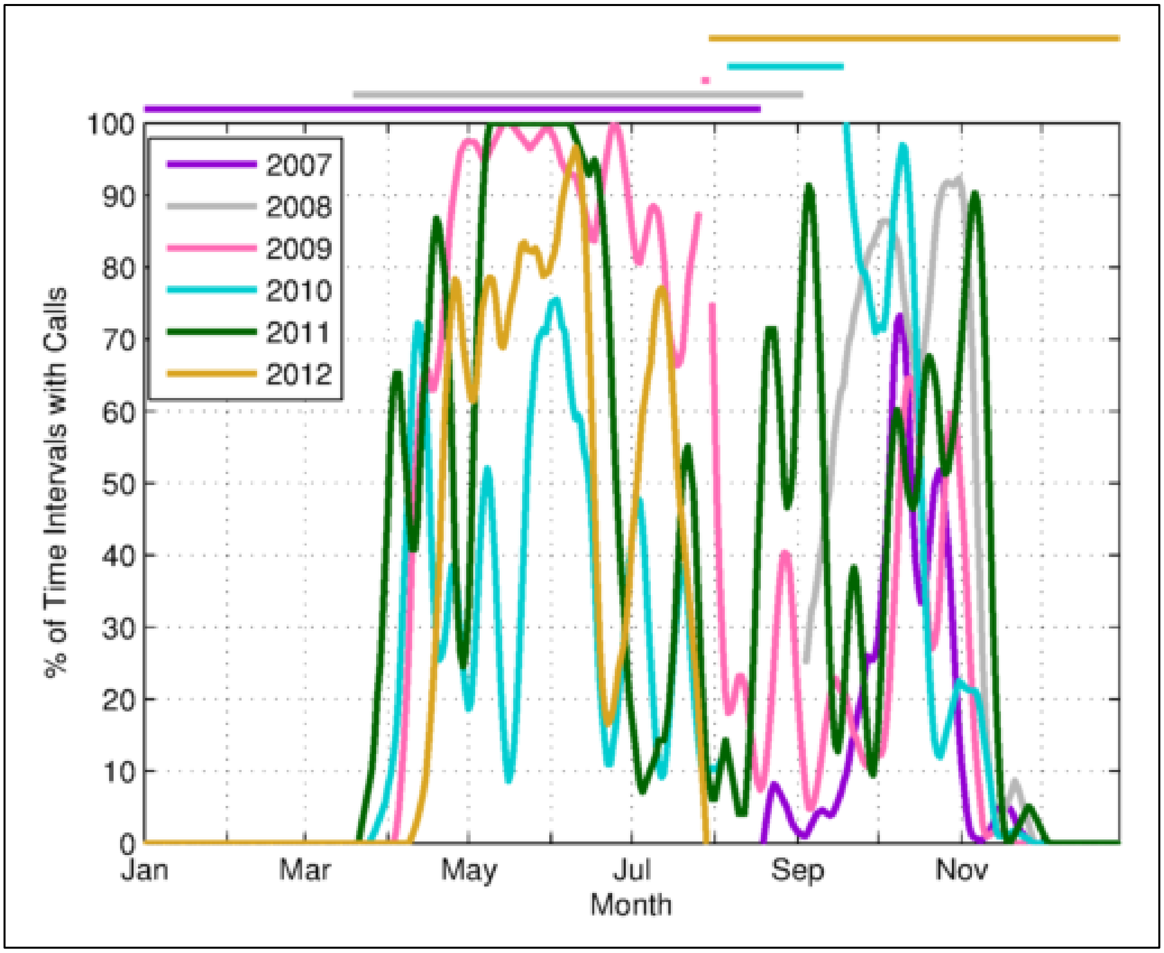

Figure II-33. *All moorings deployed at the M3 cluster location during the duration of the BOWFEST study. Bars above the plot correspond with periods of no data for those moorings.*

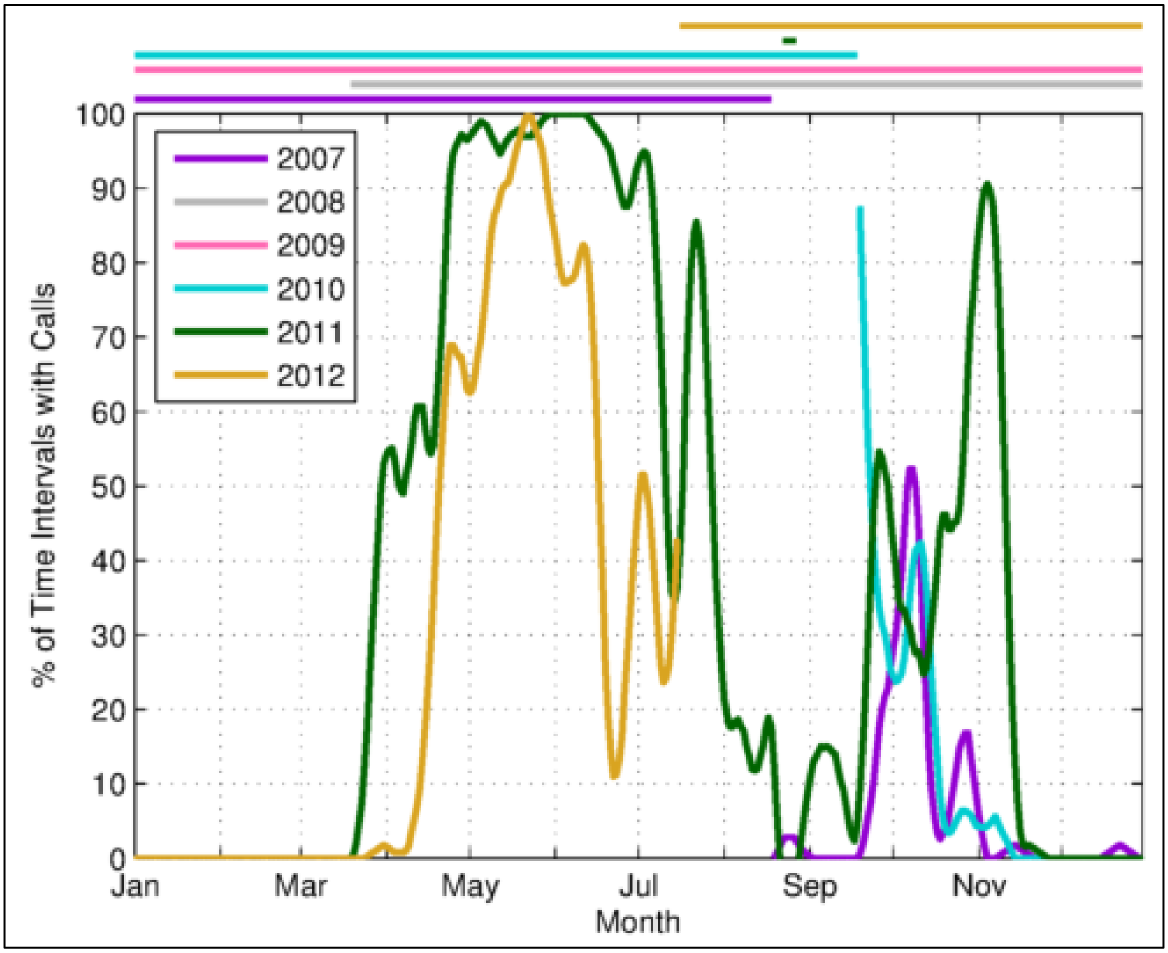

Figure II-34. *All moorings deployed at the M4 cluster location during the duration of the BOWFEST study. Bars above the plot correspond with periods of no data for those moorings.*

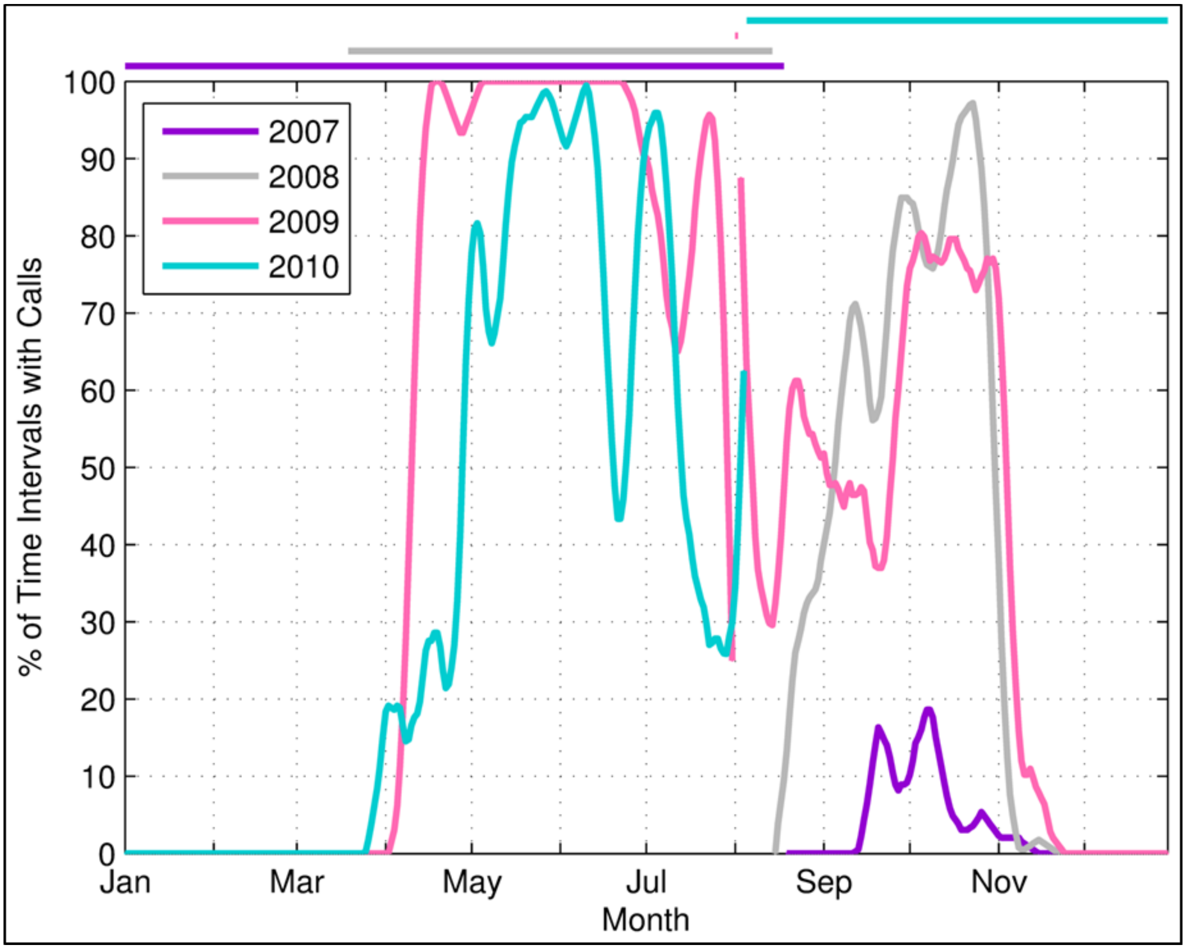

Figure II-35. *All moorings deployed at the M5 cluster location during the duration of the BOWFEST study. Bars above the plot correspond with periods of no data for those moorings. Data from the AON moorings deployed in 2011 and 2012 were unavailable at the time of this report and are not represented in this plot.*

Short-term

Throughout the BOWFEST study, the moveable short-term moorings were deployed in similar locations. Because of this, an inter-annual comparison by deployment region (NW, SW, NE, and SE) was possible. While the NW region shows varying percentage of time intervals with calls intra- and inter-annually, the NE and SE regions show consistent results across years (Fig. II-36). For the NE and SW regions, a peak in intervals with calling was seen in mid-September, and the increasing curve for the SE region seemed to indicate that this trend would be similar for the SE as well. Comparing across similar years, the NW and NE regions in 2008 both show a high peak presence (Fig. II-36; pink); in 2010 there appeared to be a consistent trend in bowhead calling presence between the SE and SW regions (Fig. II-36; light blue); and the NE region in 2011 showed a much higher percentage of time with calls than the SE region (Fig. II-36; dark green).

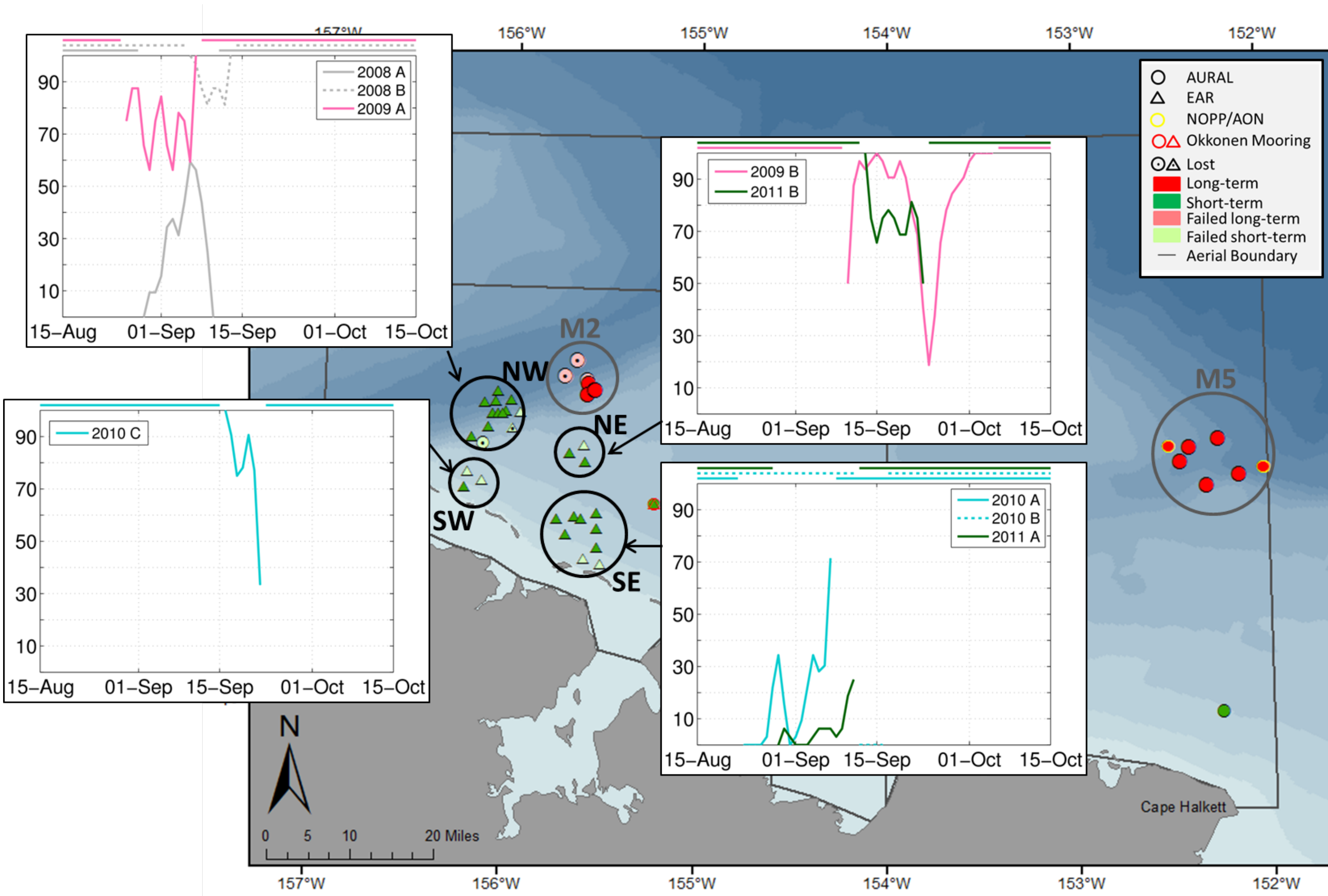

Figure II-36. *Spatio-temporal distribution of the percentage of time with bowhead whale calls (y-axis, insets) on the short-term moveable moorings, August 15th through October 15th, 2008-2011.*

Temperature

2007

In 2007, a striking correlation can be seen between bottom temperature and calling peaks at all four long-term recorder locations during the fall migration: the peak in temperature is followed three-weeks later by the peak in calling (Fig. II-37). The relative proportions of temperature among the four recorders were mirrored in the calling peaks. Highest peak temperatures were seen at M2 (5.5°C) and lowest at M5 (4.5°C). Temperatures reached 0°C at the beginning of October and remained below zero through the end of the year.

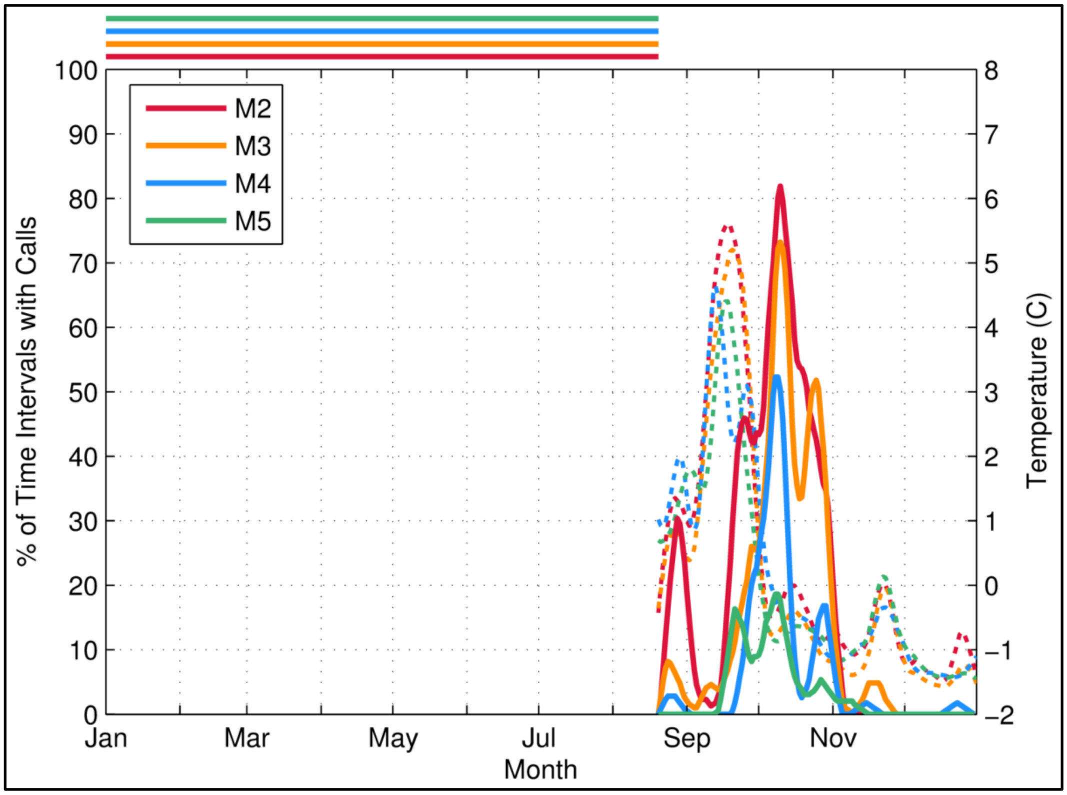

Figure II-37. *Results from all M clusters for 2007. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2008

The nice correlation seen in 2007 was not evident in 2008. . Although the spring migration was not detected acoustically in 2008, temperature data was collected until the recorders failed in mid-March. While M3, M4, and M5 remain below -1°C for the duration of this period, M2 shows a spike to 0°C in early January as well as mid-March. Both M2 and M3 show the beginning of a temperature increase in late March, which follows the trends seen in 2009, 2010, and 2012. In the fall, temperatures at both M3 and M5 stayed below 0°C from mid-August through the end of the year (Fig. II-38).

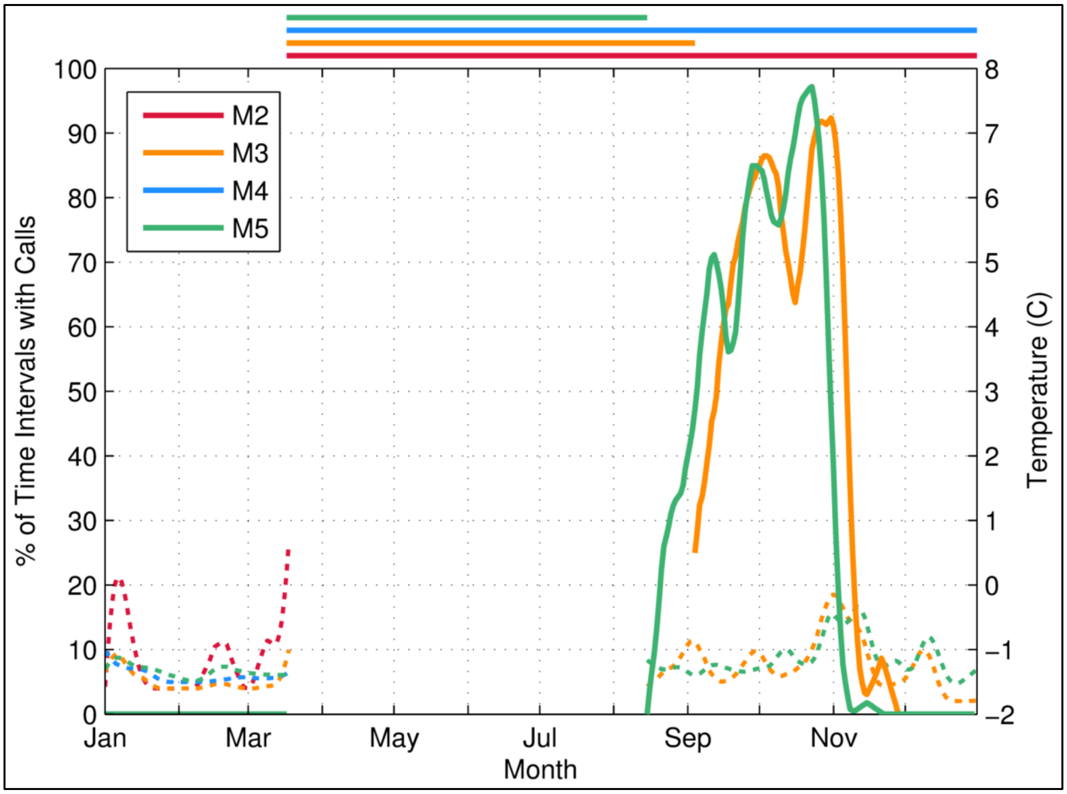

Figure II-38. *Results from all M clusters for 2008. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2009

The first year with data from the spring migration was 2009. No strong peak in temperature preceding the calling peak was seen; however, a small increase from -1°C to 0°C is seen about two weeks prior to the start of the calling pulse (Fig. II-39). The fall migration had results that were a mix of the 2007 and 2008 results. The M2 recorder showed the correlation between peak temperature and peak calling, although the delay in 2009 was around a month as seen in Figure II-39. However, the relative proportion of temperature among recorders does not correlate well with the relative proportion of calling. Temperatures varied with a peak of 6°C at M2, and 1°C at M5. The timing of the 0°C water also varied among mooring locations, it was reached in early September at M4, but not until early November at M2.

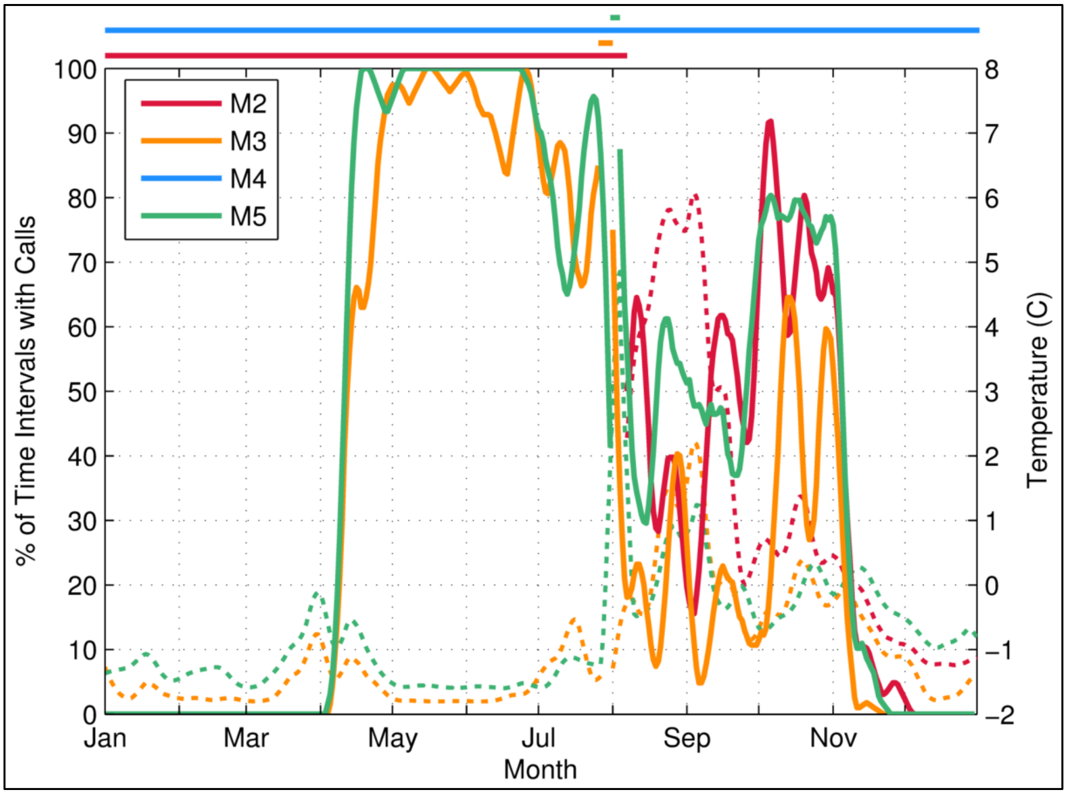

Figure II-39. *Results from all M clusters for 2009. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2010

For the 2010 spring migration, the increase to 0°C appeared to precede the increase in calling at M3 and M5, although there was another similar increase in mid-February (Fig. II-40). It is unknown what the temperature was doing in the fall of 2010 due to a late deployment of the recorders. The M2 recorder does show a strong temperature peak (7.5°C) that precedes the peak in fall calling by approximately a month (Fig. II-40). The M3 data seemed to show a hint of this trend, but the M4 data do not. The water temperature dropped to 0°C at the beginning of October.

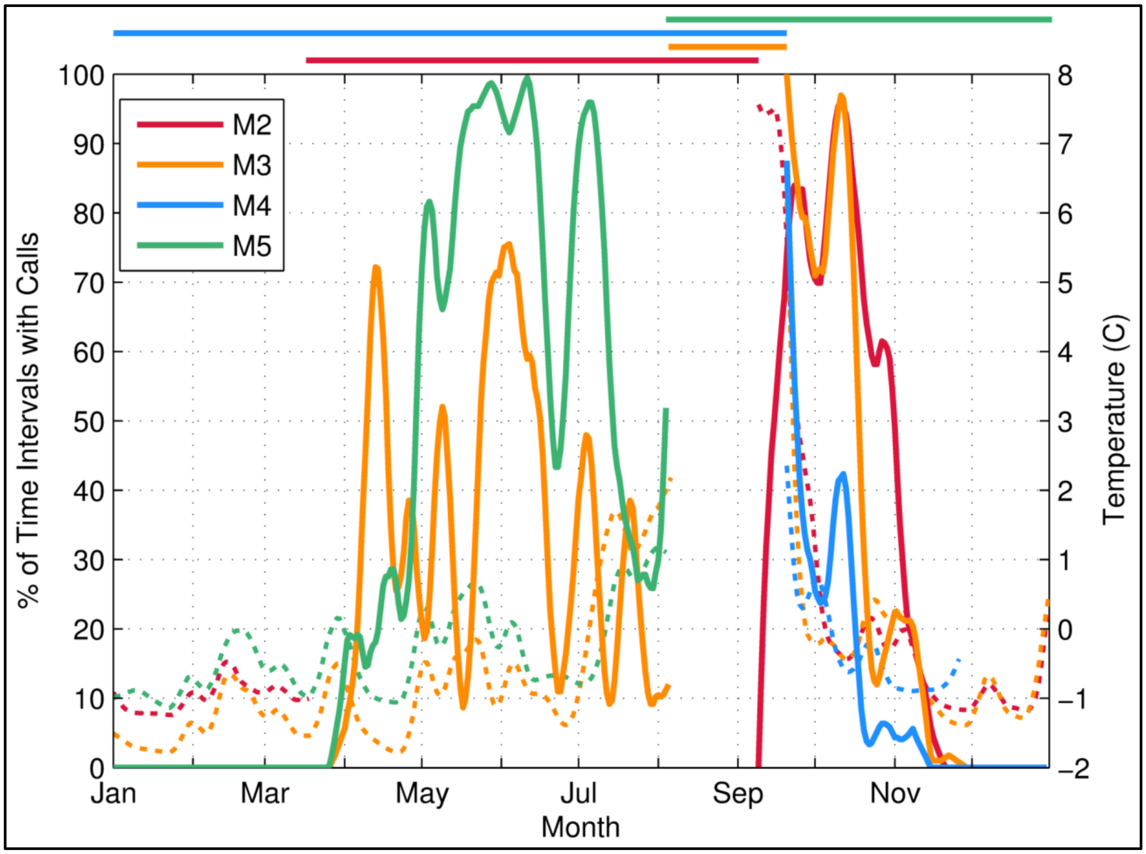

Figure II-40. *Results from all M clusters for 2010. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data. Data for the AON mooring deployed in 2010 at M5 were unavailable at the time of this report.*

2011

For 2011, no increase in temperature was seen on M2, the only recorder with spring temperature data (Fig. II-41). This was the only year where temperatures were not highest at the M2 mooring location during the fall. A high (7.5°C) peak was seen at M4 about a month before the first (smaller) calling peak on that mooring (Fig. II-41). The M2 and M5 peaks were lower at 5°C and 2.5°C respectively. All recorders showed a drop below zero that is maintained from late October through the end of the year.

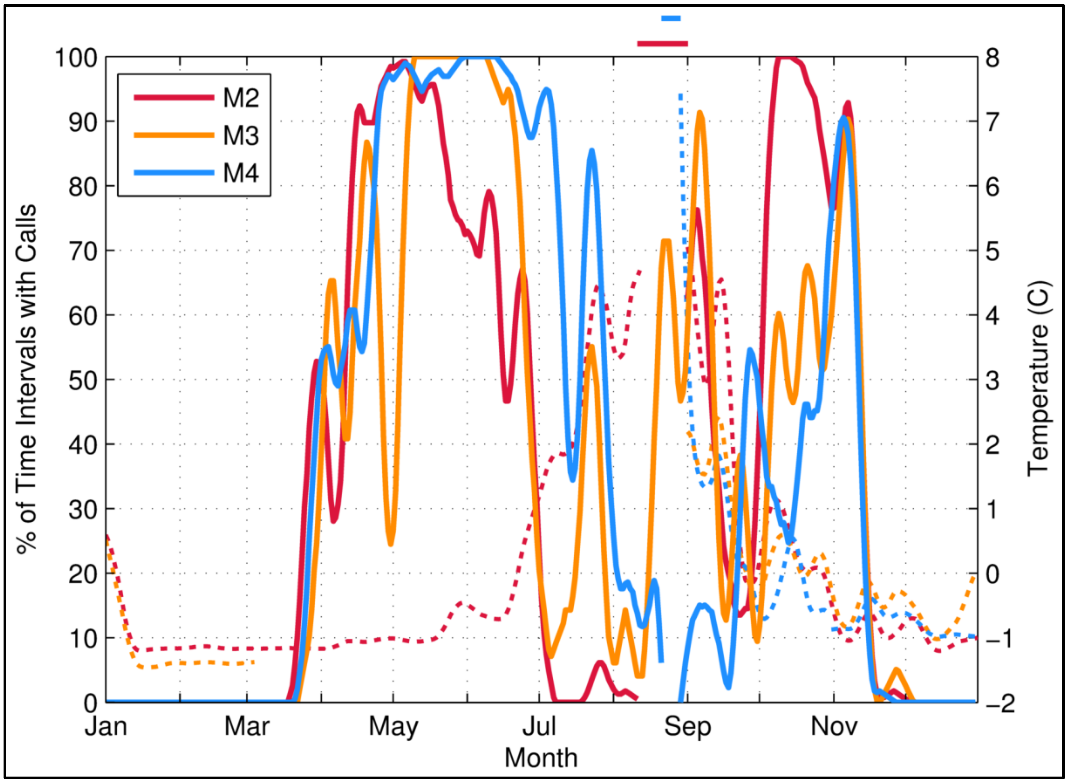

Figure II-41. *Results from all M clusters for 2011. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data. Data for the AON mooring deployed in 2011 at M5 were unavailable at the time of this report and are not represented in this plot.*

2012

A small increase in temperature about two weeks prior to the spring calling pulse occurred again in 2012 (Fig. II-42). Data for the fall of 2012 were unavailable at the time of this report.

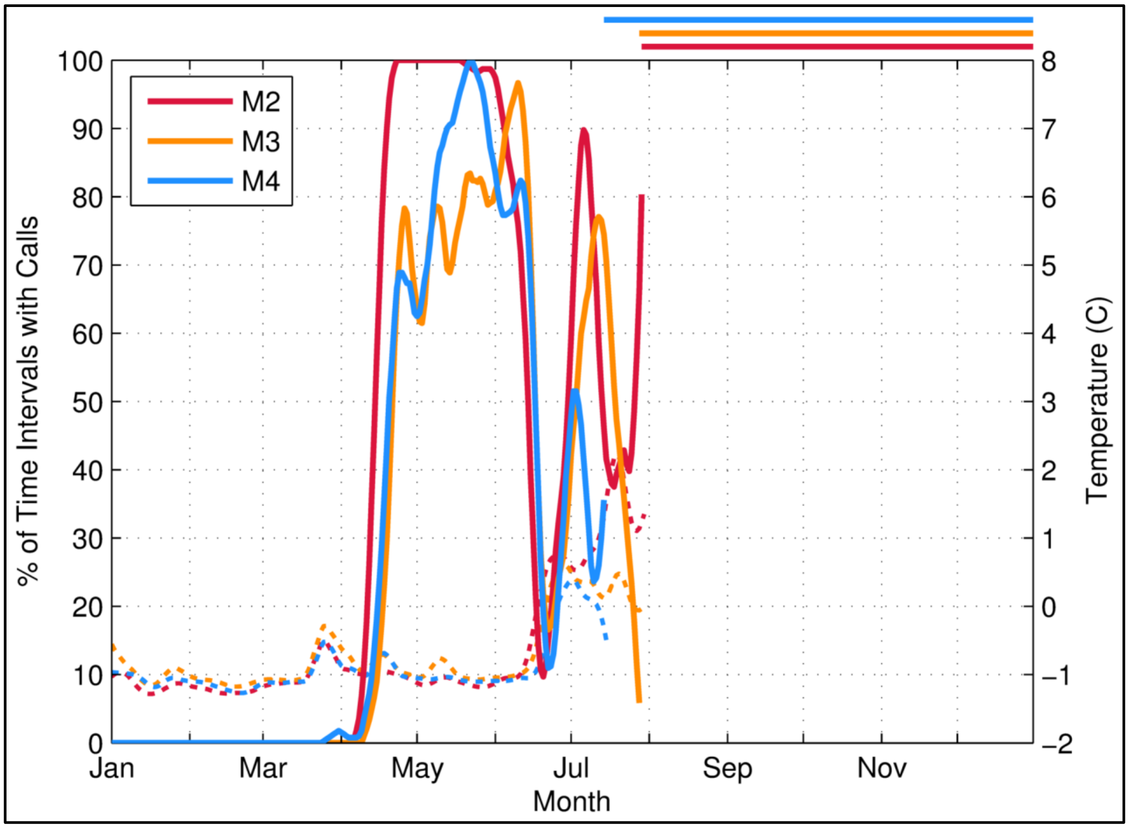

Figure II-42. *Results from all M clusters for 2012. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and temperature in degrees Celsius (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data. Data for the AON mooring deployed in 2012 at M5 were unavailable at the time of this report and are not represented in this plot.*

Ice

Two very striking trends were seen in Figure II-43, which summarizes the percentage of time with bowhead calls for each long-term mooring cluster versus the percentage of ice coverage at that location. First, for the fall migration, the decrease in calling is inversely proportional to the increase in ice coverage. Second, peak bowhead calling was detected in the spring under 100% ice cover. This can be explained by the fact that this ice coverage data comes from satellite imagery; the scale was not at a fine enough resolution to account for all leads in which bowheads could move. Ice data were only available through the fall of 2011.

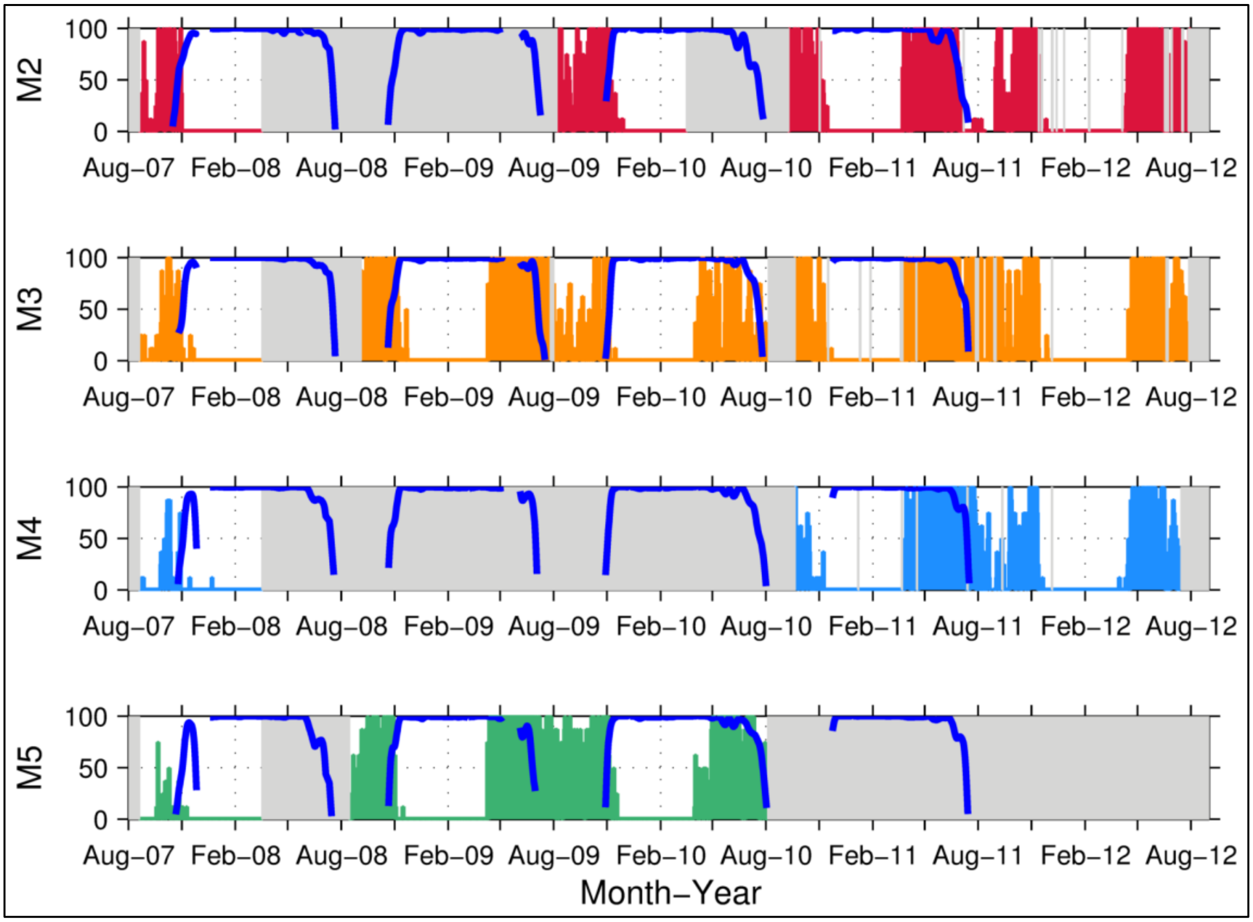

Figure II-43. *Percentage of time with bowhead calls and ice coverage for all long-term moorings over all five years of the BOWFEST study. No moving average was applied for the percentage of time with bowhead calls, but a 7 day no-phase moving average was used on percent ice coverage. Gray shaded areas were periods with no data. Calling data at M5 from August 2010-2012 were not available at the time of this report.*

<u>Annual ice coverage</u>

2007

Figure II-44 shows that during the fall of 2007 ice began to form around the BOWFEST area by mid-October. By early November, the majority of the whales were out of the area and ice coverage had reached 90% at all four mooring locations.

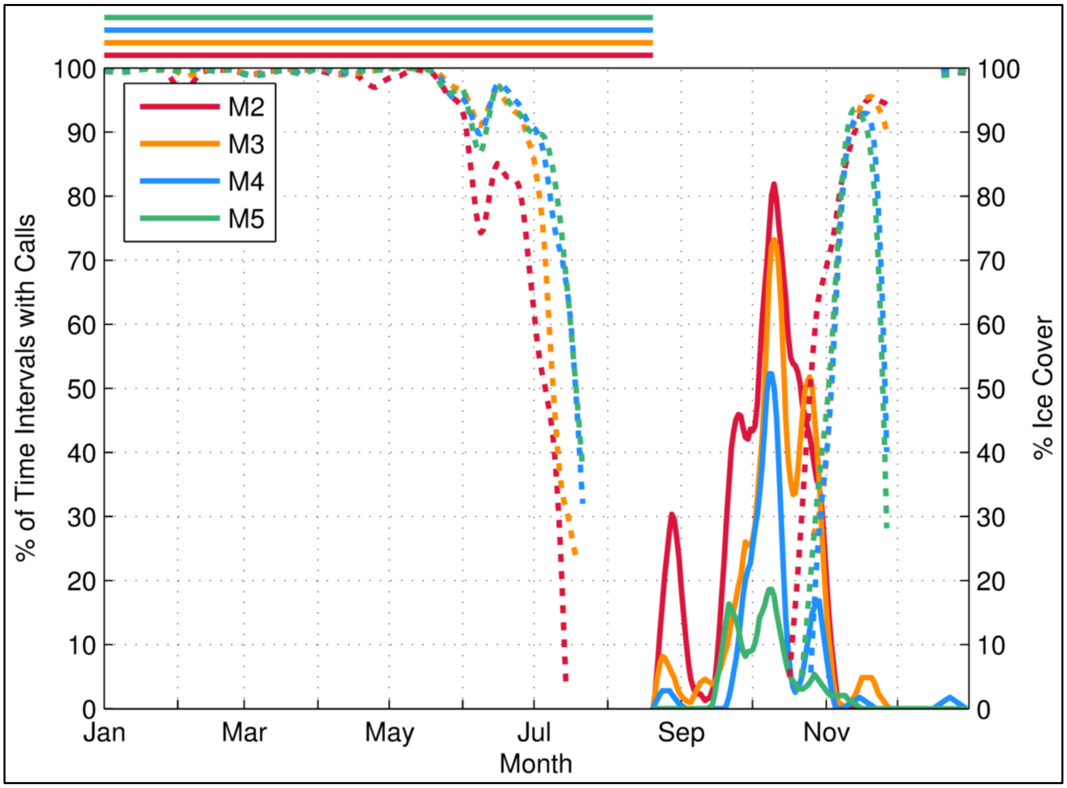

Figure II-44. *Results from all M clusters for 2007. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and percentage of ice coverage (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2008

In the fall of 2008, ice again started to form in mid-October reaching 100% by the beginning of November, which correlates with the departure of the majority of the whales at the beginning of that month (Fig. II-45).

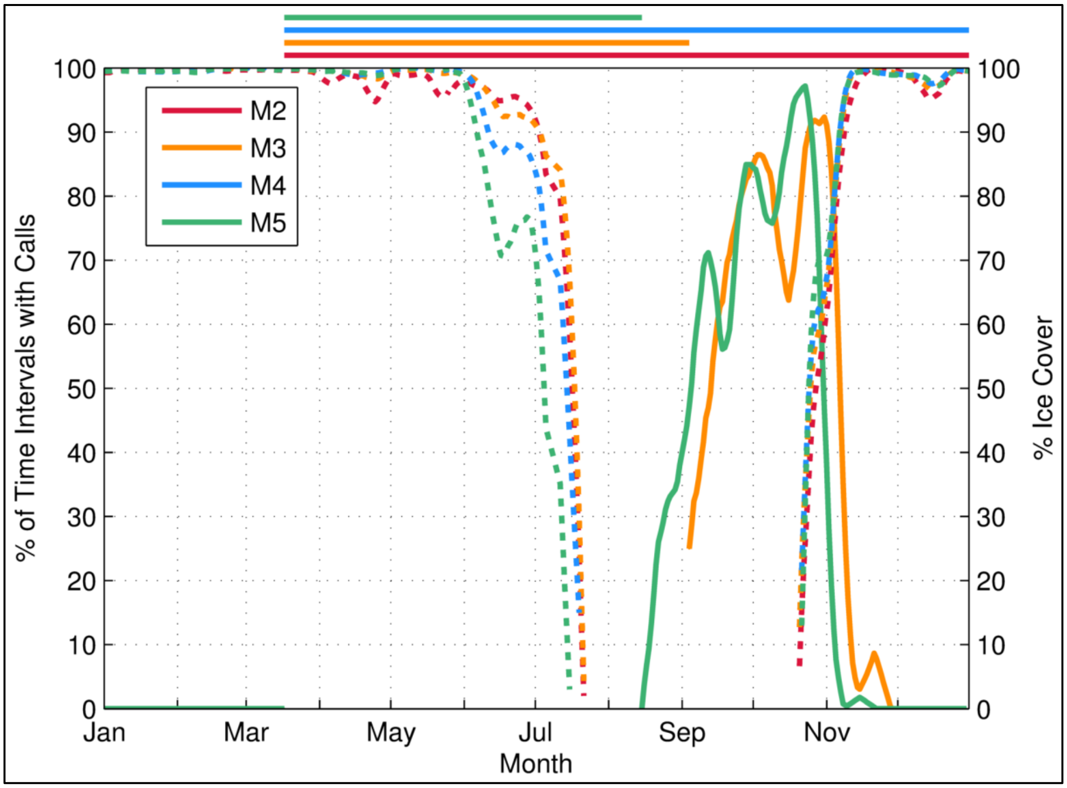

Figure II-45. *Results from all M clusters for 2008. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and percentage of ice coverage (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2009

Figure II-46 shows that ice levels remained at or near 100% well into the spring migration in 2009 (the first year with calling data during the spring migration), suggesting that the whales were moving through small cracks or leads in the ice pack. By mid-July, all four M locations were ice-free. Ice did not begin to form again until late October, roughly two weeks later than the previous two years. Again in the fall of 2009, there was a strong correlation with ice coverage increasing and whales moving out of the BOWFEST area.

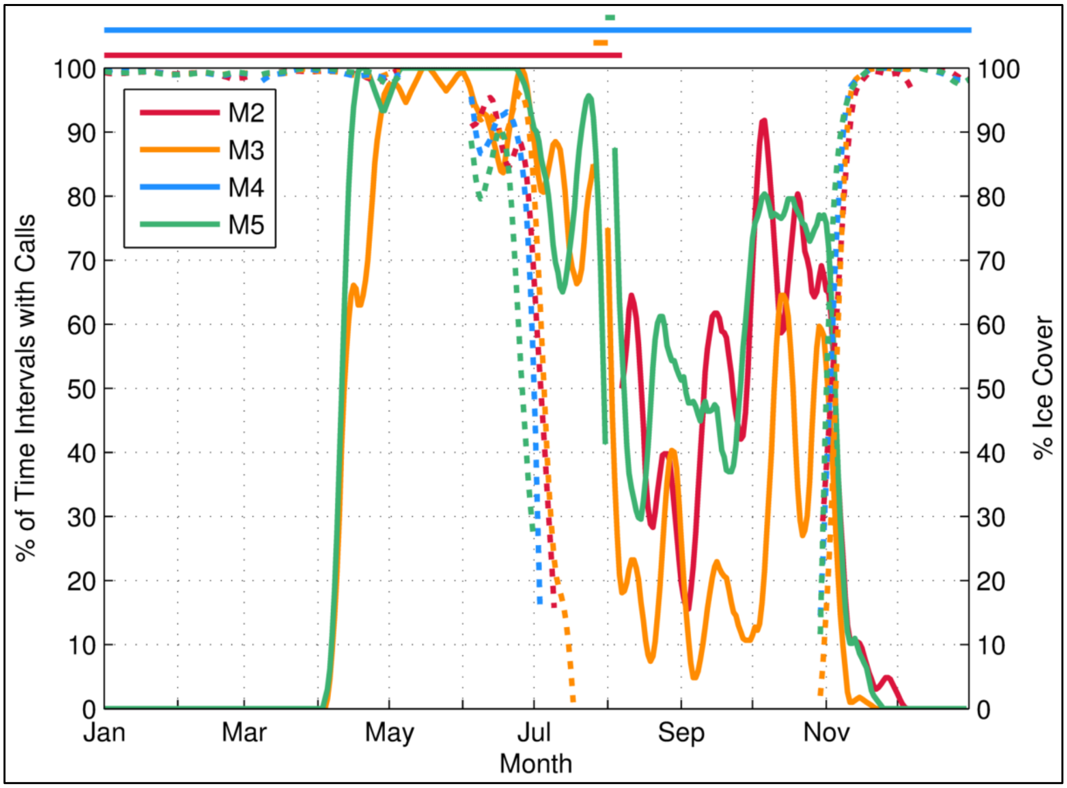

Figure II-46. *Results from all M clusters for 2009. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and percentage of ice coverage (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2010

The spring of 2010 followed similar patterns to spring 2009. However, the mooring locations did not appear to become ice-free until late July or early August, making it the year that ice remained in the BOWFEST area the latest (Fig. II-47). Due to missing ice coverage data for the fall of 2010, we were unable to draw a correlation between the onset of ice and the departure of whales; however, it is clearly seen that by late November when the ice coverage was nearly 100%, that bowheads had moved out of the area.

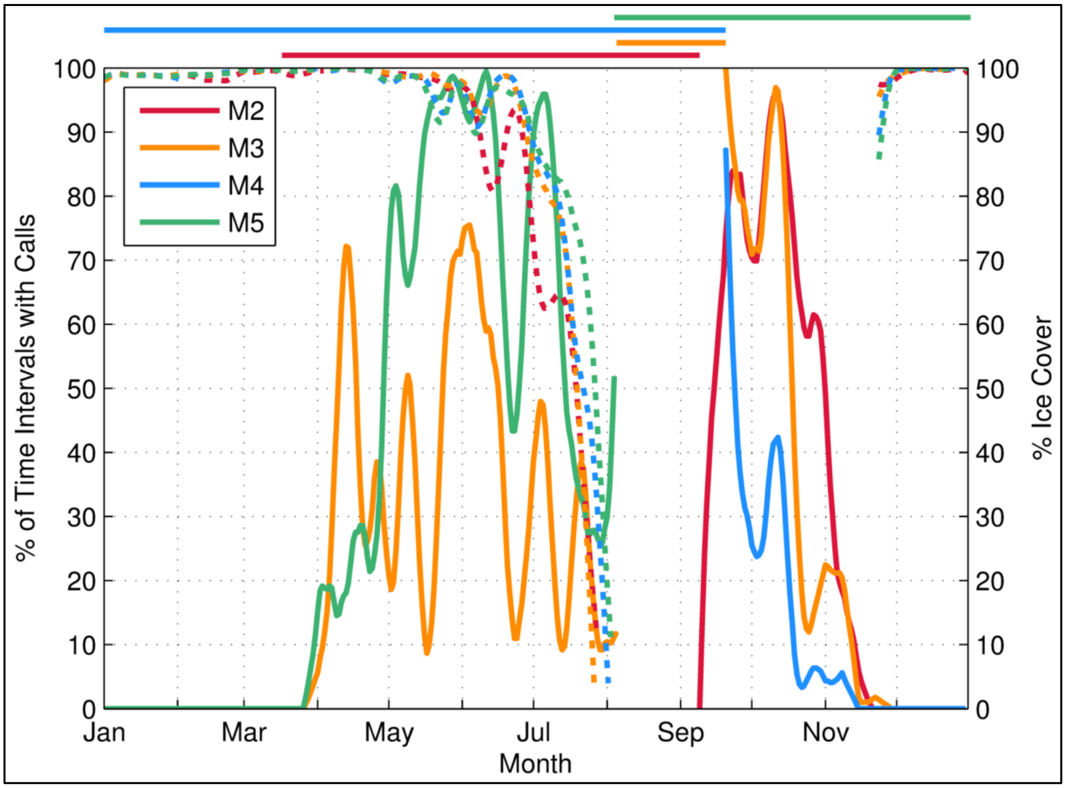

Figure II-47. *Results from all M clusters for 2010. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and percentage of ice coverage (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data.*

2011

The spring of 2011 showed a similar pattern to the two previous years, again showing the use of leads and cracks in the ice by bowheads. As in 2009, the mooring locations appeared to become ice-free by mid-July (Fig. II-48). Ice data for the fall of 2011 were unavailable at the time of this report.

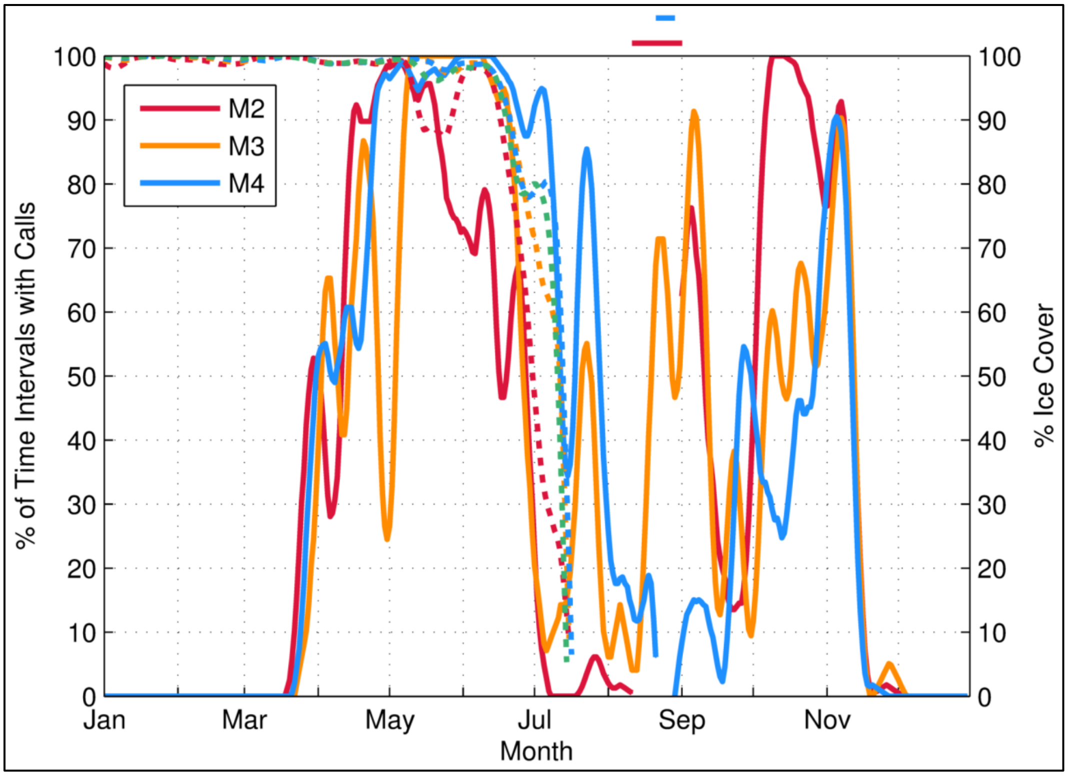

Figure II-48. *Results from all M clusters for 2011. Percentage of time intervals with calls (solid lines) is shown on the left y-axis and percentage of ice coverage (dotted lines) is shown on the right y-axis. Bars above the plot correspond with periods of no data. Data for the AON mooring deployed in 2012 at M5 were unavailable at the time of this report and are not represented in this plot.*

Interannual ice coverage

The percent of ice coverage in the spring remained fairly consistent at each M location over all years of the study (Figs. II-49 through II-52). The months of May and June showed the most variation as the ice began to break up and flow out of the area. Ice remained at each of the M locations the latest in 2010, not leaving M4 until early August. In contrast, 2009 was the year of the earliest breakup at each location with ice-free conditions beginning in early July at M4 and M5.

Ice appeared to move into the BOWFEST area the earliest during the fall of 2007 and the latest in 2009. Although, in all years the ice moves into the area quickly, reaching 100% coverage in only a few weeks.

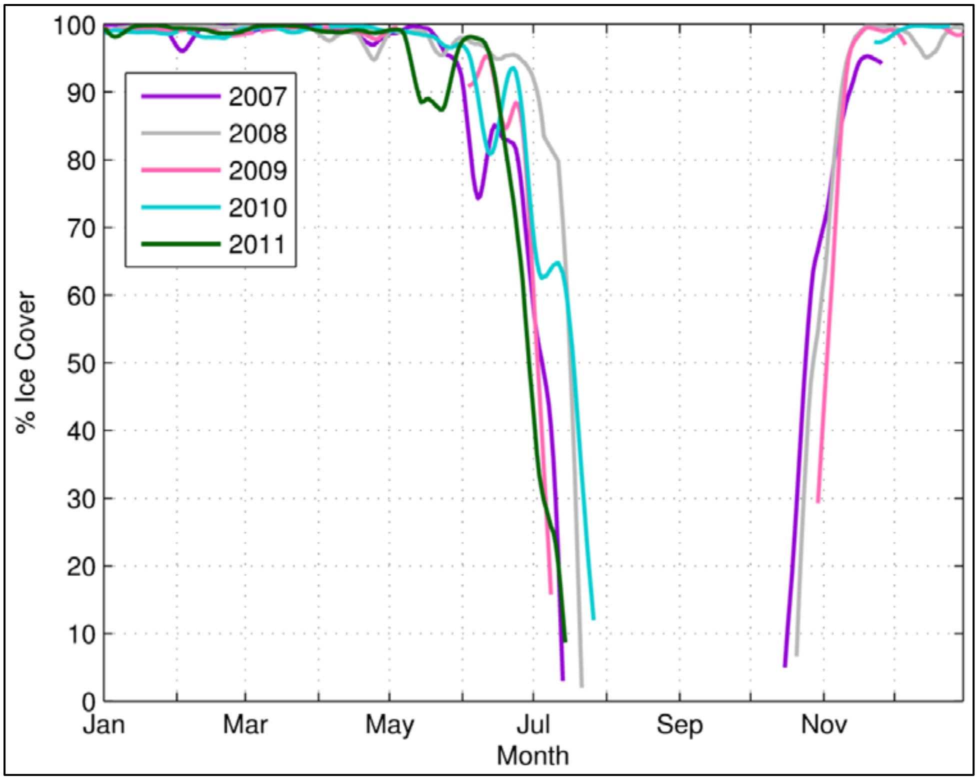

Figure II-49. *Percentage ice coverage for all years (2007-2011) at the M2 mooring location.*

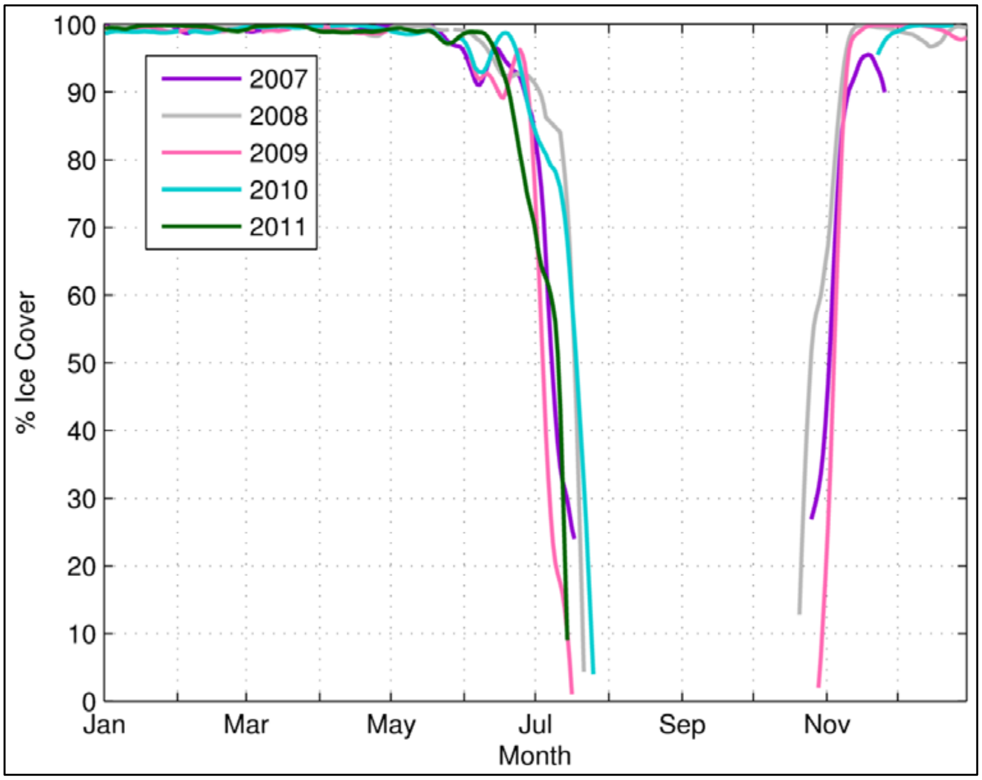

Figure II-50. *Percentage ice coverage for all years (2007-2011) at the M3 mooring location.*

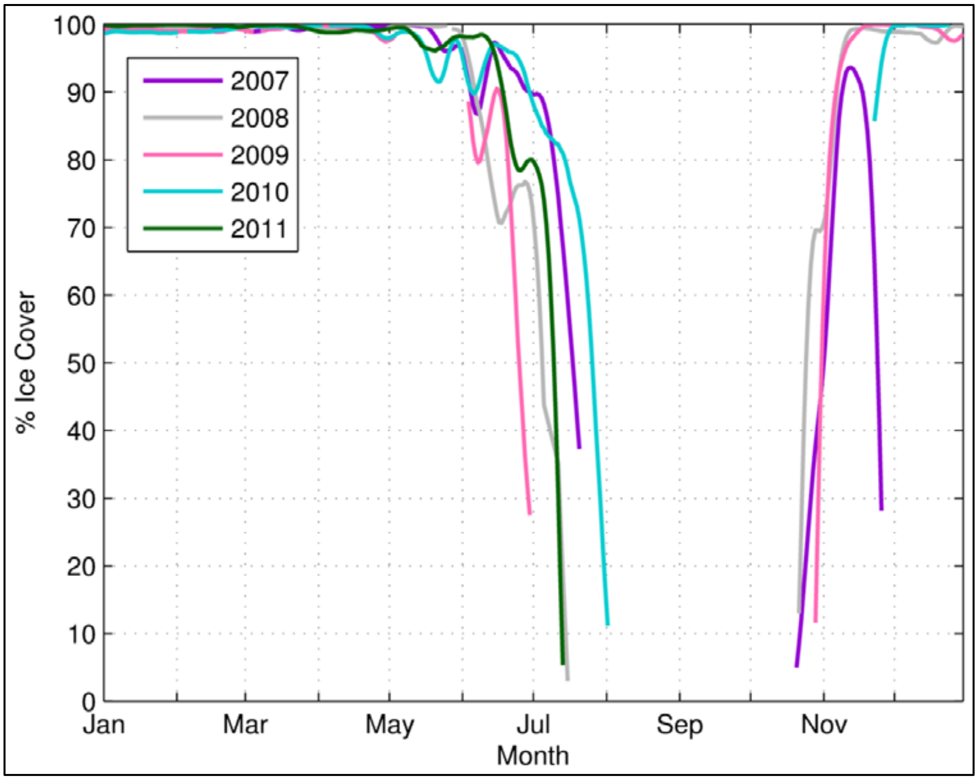

Figure II-51. *Percentage ice coverage for all years (2007-2011) at the M4 mooring location.*

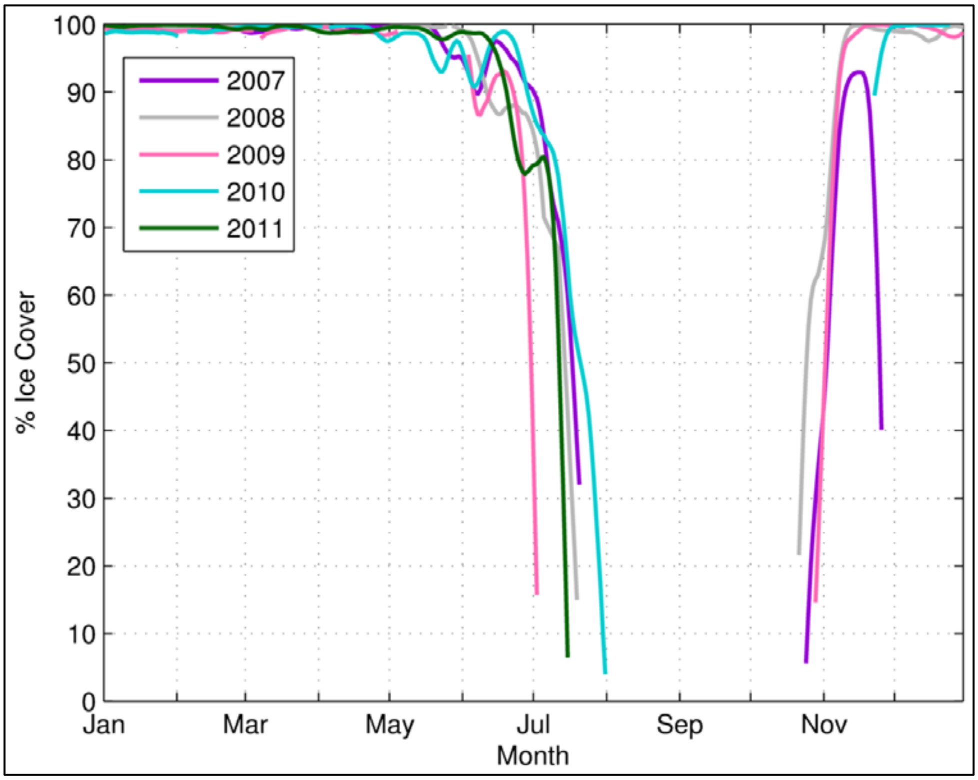

Figure II-52. *Percentage ice coverage for all years (2007-2011) at the M5 mooring location.*

Discussion

As can be seen from the results described above, use of long-term passive acoustic recorder moorings is an effective tool for monitoring not only the spring and fall migrations of bowhead whales through the BOWFEST study area, but also the presence of bowheads in this area throughout the summer.

Because of the multiple reasons listed in the individual year results above, data were not available for all of the sites in all years. The discussion that follows will focus on just those data that were available and not reiterate the reasons behind why the other data were missing.

Spring Migration

The spring migration was detected from 2009 through 2012. In all four years, a sudden and near-simultaneous onset of calling, under 100% ice cover, was seen at the long-term sites around the beginning of April. A bit of variation in the order of the recorders was seen among the years. In 2009 and 2010, calling was detected on M3 a day after M5 (Table II-3). Although the long-term recorders were all located along the 100m isobath, the isobath varies in its distance from shore, with M2 being the closest and M3 being the furthest (Fig. II-1). A possible cause of calls being detected first at M5 (the eastern-most site) may be that the migration path started off closer inshore and then spread offshore as the ice broke up. It is known that bowheads follow leads in the pack ice that form close to shore (Braham et al. 1980, Ljungblad et al. 1986, George et al. 2004), which supports these acoustic findings. In addition, the small temperature peaks seen prior to the spring calling peak (Figs. II-37 through II-42) may be indicative of leads forming at those times. The ice appeared to remain in the BOWFEST area the latest in 2010 with the area not becoming ice-free until the beginning of August.

The earliest start of the spring migration occurred in 2011, with calling detected on March 25th at M2 (Fig. II-25). Again, calls were detected at the more eastern M4 site two days before calls were detected at M3 (Table II-3). This again could possibly correspond to an inshore migration path. This pattern of later detections at M3 was also seen in 2012. Whales were detected five days later at the M3 location than at M2 or M4. The small peak of calling at M4 was the product of one lone bowhead call that was detected at M4 on March 31st. The main pulses of calling came two weeks later on April 11th and 12th at M4 and M2, respectively. The spring migration saw an extensive pulse of calling that was maintained at peak presence levels through August in all years, except for 2010 when levels dropped in July (Figs. II-32 through II-35).

Fall Migration

The fall migration, on the other hand, was detected in all five years of the study. The main pulse of the migration, however, had a lower peak and was much more compressed than that from the spring migration (Figs. II-32 through II-35). Detections were also made inshore on the short-term recorders during the fall migrations of 2008-2012 (Figs. II-14, II-15, II-19, II-23, II-27, and II-31). These, in addition to differences in detection timing among the long-term recorders, suggested different migratory paths taken among the years. The end of the main pulse of calling for the fall migration varied between early November (2007) to mid-November (2008-2011).

In 2007, the offshore M3 cluster saw the earliest arrival of the fall migration peak followed by the later, but lower, peak at M4, and a much higher peak at M2 (no bowheads were heard on M5 during this time, Fig. II-8). This seems to suggest the whales took a route into the BOWFEST area from the north and were funneled past M2. Lack of calling from the short term recorder located close to Cape Halkett (Fig. II-9) also supports this theory. All sites showed a decrease in calling around early September, which correlates with the BOWFEST aerial survey

(Rugh et al. Section I: this volume). During the main pulse of the fall migration, M2 maintained a high and constant level of calling, while calling varied in level, duration, and time period for the other three clusters. This seemed to again indicate a funneling of bowheads past Barrow. At the tail end of the fall migration, detections petered out from east to west – M5, M4, M3, and then M2 – as would be expected from a westward fall bowhead migration (Fig. II-8, Table II-3). The strongest correlation between temperature and calling was seen in 2007 and seemed to suggest the whales might be starting their migration using temperature as a cue (Fig. II-37). The temperatures peaked from M5 to M2 which might indicate a pulse of warm water passing from east to west over the study area. The earliest year for ice formation within the BOWFEST area was also in 2007.

East to west migration movements in 2008 were also very clear (Fig. II-12). Inshore-offshore comparisons showed a greater percentage of time with calling inshore than offshore at M3. This corresponds with the aerial findings where all sightings were made along the 20 m isobath. In contrast, movable cluster B, further offshore and in deeper water than the other two short-term moorings, showed a much higher percentage of time with calling in the first half of September than either the A, O, or M3 clusters (Fig. II-13). However, it also was a triad array and so had a greater detection area than any of the other sites. The lowest overall fall temperatures were seen in 2008, which agrees with the findings from Ashjian et al. (Section IIIB: this volume) (Fig. II-38).

The start of the fall migration in 2009 was unclear as a high level of calling was maintained during the August-October time period (Fig. II-17). The end of the fall migration was first detected on M3 followed by M2 and M5, again suggesting a more inshore migratory path in fall of 2009. This year had the latest date for the temperature to fall and stay below zero (early November at M2) of any year (Fig. II-39) and was also the year in which ice formed the latest within the BOWFEST study area (Figs. II-49 through II-52).

In 2010, the results showed a much lower calling presence at M4 versus the other two more western sites (M2 and M3) which had comparable (very high) calling presence (Fig. II-21). Detections from all three sites all dropped around mid-November, about a month after bottom temperatures reached 0°F, with a main departure noted at M4 first, followed by M3, then M2 (again, an expected result for an east-to-west migration, Fig. II-40). The short-term A cluster shows that there were whales moving through the area before the long-term recordings started in the fall (Fig. II-23). For the period of time (mid-September) with overlapping inshore and offshore effort, there was initially a greater calling presence inshore, but this evened out rapidly. This agreed with the aerial results that the bowheads were spread throughout the study area (Rugh et al. Section I: this volume).

Fall migration did not have a well-defined start in 2011, but the end of the main pulse was abrupt at all three sites, occurring about a month after bottom temperatures dipped below 0°F (Fig. II-41). The time with calling was almost double at M2 in the fall as compared to the other M locations, which gradually built throughout the fall migration reaching the very high M2 levels only during the last migration pulse (Fig. II-25). This seemed to indicate an initial funneling past Barrow Canyon followed by perhaps the arrival of the ice pack which would drive the whales out of the area fast (ice data for the fall of 2011 were unavailable at this time). Results for inshore/offshore comparisons in 2011 were mixed. At the beginning of September, calling was higher offshore corresponding to aerial survey findings, while the second half of September saw higher calling levels inshore, after the aerial team was done flying (Fig. II-27).

For most years, there was a distinct high temperature peak that preceded the peak in fall calling by 3 weeks to a month (Figs. II-37 through II-42). Whether this correlation was real or just a product of a migration that occurred in the fall – a time that is typically colder than summer - will require further investigation.

Summer feeding grounds

Although acoustic data do not provide the means to determine if feeding was occurring, it can determine if whales were present in an area. The most interesting result from the long-term passive acoustic recordings was the continual presence of bowheads in the study area throughout the summer and not just during the spring and fall migrations. This can be seen clearly in 2009 and 2011, where peak or near-peak presence continued between the migrations (Figs. II-17 and II-25). This reinforces past evidence (Braham et al. 1979, George and Carroll 1989, Moore 1992, George et al. 2006, Moore et al. 2010a) that bowheads use the BOWFEST area as a feeding ground and not just as a migratory corridor.

In 2009, calling was the lowest offshore on M3 during the first half of August and highest at M2 (Fig. II-17). During the second half of August into early September, M5 saw greater calling than either M2 or M3. Comparison between the short-term moorings and M2 clearly showed a much higher percentage of calling at all the inshore areas, again corresponding with aerial results (Fig. II-19).

In 2011, calling was quite high at M2 and M3 during this summer period – which corresponds to the aerial team's findings that all whales were in deep water in this year (Fig. II-25). However, low calling was seen on M4 during this period, which suggests that the whales were more concentrated around Barrow.

The dip in calling in June of 2012 appeared to track with a sudden increase in bottom temperature (Fig. II-42). However, the temperature was not inversely correlated to this calling dip, so it is unknown if or how temperature is a factor. This calling dip and temperature increase were not seen in any other year.

The passive acoustics dataset collected for the BOWFEST study is the first long-term all-season record of sounds from this important marine area. We have only begun to scratch the surface on information that can be obtained from these data. As auto-detection algorithms improve, this same analysis can be carried out for all other vocalizing marine mammal species. Furthermore, NMML has made it a priority to continue to obtain recordings at the deep water sites to maintain this valuable long-term data set.

Acknowledgements

We would like to thank Steve Okkonen and the crew of the R/V *Annika Marie* for their help with the deployment of all our moorings in 2007. In addition, we would like to thank them for their help with deployment and retrieval of a short-term recorder each summer from 2007-2012. We are deeply indebted to Dr. Bob Pickart (WHOI), the chief scientist on the USCGC *Healy* during the annual cruise funded by the National Ocean Partnership Program (NOPP) grants of several BOWFEST Principal Investigators (Ashjian, Okkonen, Stafford), for allowing retrieval and deployment of several of our long-term AURAL recorders from 2008-2010. Aboard the USCGC *Healy*, we would like to thank Kate Stafford (2008-2009) and Sharon Nieukrik (2010) for overseeing the mooring work. We greatly appreciate Billy Okpeaha, Craig George, and Josh Bacon of the North Slope Borough-Division of Wildlife Management's (NSB-DWM) for deploying our moorings from the M/V *Iipuk*, and Eugene Brower, Craig George, and a local hunter named Zach for deploying and retrieving our moorings from the M/V *Little Whaler* during the 2008 field season. In addition, we appreciate Fredrick Brower's continued support of our efforts by deploying and retrieving the short-term moorings from 2009-2011 aboard the M/V *Little Whaler*. We are grateful for the captains and crews of the F/V *Alaskan Enterprise,* F/V *Mystery Bay*, and the R/V *Aquila* for their support during all long-term mooring operations in 2010, 2011, and 2012, respectively.

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SECTION III - MOORINGS AND BROAD-SCALE OCEANOGRAPHY
A - MOORINGS

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Abstract

The mechanisms for trapping and aggregating krill, a key food source of bowhead whales, are not well understood. Current velocity and relative acoustic backscatter measurements were acquired by using year-round and short-term current meters moored in Barrow Canyon and in the shallow waters of the western Beaufort shelf from 2006-2011. These measurements, in combination with wind velocity data from Barrow, were used to identify generalized wind-driven circulation patterns and infer relative krill abundances associated with these circulation patterns. Two wind-current regimes collectively define a krill trap conceptual model for the BOWFEST study area. Moderate-to-strong upwelling-favorable winds from the east bring krill onto the shallow western Beaufort shelf. Subsequent relaxation of the winds and shelf currents promotes the retention and aggregation of krill on the shelf. Consequently, the krill trap conceptual model predicts that feeding opportunities for bowhead whales tend to be limited during moderate-to-strong upwelling-favorable winds from the east and enhanced when weak winds follow upwelling-favorable winds.

Introduction

In September and October, bowhead whales leave their summer feeding grounds in the eastern Beaufort Sea and begin their westward migration, often pausing near Barrow at a recurring feeding hotspot to graze on abundant krill (Moore et al. 2010). With respect to this feeding hotspot, both remote and local processes are necessary to create an attractive feeding environment in which krill are present in sufficiently large numbers and dense aggregations for energetically efficient predation by bowheads. Large numbers of krill occur at Barrow only if they have first been carried there by ocean currents from their source region in the northern Bering Sea, a journey of many months and more than one thousand kilometers (Berline et al. 2008, Ashjian et al. 2010). Once krill arrive in the Barrow area, two events associated with local wind forcing are needed to occur in sequence. Moderate-to-strong upwelling-favorable winds from the east are necessary to move krill onto the shallow western Beaufort shelf. If these moderate-to-strong winds from the east persist, the wind-driven, northwestward-flowing shelf currents will carry the krill back into the deep waters of Barrow Canyon. Consequently, the upwelling winds must relax to promote convergence of Alaska Coastal Current (ACC) waters from Barrow Canyon with Beaufort shelf waters, leading to the trapping and aggregation of krill on the western Beaufort shelf adjacent to the southeastern edge of Barrow Canyon (Ashjian et al. 2010, Okkonen et al. 2011).

In this section, current velocity and relative acoustic backscatter measurements acquired by current meters moored in Barrow Canyon and in the shallow waters of the western Beaufort shelf were used to illustrate representative circulation patterns and to infer the relative occurrence of krill on the shelf. These measurements, and wind velocity data from Barrow, were used to develop a krill trap conceptual model based upon the two wind-current regimes that contribute to creating a bowhead whale feeding hotspot near Barrow.

Methods and Data

A number of current meter moorings, both short-term and year-round, were deployed within the BOWFEST study area during the years 2006-2011 (Fig. IIIA-1). Taut-line year-round moorings, instrumented with upward-looking acoustic Doppler current profilers (ADCPs), were deployed in Barrow Canyon (A1 and East Barrow Canyon) at depths well below any threats associated with overlying sea ice. Short-term, low-profile, bottom-mounted frames instrumented in most years with ADCPs were deployed at six sites located inshore of the 20-m isobath on the western Beaufort shelf (3_15m, 6_10m, 6_19m, 8_10m, 8_19m, and Halkett) and at two sites located in the shallow passages (Plover and Cooper) between the barrier islands bordering Elson Lagoon. A tethered satellite-tracked drifting buoy was deployed in Sanigaruak Pass to determine inflow and outflow responses to wind forcing, but did not provide current velocities. The potential for instrument damage or loss due to bottom scouring by sea ice at these shallow locations necessitated the recovery of these short-term shallow moorings at the conclusion of fieldwork in mid-to-late September of each year. Due to the availability of instrumentation, only two to four moorings were deployed at any time during the years 2006-2011. The locations of these moorings, their sampling intervals, and periods of deployment are summarized in Table IIIA-1.

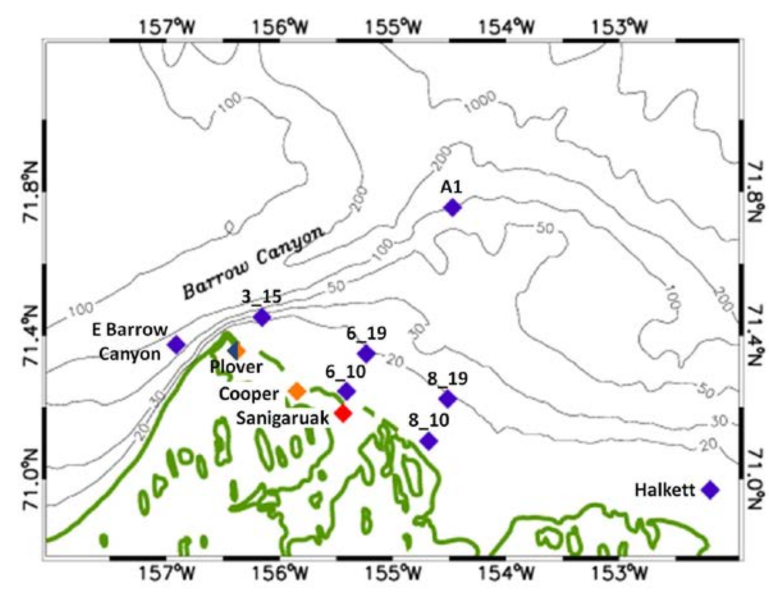

Figure IIIA-1. *Current meter mooring deployment locations and instrument types for years 2006-2011: Blue diamonds-ADCP, Orange diamonds-RCM11, Red diamond-tethered drifter.*

Prior to computing the summary statistics for the currents at each mooring location, tides (M2,N2,S2,K1,O1,P1 constituents) were removed from the RCM11-measured single-depth u (west-east) and v (south-north) currents and from the ADCP-measured u and v currents in each depth bin. The resulting non-tidal ADCP u and v current velocities were vertically averaged and, along with the RCM11 u and v currents, interpolated to hourly intervals. For mooring locations with u and v current time series from multiple years, the respective time series were concatenated to create single time series of u and v currents and then smoothed with a 13-hour boxcar filter.

Hourly interval time series of relative acoustic backscatter derived from the return echo intensity (Deines 1999) recorded by the ADCP at the 03_15m and 06_19m mooring locations were used to identify occurrences of the characteristic signature of zooplankton diel vertical migration (DVM) from which the presence of krill on the western Beaufort shelf was inferred.

Table IIIA-1. *Current meter moorings deployed in the BOWFEST study area during years 2006 - 2011. BOWFEST moorings are in boldface type.*

	Mooring Name	Location	Instrumentation	Data Acquisition UTC	Sample interval	Bottom depth
2006	Plover	71° 21.239' N 156° 21.151' W	RCM11	2100,19 Aug 2006 – 2200, 11 Sep 2006	60 min	6.4 m
	Cooper	71° 13.315' N 155° 48.705' W	RCM11	0400, 18 Aug 2006 – 2200, 15 Sep 2006	60 min	2.6 m
2007	Plover	71° 21.243' N 156° 21.227' W	1228 kHz ADCP	2345,09 Aug 2007 – 0045, 08 Dec 2007	15 min	6.5 m
	Cooper	71° 13.239' N 155° 49.759' W	RCM11	2300, 09 Aug 2007 – 2200, 06 Dec 2007	20 min	2.8 m
	Halkett	70° 58.875' N 152° 15.039' W	307 kHz ADCP	2030, 16 Aug 2007 – 1415, 11 Sep 2007	15 min	15.0 m
2008	**Line 3_15m**	71° 27.132' N 156° 07.961' W	307 kHz ADCP	0230, 23 Aug 2008 – 0200, 09 Sep 2008	15 min	15.1 m
	Line 8_10m	71° 06.827' N 154° 41.324' W	1228 kHz ADCP	0245, 20 Aug 2008 – 0015, 11 Sep 2008	15 min	9.6 m
	Line 8_19m	71° 13.752' N 154° 31.548' W	307 kHz ADCP	0145, 20 Aug 2008 – 2300, 10 Sep 2008	15 min	18.8 m
	A1	71° 45.023' N 154° 28.960' W	307 kHz ADCP	0600, 09 Aug 2008 – 0400, 13 Dec 2008	30 min	98 m
2009	**Line 3_15m**	71° 27.158' N 156° 07.816' W	307 kHz ADCP	2300, 22 Aug 2009 – 0145, 15 Sep 2009	15 min	15.6 m
	Line 6_10m	71° 13.626' N 155° 24.315' W	307 kHz ADCP	2145, 21 Aug 2009 – 1945, 15 Sep 2009	15 min	9.0 m
	Line 6_19m	71° 21.096' N 155° 13.777' W	307 kHz ADCP	2300, 21 Aug 2009 – 2100, 15 Sep 2009	15 min	18.7 m
	A1	71° 45.033' N 154° 28.955' W	307 kHz ADCP	0330, 30 Jul 2009 – 1130, 17 Aug 2010	30 min	101 m
2010	**Line 3_15m**	71° 27.219' N 156° 07.751' W	307 kHz ADCP	2000, 19 Aug 2010 – 1900, 13 Sep 2010	20 min	15.7 m
	Line 6_19m	71° 21.084' N 155° 13.743' W	307 kHz ADCP	1840, 19 Aug 2010 – 2300, 16 Sep 2010	20 min	18.7 m
	E Barrow Canyon	71° 22.623' N 156° 52.551' W	307 kHz ADCP	2320, 19 Aug 2010 – 0620, 20 Mar 2011	20 min	68 m
2011	**Line 3_15m**	71° 27.213' N 156° 07.780' W	307 kHz ADCP	0120, 19 Aug 2011 – 0020, 14 Sep 2011	20 min	14.7 m
	Line 6_19m	71° 21.069' N 155° 13.752' W	307 kHz ADCP	0000, 19 Aug 2011 – 2300, 29Sep 2011	20 min	18.5 m
	E Barrow Canyon	71° 22.590' N 156° 52.799' W	307 kHz ADCP	2000, 19 Aug 2011 – 0000, 03 Sep 2012	20 min	71 m
	Sanigaruak	71° 11.212' N 155° 25.583' W	Tethered drifter	2300, 18 Aug 2011- 0100, 07 Oct 2011	10 min	3.3 m

Measurements of wind speed and direction at Barrow for August and September 2006-2011 were obtained from the Atmospheric Radiation Measurement website (www.archive.arm.gov). Hourly interval time series were generated for use as working data sets.

Results

A composite of the mean, non-tidal circulation in the BOWFEST study area shows generally weak flow on the western Beaufort shelf directed along isobaths toward the west-northwest where it appears to undergo retroflection upon encountering the more energetic northeastward-flowing Alaska Coastal Current (Fig. IIIA-2; Table IIIA-2). Inflow to Elson Lagoon occurs through its eastern passes and outflow occurs at its western end. Although the depicted mean circulation is derived from non-concurrent mooring deployments spanning six years, the coherence of shelf currents and the coherence of currents in Barrow Canyon suggest that the composite circulation is reasonable, at least qualitatively.

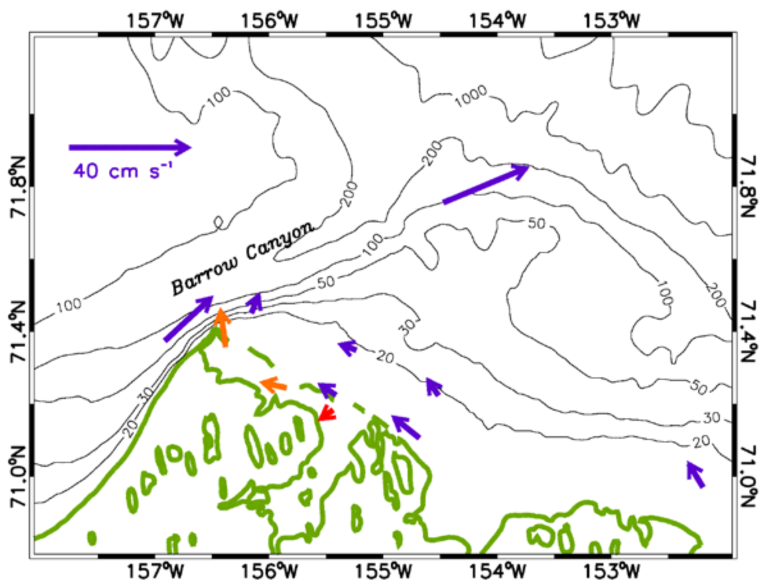

Figure IIIA-2. *2006-2011 composite of mean non-tidal currents in the BOWFEST study area.*

Aside from 2007, the deployment periods for the shallow moorings fall between 9 August and 29 September and, as such, identify a convenient period to characterize an open-water season and associated wind-driven circulation variability. A histogram summarizing the 2006-2011 late summer, open-water winds at Barrow shows that the prevailing winds were from the eastern quadrant (Fig. IIIA-3). Statistically, 77% of the wind stress variance was associated with winds blowing from the east (principal axis 087°T).

Comparisons of the principal currents in the BOWFEST study area and wind stresses at Barrow show them to be well-correlated (Table IIIA-3). The analyses indicate that currents on the southern flank of Barrow Canyon respond to changes in wind stress after roughly a half day to a day. Currents on the shallow western Beaufort shelf and in the passages between the shelf and Elson Lagoon respond to changes in the wind within a few hours.

Table IIIA-2 *Ocean current summary statistics. The tethered drifter in Sanigaruak Pass only allowed current direction to be determined.*

Mooring	N Hourly Obs	Vector mean current direction (°T)	Vector mean current speed (cm s^{-1})	Principal axis of current variance (°T)
E Barrow Canyon	1972	048	20.7	043, 223
A1	2490	068	30.0	072, 252
03_15m	2178	023	6.2	100, 280
06_10m	598	303	6.2	116, 296
06_19m	2298	289	5.5	111, 291
08_10m	526	308	10.7	128, 308
08_19m	525	325	6.0	132, 312
Halkett	613	328	8.9	152, 332
Plover	1776	352	11.8	0, 180
Cooper	1913	282	8.1	128, 308
Sanigaruak	1009	235	-	086, 266

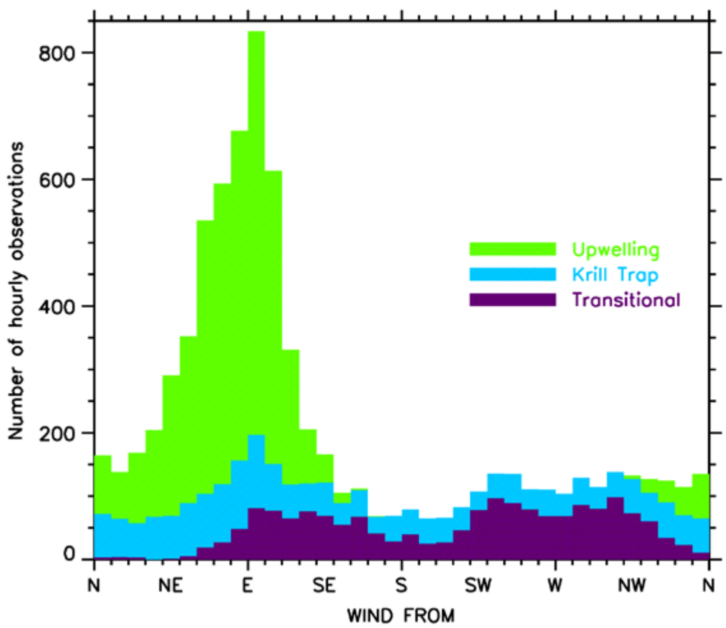

Figure IIIA-3 *Histogram of 2006-2011 late summer (09 Aug – 29 Sep) winds at Barrow.*

A least squares procedure was used to identify the best-fit linear response of ocean currents to changes in wind stress at each mooring location. These linear models were then used to determine the threshold wind velocities at which the currents reversed directions along their principal axes of variance. The relevance of wind-driven current reversals to feeding opportunities for bowhead whales near Barrow is associated with the two-stage 'krill trap' mechanism. Moderate-to-strong upwelling-favorable winds from the east put krill on the western Beaufort shelf. In order for the krill to be retained on the shallow shelf, upwelling winds must relax and westward-flowing shelf currents at the edge of Barrow Canyon reverse to flow eastward.

Table IIIA-3 *Lagged correlations between wind stresses at Barrow and currents at mooring locations and threshold wind velocities at which principal axis currents change direction. Results are significant at the 95% confidence level except the 08_19m site where the confidence level was 90%. Degrees of freedom were estimated as the quotient of the record length of the current velocity time series and the integral time scale. The integral scale time was identified as the time between the max or min and the first zero crossing of lagged wind-current correlations. There were no measured currents in Sanigaruak Pass, only occurrences of inflow and outflow.*

Mooring	**Wind-Current correlation, R^2 (lag hrs)**	**Wind stress from (°T)**	**Projected wind velocity required to reverse current direction along principal axis of variance**
E Barrow Canyon	0.54 (10)	015	4.6 m s^{-1} from 015°T
A1	0.42 (26)	034	7.0 m s^{-1} from 034°T
03_15m	0.41 (4)	037	3.3 m s^{-1} from 037°T
06_10m	0.77 (2)	089	2.2 m s^{-1} from 269°T
06_19m	0.50 (1)	050	2.8 m s^{-1} from 230°T
08_10m	0.83 (4)	095	2.2 m s^{-1} from 275°T
08_19m	0.62 (4)	096	3.1 m s^{-1} from 276°T
Halkett	0.83 (5)	048	-2.3 m s^{-1} from 228°T
Plover	0.87 (0)	100	0.7 m s^{-1} from 280°T
Cooper	0.56 (-3)	109	1.7 m s^{-1} from 289°T

Mooring 03_15m is located on the shelf at the edge of Barrow Canyon (cf. Fig. IIIA-1). As indicated in Table IIIA-3, when projected wind velocities from the northeast relax to less than about 3.3 m s^{-1}, currents at the 03_15m mooring location turn to the east and, according to the krill trap model, krill will tend to be retained on the shelf. This threshold wind velocity partitions the two generalized wind-current regimes that contribute to the Barrow area feeding hotspot: 1) currents responding to winds from the north and east quadrants with a projected velocity component from the northeast greater than 3.3 m s^{-1} and 2) currents responding to winds from any direction weaker than 3.3 m s^{-1}. Conditions not associated with either of these two regimes are characterized as transitional or undefined.

The left panel of Figure IIIA-4 shows the Regime 1 mean circulation associated with generally upwelling-favorable winds from the east. The winds driving this circulation pattern represent 52% of the wind record summarized in Figure IIIA-3 and have an average wind speed of 6.7 m s^{-1}. The wind-driven shelf currents flow toward the northwest, whereupon reaching the edge of Barrow Canyon, the red-circled current velocity vector indicates that shelf flow continues into the Canyon. Current vectors in the passages to Elson Lagoon indicate inflow to the lagoon occurs through Sanigaruak and Cooper Island passages and outflow through Plover Pass. Anecdotal observations of krill wash-ups at the western end of Elson Lagoon during strong upwelling wind events are consistent with the depicted lagoon circulation.

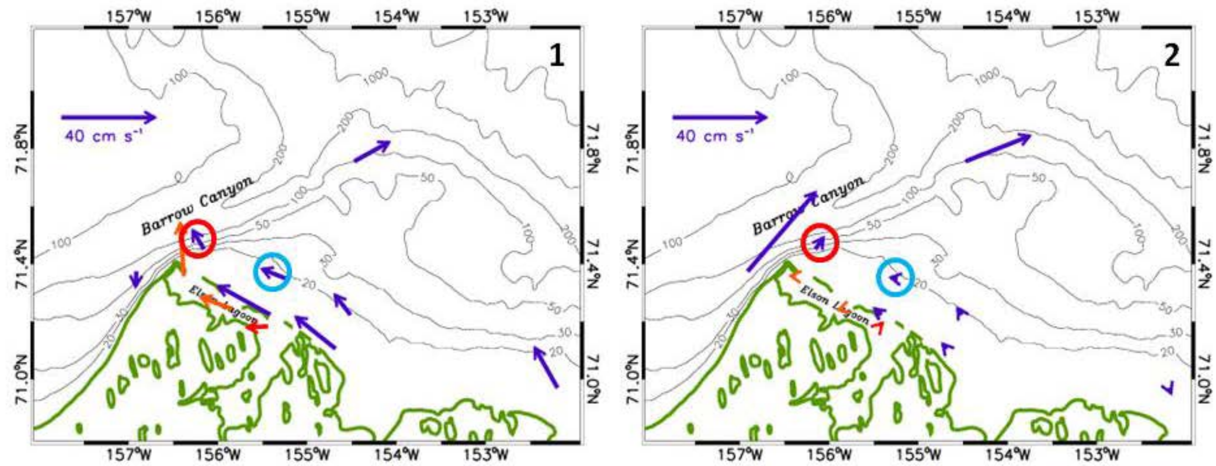

Figure IIIA-4 *Mean currents associated with (left panel) wind-current regime 1 and (right panel) wind-current regime 2. Red and blue circles highlight the mean currents at the 03_15m and 06_19m mooring locations, respectively.*

The right panel of Figure IIIA-4 shows the Regime 2 mean circulation associated with weak winds and an active krill trap. The winds associated with this regime represent 25% of the wind record and have an average wind speed of 2.2 m s^{-1}. Currents on the shelf are seen to be weak, whereas the large current vectors on the southern flank of Barrow Canyon indicate a well-developed, northeastward-flowing Alaska Coastal Current (ACC). The ACC acts as a barrier to off-shelf flow at the edge of the canyon thereby helping to retain krill on the Beaufort shelf.

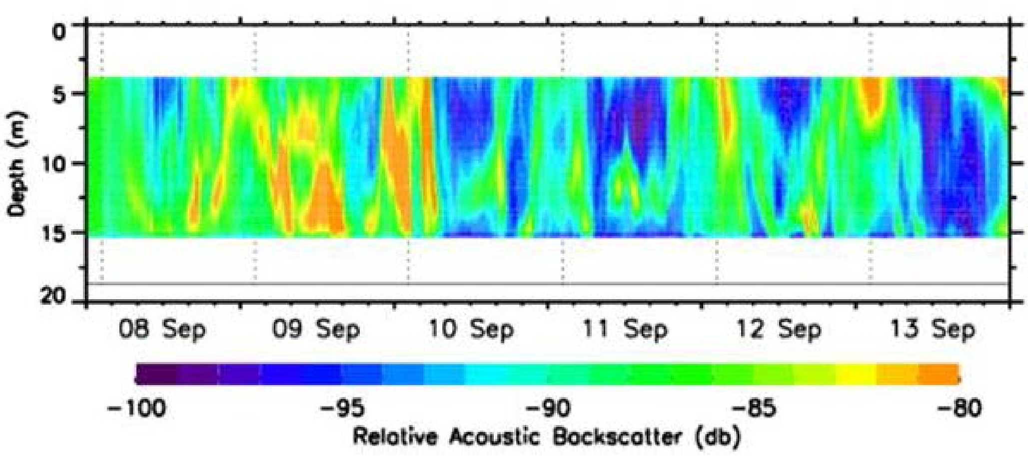

Figure IIIA-5. *Time series of ADCP-measured relative acoustic backscatter at mooring location 06_19m during September 2010. Occurrences of diel vertical migration are inferred to be associated with elevated backscatter centered on celestial midnight (Dotted vertical lines at ~ 0220 ADT).*

The presence of krill on the shelf is inferred from diel vertical migration (DVM) signatures in the acoustic backscatter measurements acquired by ADCPs. DVM appears in the backscatter data as a quasi-sinusoidal trace elevated backscatter in the water column and reflects the motion of krill moving upward in the water column to feed at night and then moving downward after midnight to avoid predation as skies brighten. The characteristic DVM profile shows elevated acoustic backscatter within the water column centered on celestial midnight which, in the Barrow area, occurs at about 0220 Alaska Daylight Time. A representative time series of relative acoustic backscatter depicting occurrences of DVM at the 06_19m mooring location is shown in Figure IIIA-5.

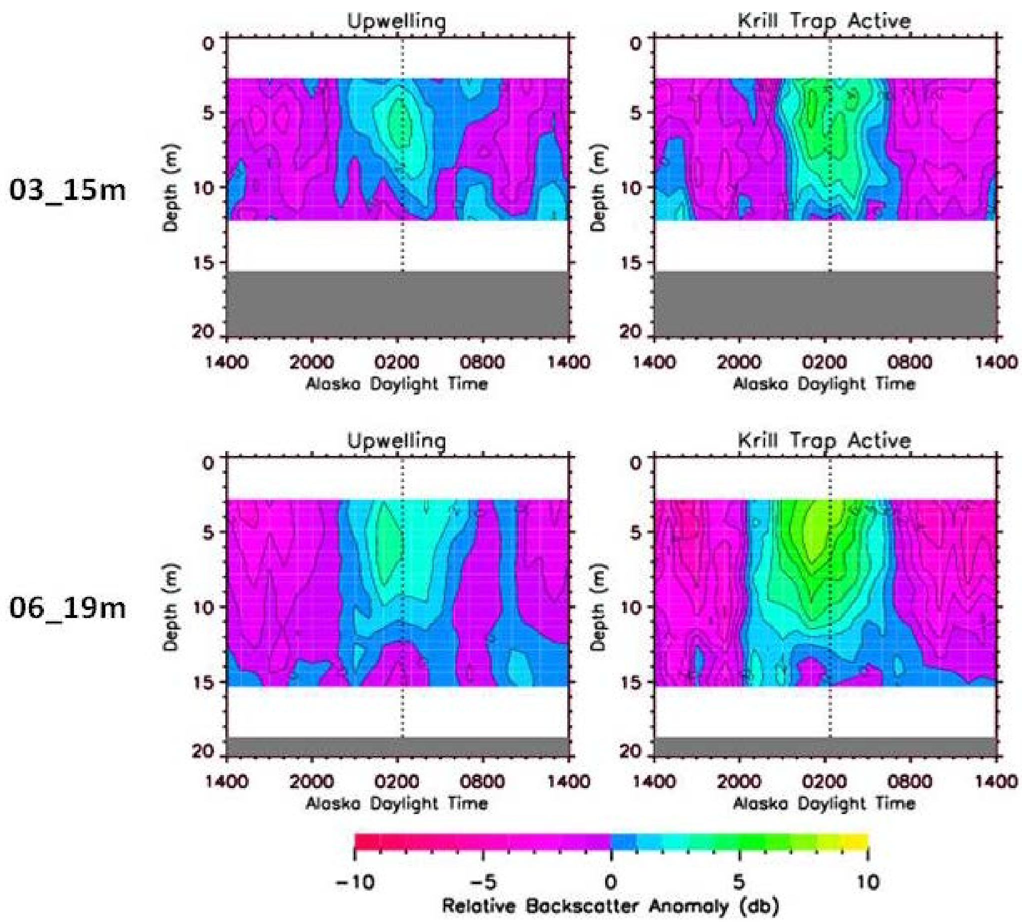

Figure IIIA-6. *Averaged acoustic backscatter anomalies at mooring locations 03_15m and 06_19m associated with (left panels) upwelling-favorable Regime 1 winds and (right panels) weak Regime 2 winds conducive to an active krill trap. The dotted vertical line corresponds to celestial midnight.*

As mentioned above, the krill trap conceptual model predicts that feeding opportunities for bowhead whales tend to be limited during moderate-to-strong upwelling-favorable winds from the east and enhanced when winds are weak. Average daily acoustic backscatter anomalies derived from measurements acquired at the edge of Barrow Canyon (03_15m mooring location) during late summer 2008-2011 and at the 06_19m mooring location during late summer 2009-2011 were computed for upwelling (Regime1) winds and for weak (Regime 2) winds associated with an active krill trap. A comparison of the plots of average acoustic backscatter anomalies at these shelf locations clearly show that the relative backscatter anomalies concurrent with DVM signals and inferred krill numbers are much greater during the weak-wind, active krill trap conditions than during upwelling-favorable winds (Fig. IIIA-6).

Discussion

Current velocity and relative acoustic backscatter measurements, along with wind velocity data from Barrow, were used to identify generalized wind-driven circulation patterns, and infer relative krill abundances associated with upwelling and active krill trap conditions.

There are some important limitations to the interpretation of the results presented above. The circulation patterns represent six-year (2006-2011) composites of non-contemporaneous wind-driven currents at different mooring locations. Despite measurements being acquired in different years, there is a general consistency among the statistics characterizing shelf currents and those characterizing the currents in Barrow Canyon. Although many zooplankton species exhibit DVM behavior, in the present context, it is assumed to indicate the presence of krill. Because ADCPs are not typically calibrated against a common target, the acoustic backscatter measurement derived from the echo intensity recorded by an ADCP at one location and time cannot be directly compared to the acoustic backscatter measurement derived from the echo intensity recorded by an ADCP at another location and time. Accordingly, inferred krill abundances associated with upwelling or active trap conditions are relative for a particular mooring location. Nonetheless, the results strongly suggest that krill are more likely to be present on the western Beaufort shelf during weak-wind active krill trap conditions than during upwelling wind conditions.

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SECTION III - MOORINGS AND BROAD-SCALE OCEANOGRAPHY
B - BROAD-SCALE OCEANOGRAPHY

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Abstract

The shelf near Barrow, Alaska, is a feeding hotspot for bowhead whales during the whales' fall migration from the Canadian Arctic to the Bering Sea. The oceanographic conditions producing this hotspot and interannual variability in biological and physical ocean conditions near Barrow were described from 2007-2011. Interannual variability in physical and biological conditions was observed over the five years. Multiple water masses were observed each year and the overall physical conditions were determined by larger scale meteorological patterns and the presence of sea ice. Zooplankton community composition varied between years and hydrographic/geographic regions. Two patterns were particularly striking, with 2007 being characterized by high proportions of the small copepod *Pseudocalanus* spp. on the shelf and 2011 being marked by high proportions of benthic and echinoderm larvae at all locations across the study area. Short-term variability in conditions on the shelf, including euphausiid abundance and distribution, was intimately tied to the direction and strength of the local winds. Elevated concentrations of euphausiids were found on the shelf in response to shelfbreak upwelling of water and euphausiids forced by east winds that were followed by south or weak winds that confined the Alaska Coastal Current against the eastern flank of Barrow Canyon, trapping and concentrating the upwelled water and euphausiids on the shelf. The relative proportion of upwelling to krill trap days varied interannually, with the lowest proportion in 2009 (0.7) and highest proportions in 2007 and 2011 (1.7, 1.5 respectively). The distributions and persistence of euphausiids on the shelf reflected these proportions, with euphausiids abundant and distributed broadly on the shelf in 2009 but much less so in 2007 and 2011 when abundances on the shelf were quite low. The abundance and relative proportions of larger adult and juvenile vs. smaller furcilia euphausiids also varied interannually, with euphausiid abundances in 2009 being dominated by large juvenile/adults, 2010 and 2011 being dominated by small furcilia, and 2007 and 2009 having more equivalent proportions of the two size categories. These differences likely were related to larger scale patterns in euphausiid population structure, abundance, and transport from the Bering Sea. The distributions of bowhead whales from boat-based oceanographic work reflected these differences in their prey availability, with bowhead whales in 2011 being found primarily in Barrow Canyon rather than on the shelf and in 2009 being widespread on the shelf, coincident with the distribution of their prey. Of the five years of the study, 2009 provided the most favorable feeding conditions for the whales, with large, high-biomass euphausiids being delivered across the shelf. Other years, although providing concentrations of euphausiids, might be considered less

favorable simply because the euphausiids were dominated by smaller life stages that provided lower biomass.

Introduction

The continental shelf near Barrow, Alaska, is an important feeding area for bowhead whales (*Balaena mysticetus*) during their spring and fall migrations between their overwintering grounds in the Bering Sea and their summering grounds in the Canadian Arctic (Moore and Clarke 1992, Moore and Reeves 1993, Moore et al. 2000). Iñupiat hunters harvest bowhead whales at Barrow as subsistence food during both the spring and fall migrations (Stoker and Krupnik 1993) and have done so for centuries (Stanford 1976, Hall et al. 1990, Krupnik and Bogoslovskaya 1999).

Bowhead whales feed on zooplankton, especially copepods and euphausiids or krill (Carroll et al. 1987, Lowry 1993, Lowry and Sheffield 2002, Lowry et al. 2004). In the Western Arctic, copepods are found in waters of both Arctic and Pacific origin while euphausiids appear to be endemic to the Pacific and are found in water that enters the Western Arctic through Bering Strait. To feed efficiently, baleen whales such as the bowhead whale must feed where aggregations of their zooplankton prey are found (e.g., Mayo and Marx 1990, Kenny 2001). The recurrence of feeding bowhead whales on the western Beaufort Shelf and near Barrow suggests that this region is a favorable feeding environment for the whales however the mechanisms that produce this environment were largely unknown. Although sightings of bowhead whales during summer on the Beaufort Shelf near and to the east of Barrow are relatively rare, bowhead whales were observed in early September during both 2005 and 2006 (Ashjian et al. 2010, Moore et al. 2010) and have been seen in mid-late August and early September during the BOWFEST years with some variability (see Rugh et al. Section I, and George et al. Section VA: this volume).

Prior to our series of oceanographic projects, including the BOWFEST project, ocean observations of the shelf near Barrow were relatively few. The oceanographic conditions there are complex and are characterized by the juxtaposition of two oceanographic regions (Chukchi and Beaufort seas) and several water masses (e.g., Weingartner et al. 1998, 2005, Okkonen et al. 2009, Ashjian et al. 2010). A submarine canyon (Barrow Canyon) just offshore markedly impacts local conditions. Relatively warm, fresh Pacific Water (PW) from the Bering Sea flows northward through the Chukchi Sea and exits the shelf through Barrow Canyon. The different water masses present on the shelf determine the composition of the zooplankton prey available to the bowhead whale.

Both observations and numerical models have demonstrated that annual-mean transports of this warm, fresh PW into the northern Chukchi Sea and along the Beaufort Shelf vary in response to changes in atmospheric conditions associated with the Arctic Oscillation and other long-period climatic signals (e.g., Proshutinsky and Johnson 1997, 2001, Thompson and Wallace 1998, Maslowski et al. 2000, 2001, Clement et al. 2005, Woodgate and Aagard 2005, Woodgate et al. 2005, 2012). Long-period variability in the northward transport of PW introduces variability to the fluxes of heat, salt, nutrients, and plankton to the Arctic that, in turn, impact the Arctic ecosystem. Recent decreases in sea ice extent in the Western Arctic (e.g., Serreze et al. 2003, Stroeve et al. 2005, Comiso et al. 2008,; Perovich et al. 2011, NAS report, NSIDC) suggest that this coastal region is highly vulnerable to climate change. A better understanding of the ocean ecosystem is necessary in order to predict and understand these potential impacts.

Physical and biological oceanographic conditions on the shelf near Barrow, at the Beaufort Shelf break, and across Barrow Canyon were investigated in 2005 and 2006 as part of a NSF-funded study investigating environmental variability, oceanography, bowhead whale distribution, and the success and resilience of Iñupiat subsistence whaling (Ashjian, Campbell, Okkonen, Sherr, Sherr, George, Moore, Maslowski, Spitz, Braund, Kruse, Nicolson, PIs). A central hypothesis of the study was that bowhead whales congregate near Barrow to utilize the favorable feeding environment there that is vulnerable to ongoing climate change. The extent of interannual and shorter-term variability in the physical and biological conditions on the shelf was striking. Multiple water mass types were observed across the study region, with close coupling between water mass type and biological (e.g., plankton abundance and type) characteristics (Ashjian et al. 2010). During 2005, little to no sea ice was present in the region while in 2006 ice cover was far more extensive and varied markedly with wind speed and direction. Higher temperatures, and salinities, and lower chlorophyll were present during 2005 than during 2006. The water column was highly stratified in 2006 due to meltwater associated with the extensive sea ice cover. Shorter-term variability in hydrography was associated with changes in wind speed and direction (Okkonen et al. 2009). Such wind events had a profound effect on the plankton taxonomic composition on the shelf. A whale feeding hotspot occurs near Barrow when winds from the east upwell euphausiids (krill) onto the shelf and are followed by low winds or winds from the south that move the northward flowing Alaska Coastal Current (ACC) tightly against the shelf and trap the euphausiid there (Ashjian et al. 2010, Moore et al. 2010). This sequence of wind/current events has been termed the “krill trap” (Okkonen et al. 2009, Ashjian et al. 2010). Sub-tidal fluxes of water in/out of the Elson Lagoon system likewise were tightly coupled to and covary with wind speed and direction. High abundances of euphausiid in and just offshore of Elson Lagoon, and coincident feeding bowhead whales, during 2005 suggested that Elson Lagoon was functioning as a reservoir for the euphausiid.

It is evident that both longer (interannual) and shorter (days-weeks) term variability are important in establishing the presence of a favorable feeding environment for the bowhead whale near Barrow. Furthermore, larger-scale factors such as atmospheric conditions, sea ice, and transport through Bering Strait that are susceptible to modification through Arctic climate change contribute to the oceanographic variability near Barrow. This variability in oceanographic conditions, and the distribution of bowhead whale zooplankton prey, can have a significant impact on the availability of bowhead prey near Barrow. Due to the paucity of observations in this region, many aspects of the temporal variability remain unknown.

The broad-scale oceanography and bowhead prey distribution near Barrow in late summer were described for five years (2007-2011) as part of the Bowhead Whale Feeding Ecology Study (BOWFEST). Several complimentary projects that ran concurrently with the BOWFEST project and that supported aspects of the work deserve recognition and acknowledgement. In 2007, support was provided by the University of Alaska Fairbanks Coastal Marine Institute (to S. Okkonen and R. Campbell), with matching funds from the Woods Hole Oceanographic Institution Arctic Initiative (to C. Ashjian). In 2008-2009, funding was provided from the National Oceanographic

Partnership Program (to C. Ashjian, R. Campbell, S. Okkonen). In 2010-2011, support was provided by the National Science Foundation Arctic Observing Network (to C. Ashjian, R. Campbell, S. Okkonen). Because the projects are so intricately entwined, the work is presented here as an integrated whole.

The objectives of the BOWFEST portion of the work were to:

(1) Monitor shelf-slope exchange of biophysical properties between Barrow Canyon and the Beaufort shelf and between the Beaufort slope and Beaufort shelf. These observations are necessary to identify the source(s) of zooplankton prey available to whales on the shelf and to understand the mechanism(s) by which the prey find their way on to the shelf.

(2) Identify the characteristic temporal and spatial scales of the hydrographic and velocity fields in and near the study area to describe frontal features.

(3) Identify locations of whale prey (plankton) aggregations, their taxonomic and species composition, and their association with physical (hydrography, currents) characteristics to describe mechanisms of plankton aggregation.

Methods

Oceanographic sampling was conducted from the 43 ft *R/V Annika Marie* (Fig. IIIB-1). Sampling was conducted both along transects and in the vicinity of feeding bowhead whales. The primary sampling scheme was to work along transects extending from the nearshore across the shelf to off of the shelf break or across Barrow Canyon, with the transects oriented orthogonally to the coastline (Fig. IIIB-2). Sampling was conducted along a subset of transects from the 2005-2006 fieldwork (Ashjian et al. 2010) and were chosen on the basis of how well they represented conditions across the region and the shelf. Typically, a single transect was sampled during a single, very long (up to 22 hours) day. When possible, multiple samplings of selected lines were conducted during a field season to determine short-term (days) variability in ocean conditions. Sampling along transects extending along-shelf at specific isobaths also was conducted. For work near bowhead whales, when a whale or group of whales were observed feeding on the shelf, sampling was conducted around the location of the whale(s), but not directly adjacent to the whale, and across frontal structures at those locations to identify physical water column structure and associated whale prey concentrations. Finer-scale sampling to identify whale feeding behavior relative to the whale prey distribution was done by the fine-scale prey distribution and whale feeding behavior team (Baumgartner Section IV: this volume). In 2007, a single ring-net tow was conducted at the mouth of Elson Lagoon on each sampling day. During 2010 and 2011, a new line of stations across Barrow Canyon was added as part of the international Distributed Biological Observatory project (http://www.arctic.noaa.gov/dbo/).

Figure IIIB-1. *The 43 ft* *R/V Annika Marie* *in Elson Lagoon. The* *R/V Annika Marie* *is owned and operated by Bill Kopplin of Oceanic Research*

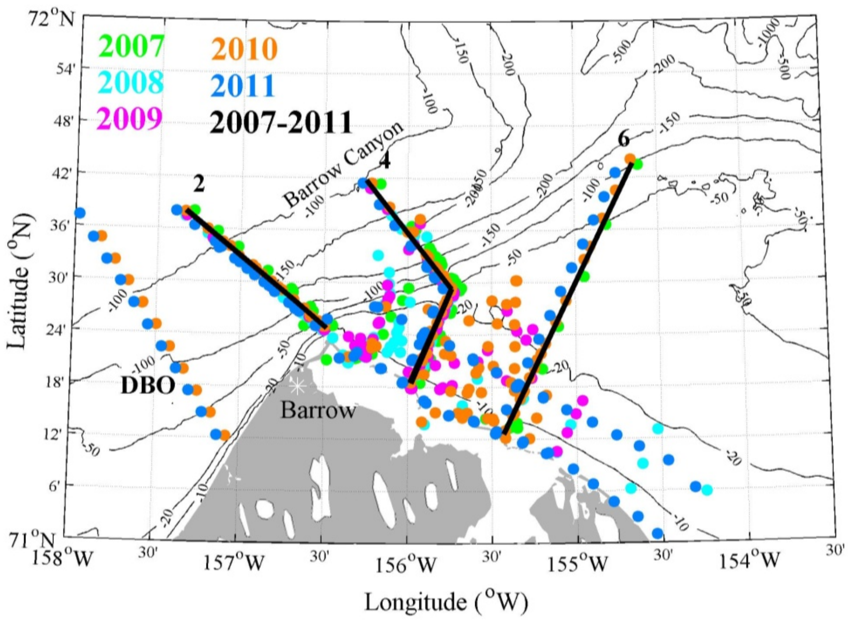

Figure IIIB-2. *Locations of all samples (symbols) and the three transect lines across which underway surveying was conducted (black lines). Transect designations (2, 4, 6, DBO) also are shown. Bottom topography from IBCAO v. 3.0 (Jakobsson et al. 2012).*

On the outbound portion of most transects, underway sampling was conducted using an Acrobat towed profiling vehicle (Sea Sciences Inc.) equipped with a Seabird 49 conductivity-temperature-pressure (depth) (CTD) sensor and a Wetlabs Eco-Triplet consisting of chlorophyll and C-DOM (colored dissolved organic matter) fluorometers and an optical backscatter sensor (Table IIIB-1). The Acrobat profiled from near surface (1-m) to within a few meters of the bottom or to a maximum depth of ~ 50 m where the bottom was deeper than 50 m. The inter-profile distance was ~150 m over the shallow shelf and ~1 km seaward of the shelf break. The Acrobat suffered a catastrophic failure upon impact with the seafloor on August 22, 2011 and could not be revived so Acrobat data were not collected during that year. Underway sampling of water column velocity and acoustic backscatter was conducted using a towed 307 kHz broad-band Acoustic Doppler Current Profiler (ADCP; RD Instruments Inc.) mounted on a Biosonics sled. Processing of the ADCP data was conducted by F. Bahr (WHOI) in 2008 and 2010-2011. Relative backscatter was calculated according to the method of Deines (1999).

Following completion of each outbound transect, sections of temperature, salinity, density, chlorophyll and C-DOM fluorescence, and optical backscatter were plotted to identify different water mass types, fronts, and high chlorophyll fluorescence features. The plots were then used to target locations for discrete sampling of full water column temperature and salinity, extracted chlorophyll, and zooplankton (whale prey) abundances during the inbound transit of the transect. A Sea-Bird 19+ CTD equipped with a WetStar fluorometer and a Biospherical/Licor photosynthetically available radiation (PAR) sensor was deployed surface to bottom at most locations/stations. Niskin bottles were deployed at 0, 10, and 40 m depths either from the hydrowire just above the CTD or from a hand-held line to collect water for determination of chlorophyll concentration to calibrate the Acrobat WetLabs and the WetStar fluorometers.

In 2007-2011, plankton tows were conducted at selected stations using oblique surface-bottom tows with a 60-cm ring net equipped with 150, 200, or 500 µm mesh nets, flow meters, and a time-depth recorder. In all years except 2009, when only 500 µm mesh was used, samples were collected using 150 and 200 µm mesh. In 2009-2011, plankton tows also were conducted using a ¼ m^2 Tucker Trawl with three nets equipped with 500 µm (first or lower net) or 333 µm (second/middle and third/upper) mesh nets, a time depth recorder, and a flow meter mounted outside of the net. In order to sample the near bottom, the Tucker Trawl was mounted in a custom-made “sled” equipped with skis that permitted the net to touch, and occasionally sample along, the bottom (Fig. IIIB-3; net design after that of J. Napp). Typically, the first net sampled the full water column on the descent to the bottom while on the upcast the second and third nets sampled discrete water column depths (e.g., cold Winter Water (WW) at depth, warmer ACC above) that were identified on the basis of the hydrographic transects from the outbound leg. For very shallow tows on the shelf, oblique tows of the full water column were conducted with no discrete vertical depths sampled. The volume of water filtered for the Tucker Trawls was calculated based on the distance traveled from GPS locations noted at the start and end of each net tow period coupled to the net mouth area. Calculations were also made from applying the proportion of time for the tow that each net was open to the total volume of water sampled calculated from the flow meter that was mounted on the exterior of the net and the mouth area of the net, assuming that the net was at a constant 45° angle. Because the net was mounted at 45° in the sled, net angle changed very little during the tows. This was verified using a Star-Odi Pressure-Depth sensor that recorded the angle of the net. Zooplankton samples were preserved in 5% buffered formalin-seawater immediately following collection. Enumeration of selected samples to species and life stage was conducted by the Atlantic Reference Center, Huntsman Marine Center, New Brunswick, Canada under the direction of Dr. Gerhard Pohl. For some samples, euphausiid sizes and abundances were determined using silhouette analysis (Davis and Wiebe 1985, Ashjian et al. 2004) at the Woods Hole Oceanographic Institution (WHOI).

Table IIIB-1. *Oceanographic parameters and depth ranges measured using the various instruments and sampling gear.*

Instrument/Equipment	Parameters Measured	Depth Range
Acrobat	Temperature, salinity, pressure (depth), chlorophyll *a* fluorescence, colored dissolved organic material, optical backscatter	Near-surface (1-m) to near bottom or to 50 m max. depth
Acoustic Doppler Current Profiler (ADCP)	Water column velocity and relative acoustic backscatter	Near surface to ~150 m max depth
Sea-Bird CTD, Fluorometer, PAR	Temperature, salinity, pressure, chlorophyll *a* fluorescence, photosynthetically available radiation	Surface to near-bottom
Niskin Bottles	Water collected for chlorophyll *a*	0, 10, and 40 m
Ring Net (60 cm diameter; 150, 200, 500 µm mesh)	Mesozooplankton abundance	Surface to near-bottom
Tucker Trawl (1/4 m^2, 355 and 500 µm mesh)	Mesozooplankton abundance, particularly krill	Surface to bottom, depth stratified

Figure IIIB-3. *Tucker Trawl mounted on sled.*

Water for chlorophyll *a* determination was filtered immediately after collection through 25 cm, GF/F glass fiber filters using a 60 cm syringe and filter holders, buffered with $MgCl_2$, and frozen at -20°C on board (adapted from Lambert and Oviatt, 1986). Filters were transferred to a -80°C freezer within 12-24 hours of collection, after return to the onshore laboratory. Based on experience from 2005 and 2006 (Ashjian et al. 2010), 100 ml of water was filtered for each sample and triplicate samples were filtered from each depth. Chlorophyll *a* analysis was conducted at the University of Rhode Island (URI) within a few weeks of return to that laboratory. The filters were extracted in glass tubes in 6 ml of 90% acetone at -20°C for 24 hours. Filters were removed from the tube and the chlorophyll *a* concentration was measured using a calibrated Turner Designs fluorometer following the acidification method (Parsons et al. 1984). A solid chlorophyll *a* standard was used to check fluorometer drift.

Sampling was highly weather dependent and could not be done in winds of ~20 knots or greater. As a result, the number of stations that could be occupied or lines that could be surveyed varied by year (Table IIIB-2). The stormiest year was 2007, with only 64 stations occupied and only 41% of the total available days suitable to work on the water. By contrast, the least stormy year was 2008, when sea ice lingered near Barrow and much less open water was present. The number of stations occupied in each year was directly proportional to the number of work days ($r^2 = 0.96$). The length of the boat charter, and the field season, was shorter in 2007 and 2008 than in 2009-2011.

Table IIIB-2. *Numbers of stations and work or weather days in each year. The number of available days reflects the length of the boat charter.*

Year	# Available Days	# Stations	# Work Days	# Weather Days	% Work
2007	22	64	9	13	41
2008	21	89	11	10	52
2009	26	103	13	13	50
2010	27	126	14	13	52
2011	29	127	15	14	52

Results

Sampling Locations

The regions sampled, and types of sampling (e.g., transects vs. surveys near feeding whales) varied by year according to the occurrences and locations of bowhead whales (Appendix IIIB-I). In 2007 and 2011, when few bowhead whales were present during the sampling season (2007) or on the Beaufort Shelf (2011) (see Rugh et al. Section I, and George et al. Section VA: this volume), oceanographic sampling occurred primarily along prescribed transect lines both across shelf and also along the shelf at fixed isobaths (Fig. IIIB-4). By contrast, in 2008-2010, bowheads were regularly observed on the Beaufort Shelf and oceanographic sampling was conducted in proximity with feeding bowheads on several occasions, as demonstrated by the concentrations of stations distributed somewhat haphazardly on the Beaufort Shelf in those years.

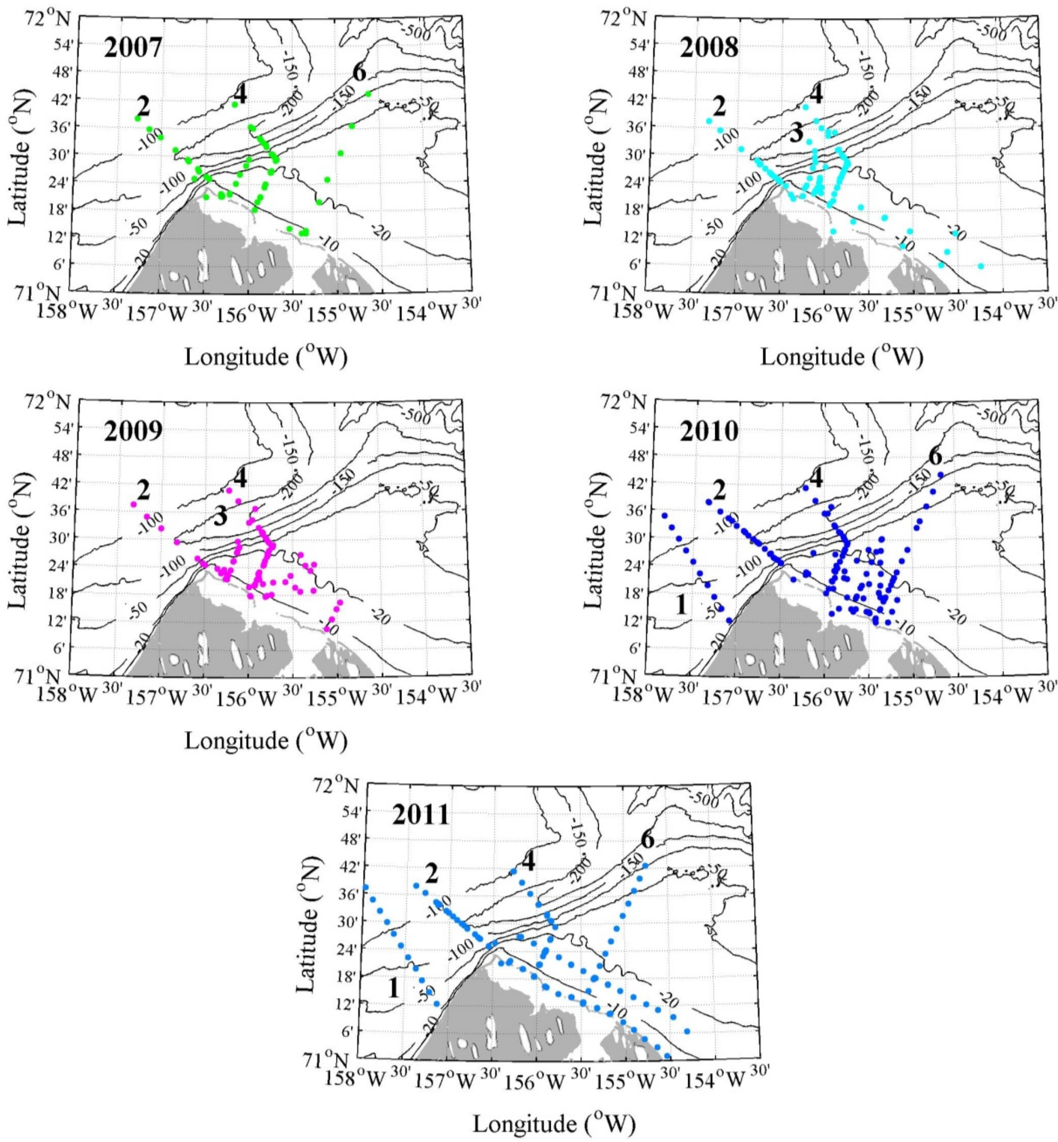

Figure IIIB-4. *Station locations for each of the five years of the BOWFEST program. Bottom topography from IBCAO v. 3.0 (Jakobsson et al. 2012). Transect line numbers were defined in 2005 and are described in Ashjian et al. (2010).*

<u>Physical Characteristics</u>

Atmosphere and ocean conditions varied markedly between the years. All five of the years showed very little sea ice during the period of the BOWFEST fieldwork (Fig. IIIB-5). However, in 2008 sea ice retreated from the Barrow area in mid-August, just prior to the field sampling, while in other years, sea ice retreat occurred in early August.

Representative sections from the upper 50 m of Line 4 (Fig. IIIB-6) that extends across the Beaufort Shelf to the NE of Barrow and then across Barrow Canyon characterize the hydrographic conditions for each year. Warmest upper ocean (0-10 m) temperatures, and highest salinities were seen in 2007, reaching almost 12°C near the surface in Barrow Canyon. Quite warm (~8°C) temperatures also were present in 2011. Lowest temperatures and freshest upper ocean salinities were observed in 2008, the year in which sea ice retreated from Barrow the latest of the five years. Distinct water mass types were seen (Figs. IIIB-6 and IIIB-7) with vertical stratification of their distributions. Water originating in the PW, or alternatively Alaska Coastal Water (ACW) and flowing through the Chukchi Sea out of Barrow Canyon as the ACC, of intermediate salinity and temperatures (> ~4°C), was observed in all years in the upper portion of the water column, on the Beaufort Shelf, and, in 2007, 2009, and 2011, extending to 50 m depth (Fig. IIIB-6), although the maximum temperature, as discussed above, was variable between years. Very fresh, colder melt water, resulting from the melting of sea ice, was seen in the upper water column during 2008. Cold, salty WW resulting from the formation of sea ice during the previous winter was present below the PW at all depths across all transects. The depth of the PW mass varied between years and between locations across the transect, extending to 25 m in 2008 across the entire transect but to 50 m on the eastern side of Barrow Canyon in 2010. The location of the ACC relative to the shelf break varies according to the strength and direction of the wind (Okkonen et al. 2009) and can change on the order of days (Fig. IIIB-8); this mobility of the ACC is a key component of the physical mechanism of the krill trap.

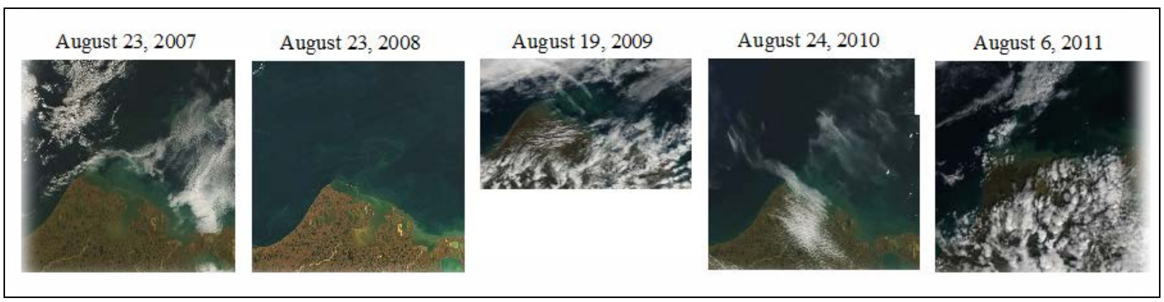

Figure IIIB-5. *MODIS satellite imagery showing region near Barrow, AK in August of each year. Because of cloud cover, images were not available for the same day or range of days for each year.*

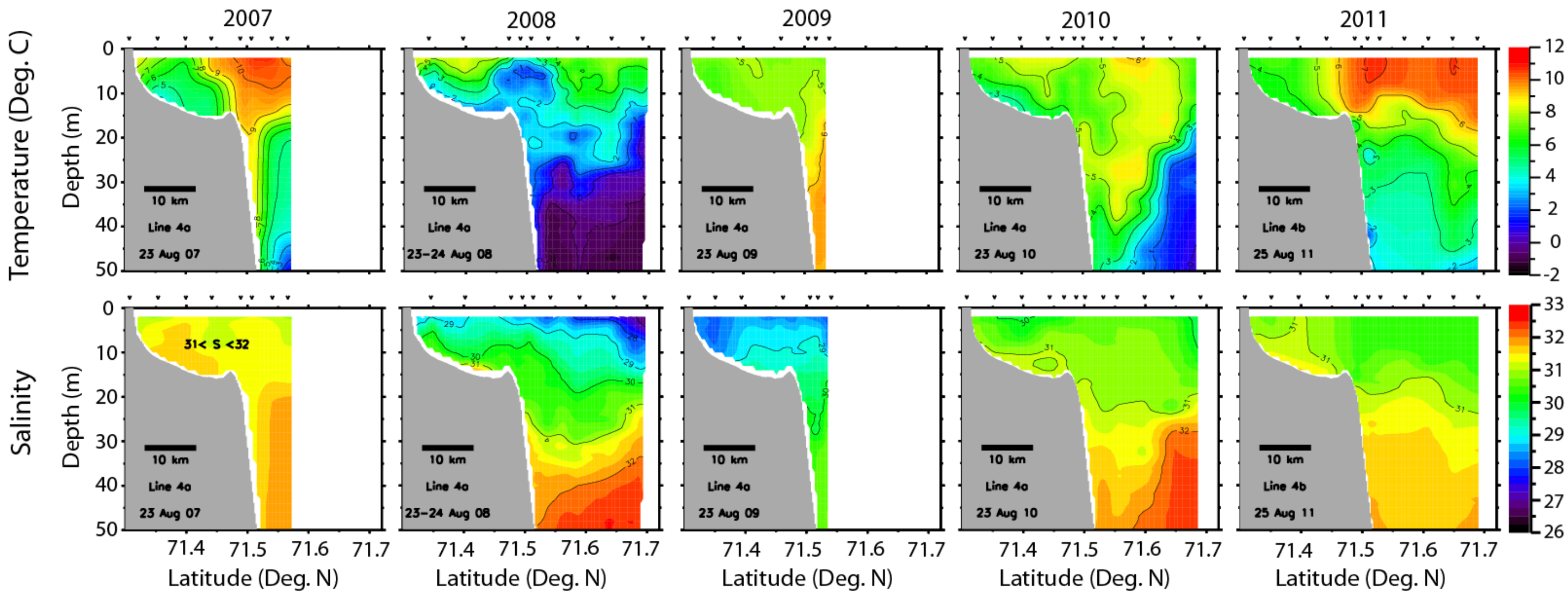

Figure IIIB-6. *Temperature and salinity sections in the upper 50 m from across transect line 4 for representative realizations in each of the five years.*

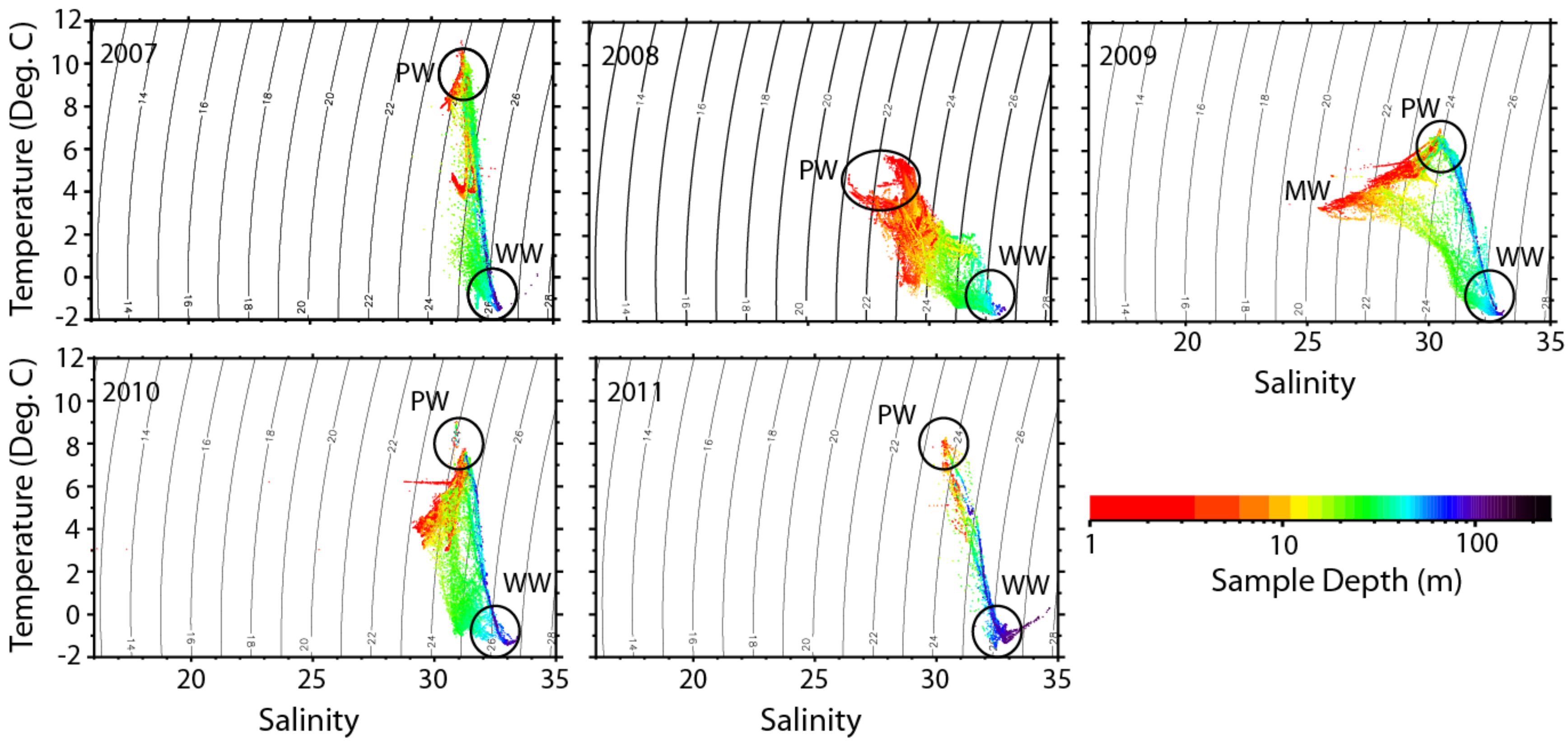

Figure IIIB-7. Temperature-salinity diagrams from across Lines 2 and 4 for each of the five years from data collected using both the Acrobat towed vehicle and the CTD. Lines of constant density are noted on the graphs. Dominant water types are indicated (PW=Pacific Water; WW=Winter Water, MW=Melt Water). Because the Acrobat was not functioning in 2011, fewer data points were available.

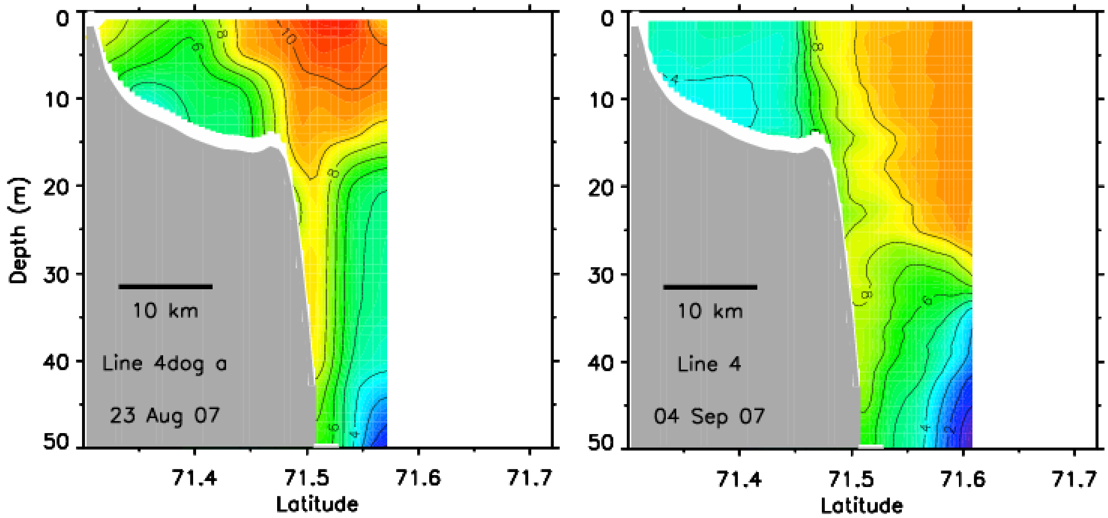

Figure IIIB-8. *Representative sections from across Line 4 described in 2007 during a period when warm PW was on the shelf (winds from the SW), left, and a period when the warm PW/ACC was away from the shelf break (winds from the east), right.*

Wind records collected at the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) site in Barrow and available at the DOE ARM web site, were used to determine days when upwelling was occurring and when the krill trap was operating (Fig. IIIB-9). The greatest numbers of upwelling days occurred in 2007 and 2011 (> 50% of the days) (Table IIIB-3). The krill trap was active the greatest proportion of days (45%) in 2009, and was active for ~10% fewer days in the other four years. The number of upwelling days greatly exceeded krill trap days by 50% or more in 2007 and 2011 (upwelling/krill trap active: 1.7 and 1.5, respectively), but were much lower than the number of krill trap days in 2009 (0.7). There was no correlation between the number of days that upwelling occurred and the number of days that the krill trap was active, since those two mechanisms are established by different wind conditions (although the krill trap can only be active when winds are weak or from the south and follow upwelling conditions).

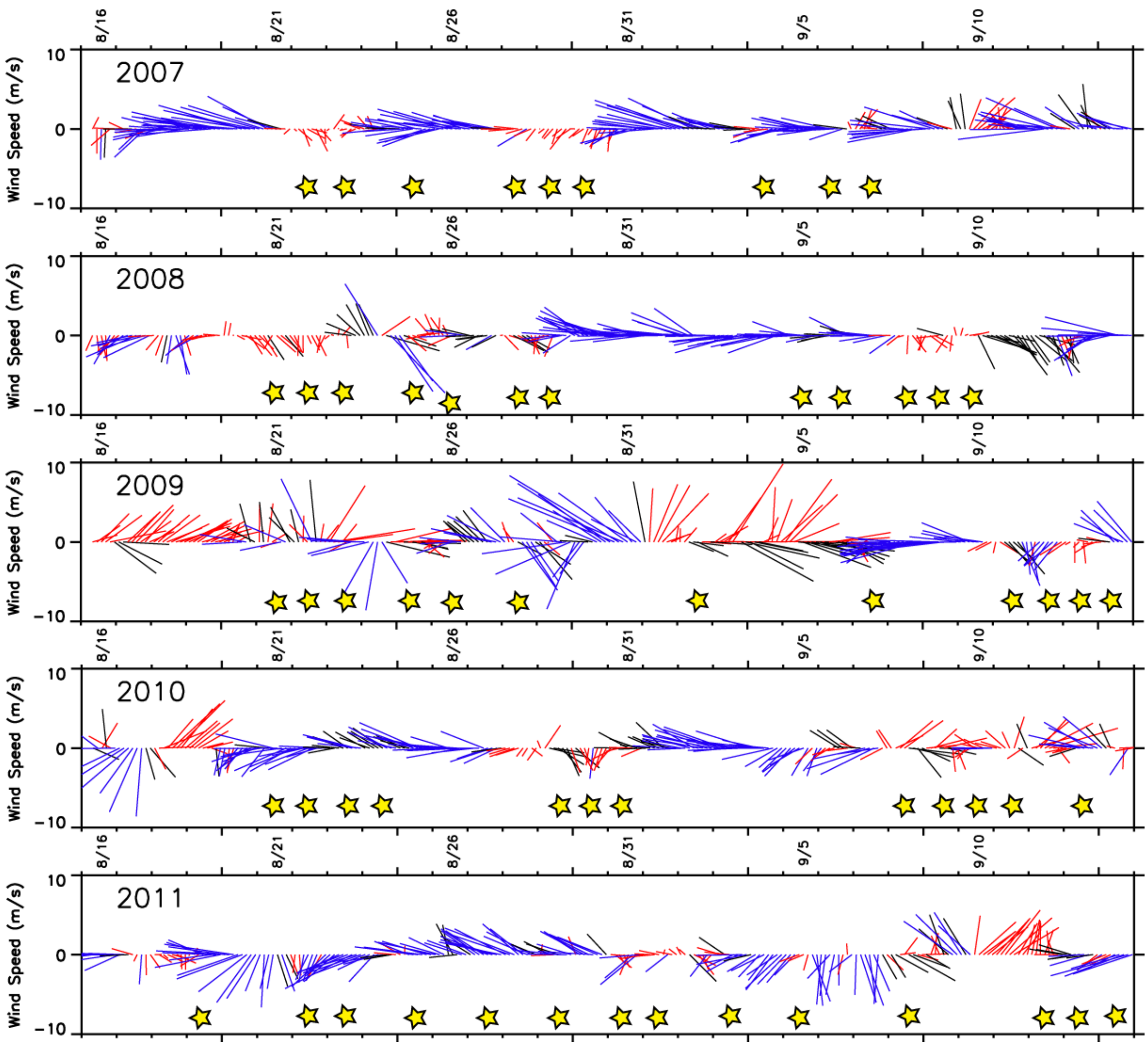

Figure IIIB-9. *Wind records from Barrow for mid-August to mid-September of each year. The direction of the vector indicates the direction to which the wind was blowing and the length indicates the magnitude. Color-coding indicates the status of the krill trap (Okkonen et al. 2009; Ashjian et al. 2010), with blue indicating upwelling favorable winds (projected components from E > 4.3 m/s and NE > 3.3 m/s), red indicating winds during which the krill trap could operate (winds from any direction of < 3.3 m/s or winds from the SW), and black indicating winds of other conditions. Yellow stars indicate dates on which the R/V Annika Marie was working.*

Table IIIB-3. *Activity of krill trap during mid-August to mid-September of each year. Data derived from wind vectors shown in Figure IIIB-9.*

Year	# Days Upwelling	# Days Trap Active	Upwelling/Trap Active	% of 30 days Upwelling	% of 30 days Trap Active	% of 30 days Other
2007	17	10	1.7	55.9	33.6	10.5
2008	13	11	1.2	42.9	36.6	20.6
2009	10	14	0.7	33.6	45.0	21.4
2010	13	11	1.2	43.3	35.3	21.4
2011	16	10	1.5	52.1	34.9	13.0

Chlorophyll

Chlorophyll concentrations were generally low across the study area, although some elevated concentrations were observed in Barrow Canyon. This was particularly true at the interface between the WW and overlying PW in 2008 where patches of high chlorophyll were seen (Figs. IIIB-10 and IIIB-11). Elevated chlorophyll at this interface also was observed in 2010. In 2010-2011, elevated chlorophyll was observed in the warm ACC/PW type water as well (Fig. IIIB-11; Note that this figure shows data collected across all transects while Figure IIIB-10 shows only a single occupation of Transect Line 4 from each year and does not reflect the full range of chlorophyll values sampled). At locations with particularly high chlorophyll, significant quantities were retained in the plankton net and were comprised primarily of diatoms.

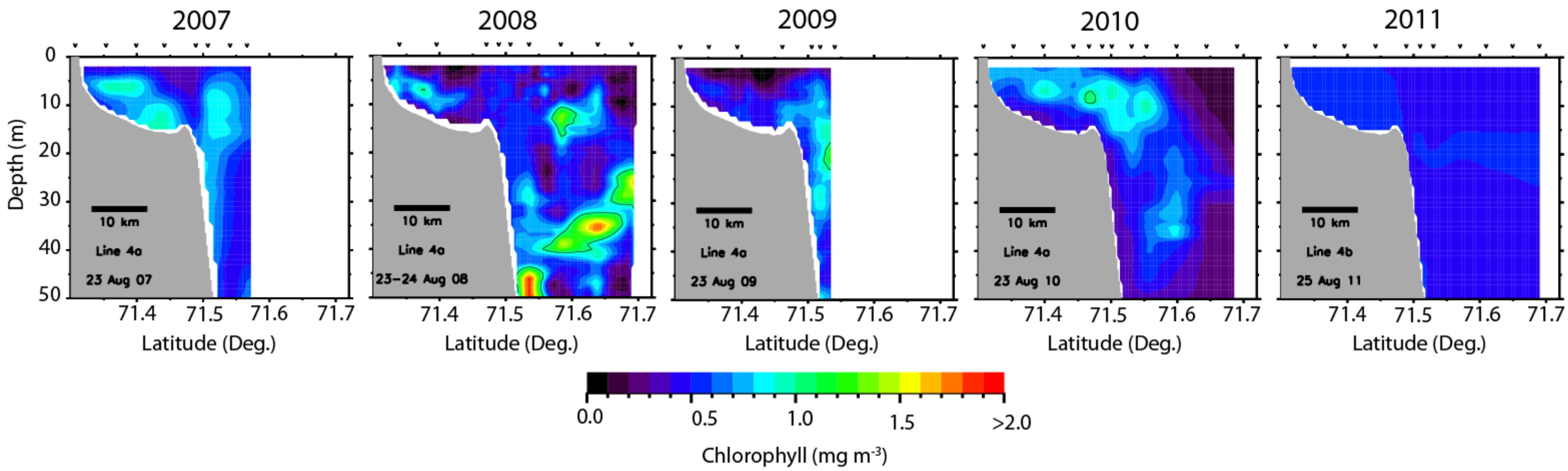

Figure IIIB-10. *Sections across Line 4 from August 23-25 of each year of chlorophyll a from the chlorophyll fluorometer that was part of the CTD package. Fluorometer data in volts were converted to equivalent chlorophyll using calibration from extracted chlorophyll values.*

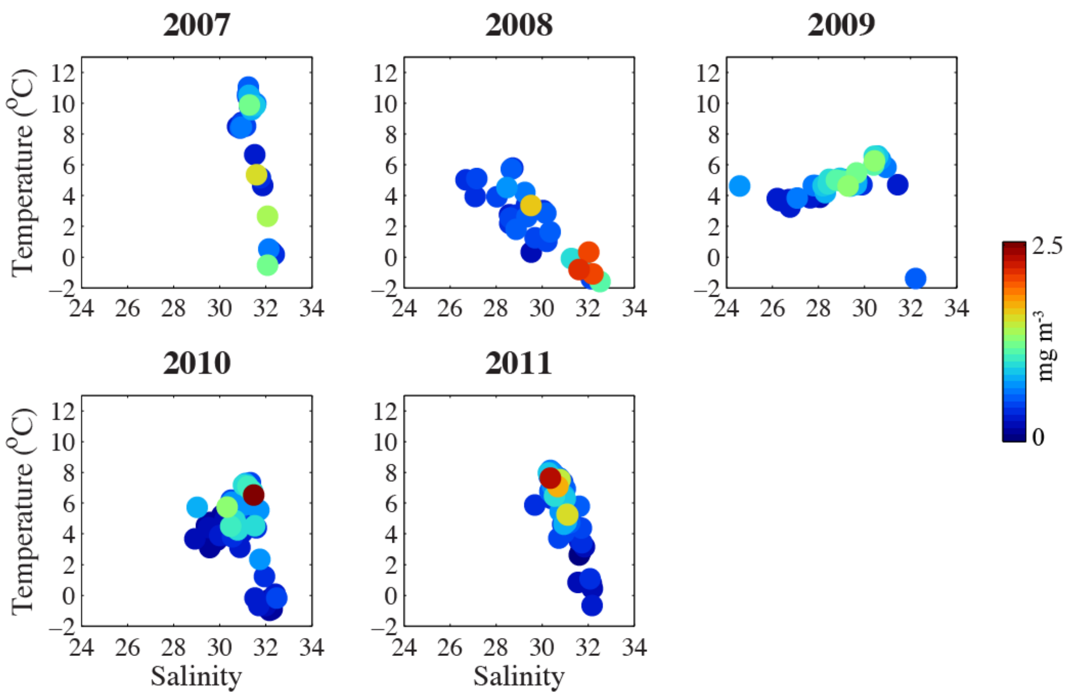

Figure IIIB-11. *Temperature-salinity-chlorophyll plots for each year. Chlorophyll a concentrations (mg m^{-3}) from water samples are plotted as a function of the water temperature and salinity at which each sample was collected. The T-S data demonstrate the same water mass types as described in Figure IIIB-8.*

<u>Zooplankton</u>

For many of the comparisons of zooplankton abundances and composition, it was useful to group stations from each year into hydrographically and geographically defined regions and to calculate average abundances for zooplankton types from all of the stations within those regions. Four regions were defined on the basis of both location and water column temperature and salinity characteristics from the CTD data collected at each station. Average water column temperatures and salinities were calculated for each station and plotted on a T-S diagram to show groupings of stations that had similar water mass characteristics. In this manner, stations on the shelf that were dominated by ACC/PW under conditions of winds from the southwest when this water intrudes onto the shelf would be grouped with stations that were geographically located off of the shelf break but that also were ACC/PW dominated. Presumably these stations would all exhibit similar zooplankton compositions and abundances because of the commonality of the water masses. Both hydrography and geography were considered in grouping the stations. Generally, the coastal region was defined as being of < 6 m bottom depth (Fig. IIIB-12). Shelf stations exhibited water temperatures of ~4-6°C and salinities of 30-31.2 (with the exception of stations in 2008 that had melt water near the surface and thus were much fresher). Offshore stations had average water temperatures of < 4°C. ACC/PW stations had water temperatures of > 6 °C.

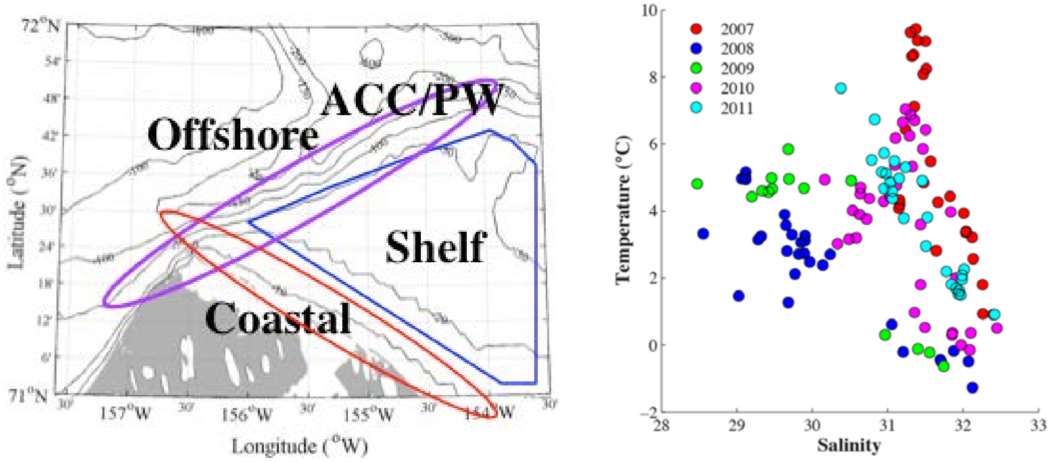

Figure IIIB-12. *Regions of the shelf for which zooplankton abundances were averaged (left). The location of the ACC/PW boundaries varies with the strength and direction of the wind and so differentiation between offshore, ACC/PW, and shelf stations was done on the basis of both average temperature and salinity characteristics (right) and geographic location for each station.*

Total (water column integrated) zooplankton abundance was highly variable (Fig. IIIB-13) and clear differences between regions within years and between years for each region did not emerge, based on analyses of variance. Only one interannual difference was observed; 2008 and 2011 had significantly different abundances in the offshore region (but other years were not different from those two; *ANOVA*, $p = 0.034$; Tukey-Kramer post-hoc test, $p < 0.05$). Similarly, a regional difference was observed only in 2008 when the offshore abundances were significantly greater than those on the shelf or in the shallow water along the Plover Islands ("Coastal"; *ANOVA*, $p = 0.043$; Tukey-Kramer post-hoc test, $p < 0.05$).

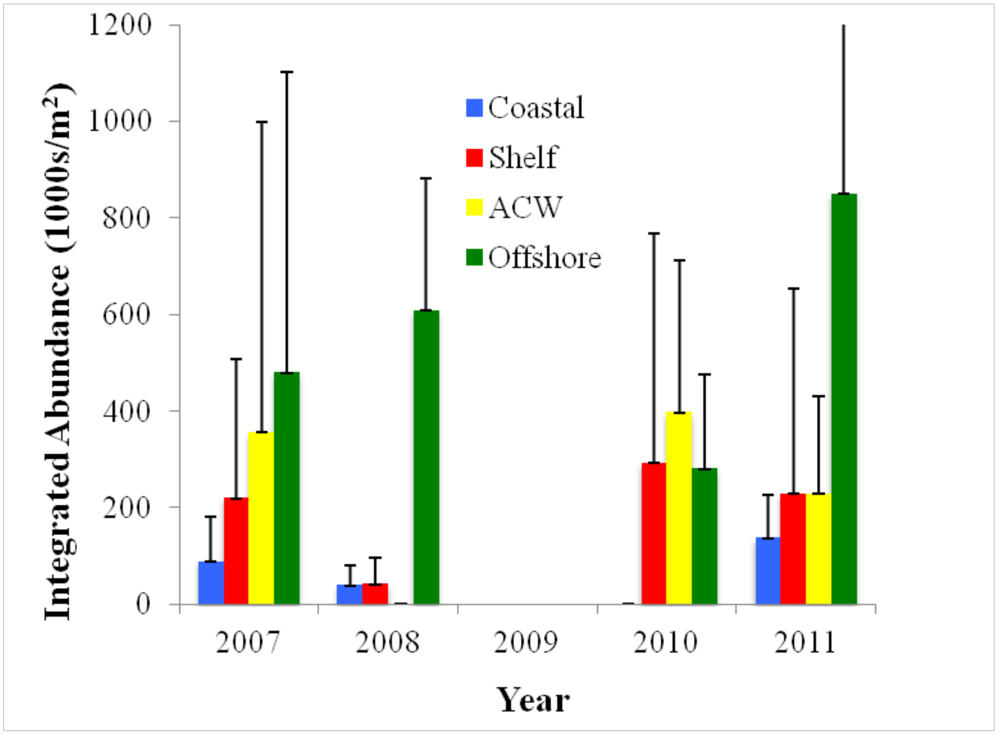

Figure IIIB-13. *Average water column integrated abundance of zooplankton from 150-200 µm ring net samples from the four regions for each year except 2009, in which only 500 µm ring net samples were collected (and thus are not comparable). Analyzed samples were not available for all regions within each year. Error bars show one standard deviation.*

Notable differences in the community composition in each of the four regions were present between the five years (Fig. IIIB-14). The shelf region was dominated overwhelmingly by the small copepod *Pseudocalanus* spp. in 2007 and in 2010, with a proportion also present in 2008. The coastal region was dominated by *Pseudocalanus* in all years. Much higher diversity was present in the offshore region and in the ACC/PW region. The large copepod *Calanus glacialis* was seen in significant proportions only in the offshore region. Other important taxa in those regions included appendicularians and the extremely small copepod *Oithona similis*. Remarkably, a high proportion of benthic larvae and/or echinoderm larvae were present in 2011 in all four regions. Benthic larvae were present in the ACC/PW in both 2007 and 2010 and on the shelf in 2010 and coastal region in 2007 but 2011 was notable in the prevalence of benthic larvae across most regions, with the exception of the coastal region, and in the occurrence of echinoderm larvae at all locations. Echinoderm larvae were not observed prior to 2011 at any location.

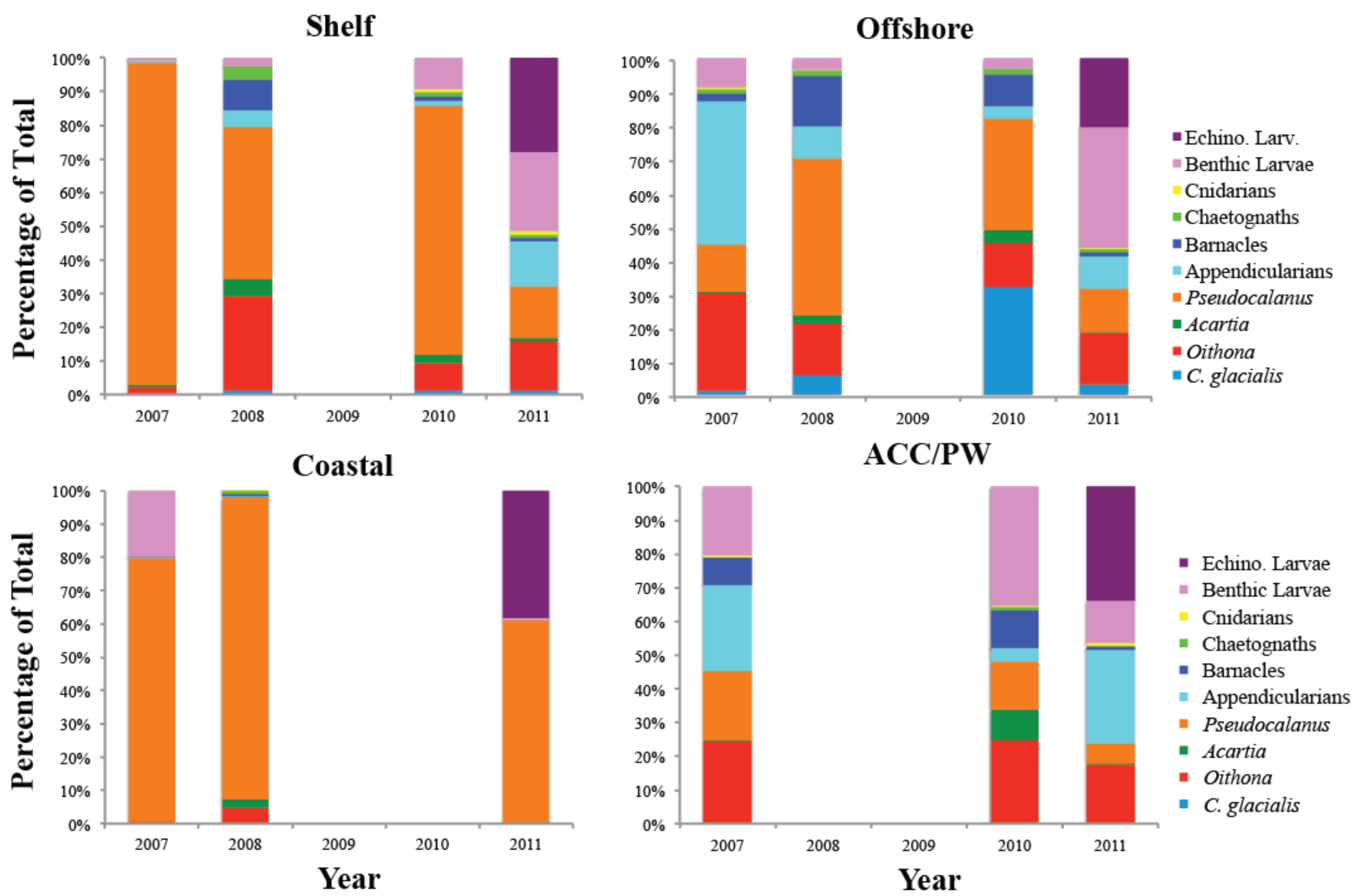

Figure IIIB-14. *Average percent composition of the dominant zooplankton taxa and species from the 150 and 200 µm ring net tows for the four regions for all years except 2009 in which year only 500 µm ring net tows were conducted. No samples from the ACC/PW water mass type were enumerated for 2008.*

Abundances of euphausiids were much lower than those of copepods and larvae and thus are not included in the community composition plots. The most consistent record of euphausiid abundances are derived from the ring net samples, since ring net tows were conducted in each of the five years. Because euphausiids can easily escape ring nets, it is likely that these abundances are underestimates (see below). Abundances were highly variable and significant differences were observed (Kruskall-Wallis, $p < 0.05$ or better) both between regions within a year and between years within a region for both adult/juvenile and furcilia stage euphausiids (Fig. IIIB-15). However, for adults/juveniles these differences usually resulted from a single year/region in which the average integrated abundance was different from the other years/regions rather than because of consistent patterns within regions or for a given year. For furcilia, average integrated abundances were greatest in the offshore region for all years. Despite the high variability and difficulty in observing significant differences, furcilia were also relatively abundant on the shelf in 2010 and 2011, juveniles/adults were less abundant in 2010 and 2011 than in previous years, juveniles/adults were present in equivalent abundances in all regions in 2009, and both juveniles/adults and furcilia were consistently present in the offshore region in all years. Furcilia were more abundant than juveniles/adults in all years except for 2009 when the euphausiid population was dominated by juveniles/adults (Fig. IIIB-16). The contrast between 2009, with overwhelming dominance of juveniles/adults, and 2010-2011, with overwhelming dominance of furcilia, is striking.

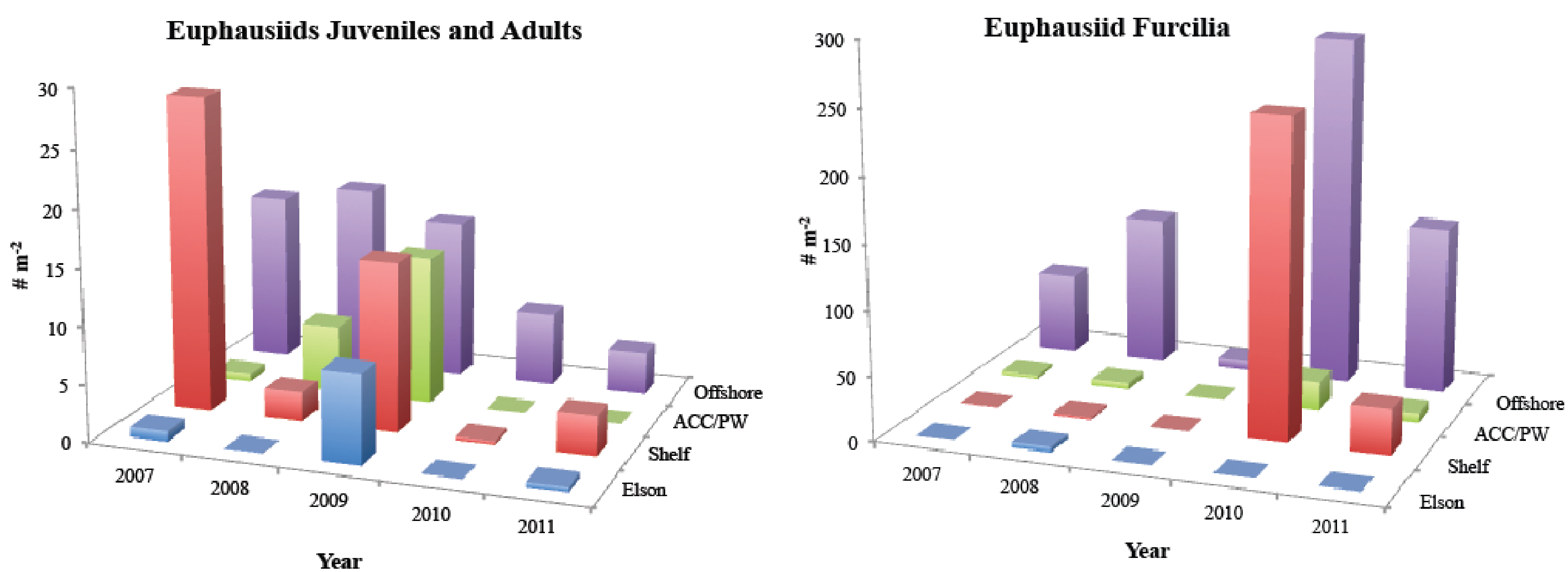

Figure IIIB-15. *Average integrated water column abundance of juvenile and adults (left) and furcilia (right) stages of euphausiids in the different regions collected using 150, 200, and 500 µm ring net tows.*

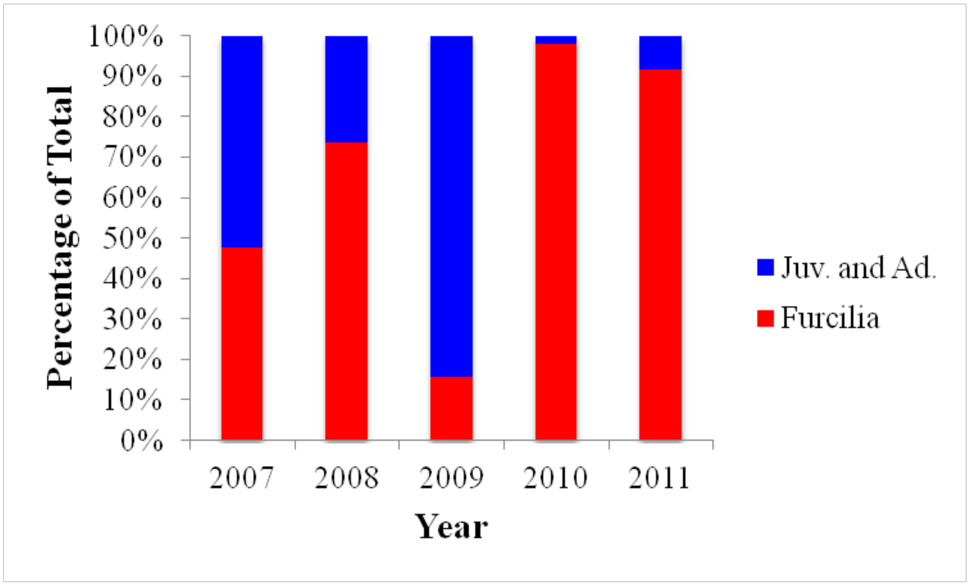

Figure IIIB-16. *Average percentage of total abundance of furcilia and juveniles/adults from the ring net tows. Similar life stage composition was noted in the Tucker Trawls.*

The abundances of euphausiids on the shelf were further divided into those that were quantified during periods when the krill trap was operating, and should be enhancing euphausiid abundances on the shelf, and periods when the krill trap was not operating (Fig. IIIB-17). Abundances of juveniles/adults were significantly greater on the shelf when the krill trap was operating than when it was not (Kruskal-Wallis, $p < 0.05$ or better) in 2008-2010, but not in 2007 or 2011 (likely because only two samples were analyzed in each year from days when the trap was not operating). No significant differences were observed on the shelf for furcilia.

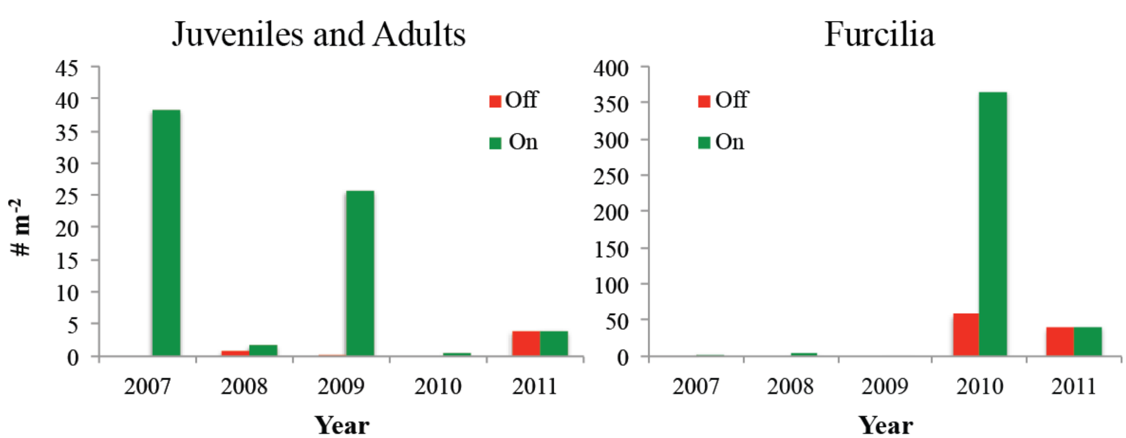

Figure IIIB-17. *Integrated water column abundances of juvenile/adult (left) and furcilia (right) euphausiids on the shelf during periods when the krill trap was operating ("on") and not-operating ("off").*

The spatial distributions of euphausiid abundances coded according to life stage and krill trap operational status also show similar patterns in samples collected using the ring nets over the five years (Fig. IIIB-18). Very few furcilia were present at any of the locations or under either krill trap condition in 2009. Abundances of juveniles/adults in 2009 were similar to other years at most locations. Highest abundances of both life stages were observed in Barrow Canyon, suggesting that one of the water masses there is the source for the euphausiids that are found to upwell onto the shelf. Little difference was observed in Barrow Canyon abundances between krill trap condition (note particularly 2011 where abundances of furcilia were of the same order of magnitude under both conditions). Both furcilia and juveniles/adults were most often seen on the shelf under active krill trap conditions in all years but 2011.

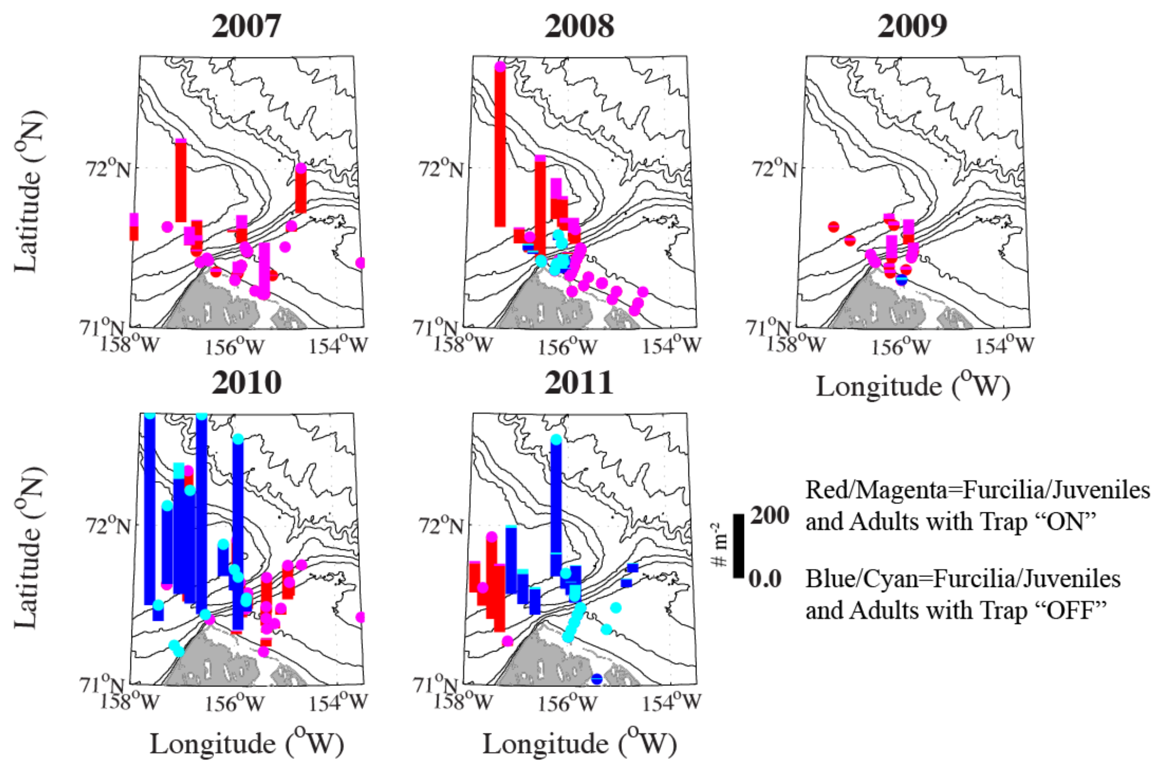

Figure IIIB-18. *Integrated water column abundance (# m^{-2})of larval and juvenile/adult euphausiids under conditions when the krill trap was operating and when it was not operating at the different sampling locations collected using 150, 200, and 500 µm ring net tows. Note that not all locations were sampled in all years under both krill trap conditions.*

Abundances were determined using the Tucker Trawl starting in 2009 (Fig. IIIB-19). Tucker Trawl abundances are considerably higher than ring net abundances because the Tucker Trawl is more effective at capturing the evasive, visually acute euphausiids. In both 2009 and 2010, euphausiids were captured on the shelf using the Tucker Trawl during periods when the krill trap was active. Although life stage was not differentiated in the Tucker Trawl data of Figure IIIB-19, the ring net data (Fig. IIIB-18) indicate that the 2009 euphausiids were composed primarily of juveniles and adults while those captured in 2010 and 2011 were comprised of abundant furcilia (Fig. IIIB-16). In 2011, surprisingly, few euphausiids were captured on the shelf under either krill trap conditions, despite substantial abundances being present on the far side of Barrow Canyon.

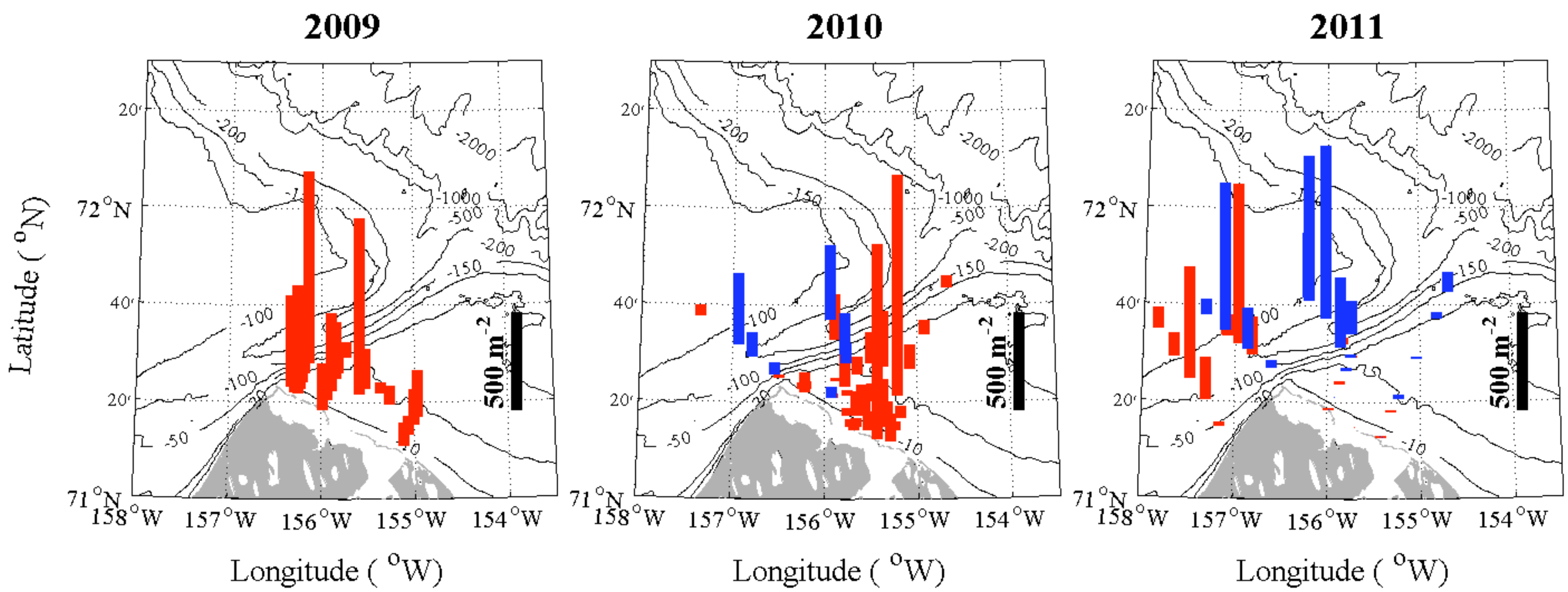

Figure IIIB-19. *Integrated water column abundance of euphausiid (furcilia and juveniles/adults combined) under conditions when the krill trap was operating (red) and when it was not operating (blue) at the different sampling locations collected using the Tucker Trawl in 2009-2011. Samples in 2009 and 2010 were analyzed using silhouette analysis while those from 2011 were analyzed using microscopic enumeration.*

The use of silhouette analysis permitted an assessment of the total biomass of the euphausiids present at each location by summing the length-specific biomasses of the individuals in each sample. In 2009, when the dominant life stages were juveniles and adults, biomass of euphausiids on the shelf was much greater than in 2010 when the dominant life stages were the much lower mass furcilia (Fig. IIIB-20).

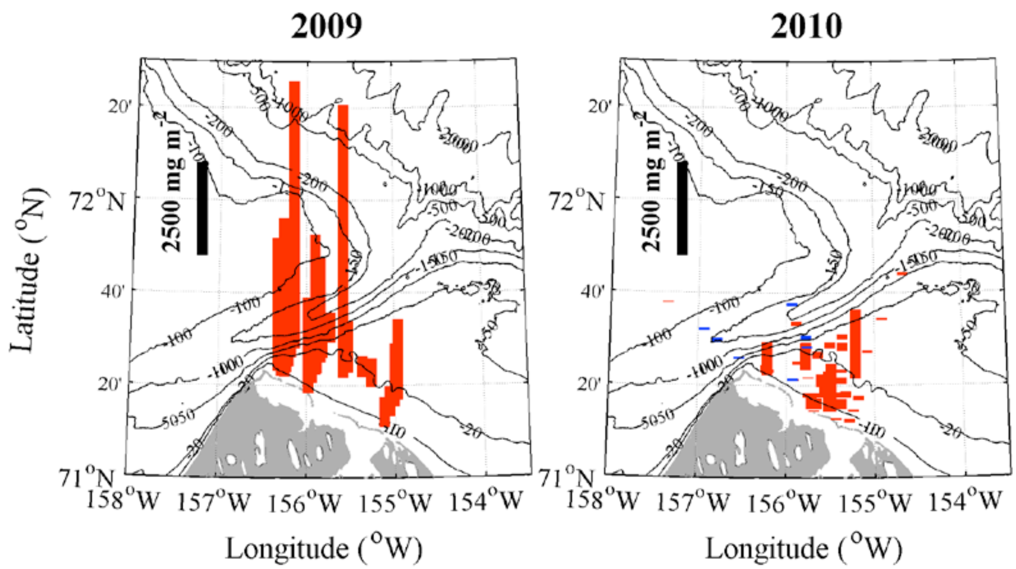

Figure IIIB-20. *Integrated water column euphausiid biomass estimated from silhouette analysis. Samples collected during periods when the krill trap was operating are plotted in red; those collected during upwelling or when the trap was not operating are plotted in blue.*

An example of finer scale distribution of euphausiids in association with a feeding bowhead whale is shown in Figure IIIB-21. Whales were observed feeding intensely off of Plover Point on Sept. 13, 2009. Elevated backscatter from the ADCP coincided with locations of high euphausiid biomass collected using the Tucker Trawl and analyzed using silhouette analysis. Euphausiid biomass was very patchy, as seen in the acoustic backscatter, and the bowhead whales near Plover Point clearly were utilizing this resource.

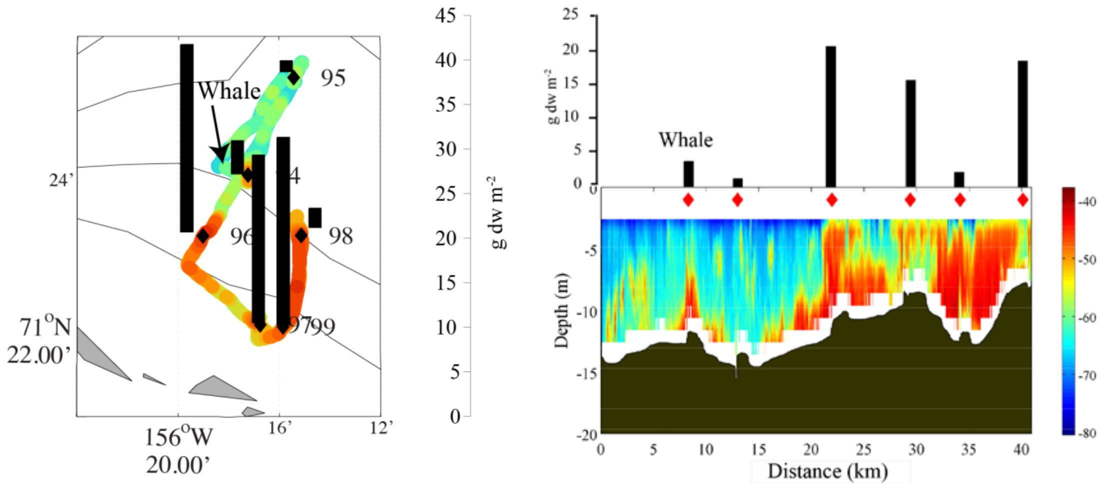

Figure IIIB-21. *Distribution of euphausiid biomass estimated from silhouette analysis (black columns) and relative quantity of euphausiids estimated from ADCP relative acoustic backscatter (color shading) observed near the Plover Islands just to the east of Point Barrow (Nuvuk) on Sept. 13, 2009. Left panel shows average relative acoustic backscatter in color; right panel shows vertical distribution of relative acoustic backscatter along-track (right). A whale was observed feeding near the start of the survey.*

Another example occurred on Sept.11, 2010, when echelon feeding bowhead whales were observed off of the Plover Islands in association with elevated euphausiid abundances (Fig. IIIB-22). The higher abundances of euphausiids were seen in the colder water on the shelf while the warmer water to the north and west, originating in the ACC, had lower euphausiid abundances.

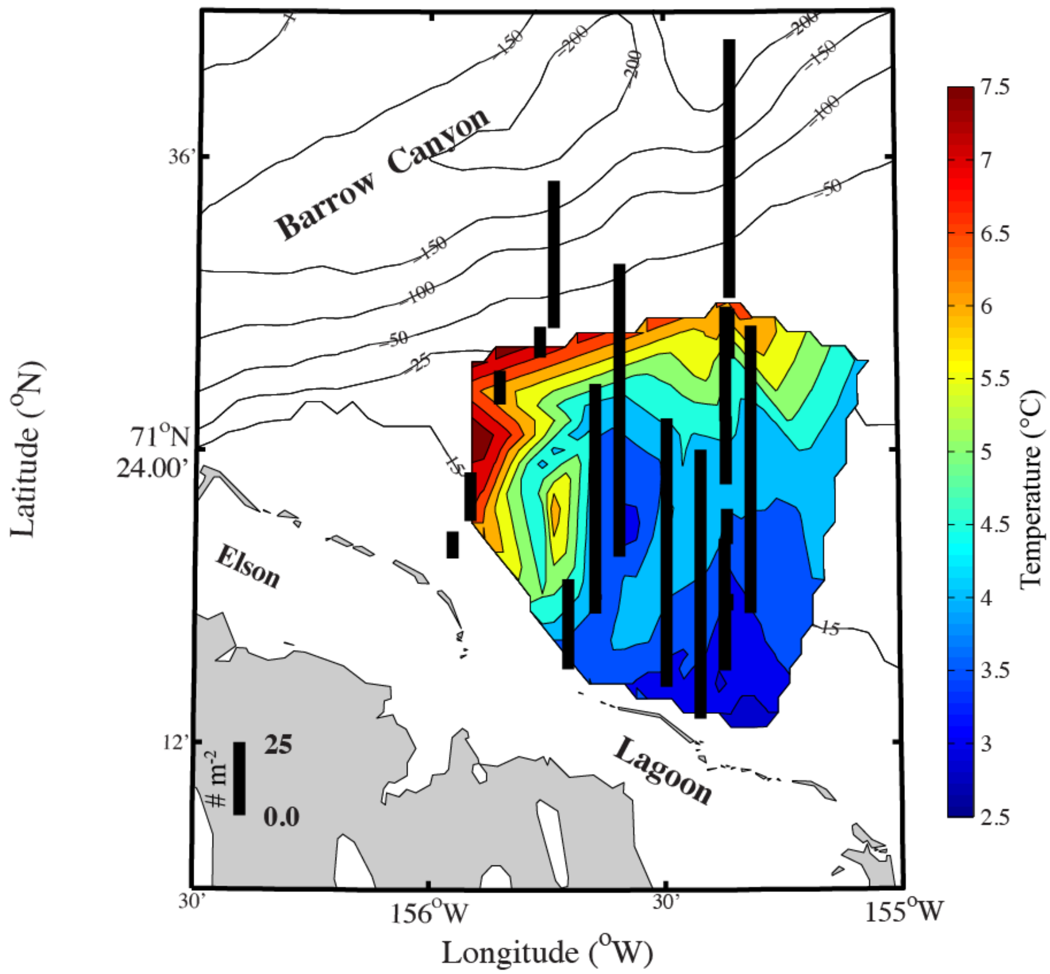

Figure IIIB-22. *Euphausiid integrated water column abundance (# m^{-2}; black bars) from Tucker Trawls from Sept. 8-11, 2010 plotted over water temperature at 5-m from Sept. 9-11. Echelon feeding bowhead whales were observed along the Plover Islands in the colder water.*

Euphausiid Net Avoidance

Euphausiids, or krill, are very mobile and visually perceptive and can easily escape slowly towed nets, particularly during daylight or when the net bridle is positioned in front of the mouth of the net such as for a ring net. Starting in 2009, a ¼ m^2 Tucker Trawl that could be towed at up to 3 knots was used to increase capture of euphausiids and to better quantify euphausiid abundance and standing stock. Comparison of the euphausiid catches using the two different nets (Fig. IIIB-23) revealed that the ring net captured only ~50% of the euphausiids as the Tucker Trawl (mean = 0.51, SD = 0.70) and that this difference was significant (Wilcoxon signed rank test for paired samples, $p = 5.44 \times 10^{-7}$, $n = 51$). The ring net catches, therefore, are underestimates of the total euphausiid abundance but are useful indicators of euphausiid presence or absence and relative abundance. Although the estimates of euphausiids from the Tucker Trawl samples should be closer to actual abundances, it is important to recognize that these abundances also are likely to be underestimates.

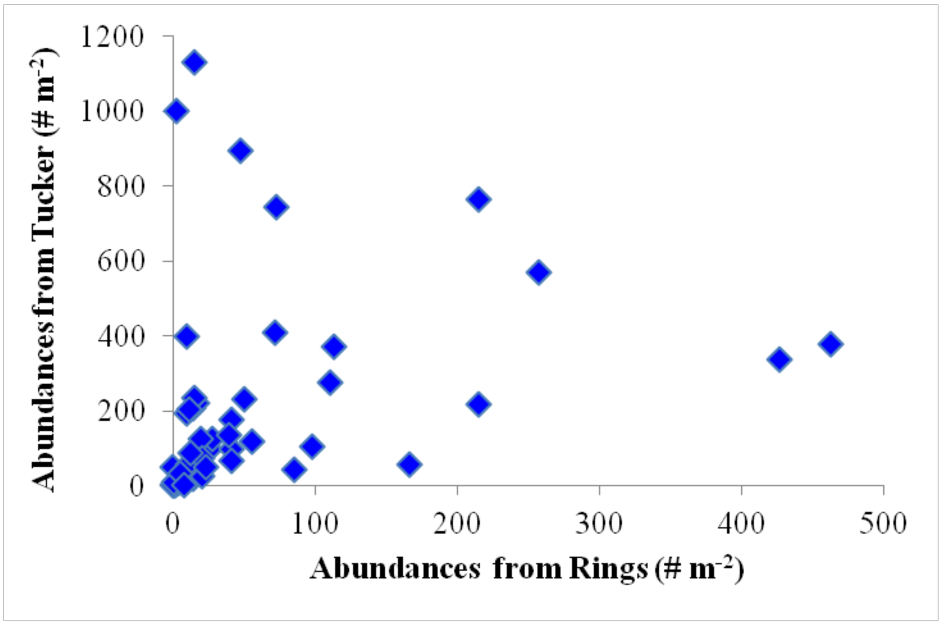

Figure IIIB-23. *Comparison of integrated water column abundances from tows using the ring net equipped with 150, 200, or 500 µm mesh and tows using the Tucker Trawl equipped with 333 or 500 µm mesh.*

Discussion

The dominant characteristic of this region over the five years of the study is the large interannual variability in the physical and biological environment. These conditions dictate the composition and location of the bowhead whale prey hotspot near Barrow that, in turn, may influence the distribution and persistence (residence time) of whales on the shelf.

The period of the study coincides with a period of dramatic physical change in the Arctic and particularly in the western Arctic. The BOWFEST sampling years encompassed some of the lowest total summer sea ice extents in satellite history, with 2007 being the second lowest year on record (e.g., NRC 2012, Parkinson and Comiso, in press). The field study years also coincided with a period of (on average) declining sea ice extent in the Western Arctic, although there was individual variation both between years and locally in the Barrow area. These ice conditions were reflected in the hydrographic conditions in the BOWFEST study area.

Both as a consequence of and as a driver of the changing ice conditions, the hydrography showed marked interannual variability. For most years, the region near Barrow had been sea-ice free sufficiently long at the commencement of the BOWFEST fieldwork in mid-August that little evidence of sea ice melt water was present. An exception was 2008, when sea ice persisted locally near Barrow into mid-August and slight evidence of melt water was seen in the temperature-salinity characteristics. Melt water also was present in 2009 at locations on the western side of Barrow Canyon, likely originating from Hanna Shoal to the west of the Canyon where sea ice often persists until later in the summer or into early fall. Warmest ocean temperatures were seen in the PW of the ACC in Barrow Canyon in 2007, the year with the lowest sea ice extent of the field years. These warm ocean temperatures have been attributed both to very warm PW entering through Bering Strait and a low cloud cover over the Chukchi Sea that promoted solar warming of the upper ocean (Schweiger et al. 2008, Steele et al. 2008, Stroeve et al. 2008, Woodgate et al. 2010). The very warm temperatures in turn contributed to increased sea ice melting both in the Barrow region and to the north.

Shorter term variability in the vertical structure of the water column in Barrow Canyon and on the shelf was forced by variations in wind speed and direction with weak winds or winds from the south confining the ACC against the eastern flank of Barrow Canyon and potentially promoting intrusion of the ACC onto the adjacent western Beaufort Shelf (Fig. IIIB-8). The wind conditions likewise influenced the depth at which WW was observed along the eastern flank of Barrow Canyon, with WW within 50 m of the surface in 2008 but deeper in other years.

These interannual differences were reflected in the biological characteristics as well. Greatest chlorophyll concentrations were present both in melt water and in the upper portion of the WW because of the greater nutrient concentrations found in those water masses (Ashjian, Campbell, Okkonen, unpub.). Markedly different zooplankton community composition was seen between the years. Two patterns stand out: the dominance of *Pseudocalanus* spp. on the shelf in 2007 and the importance of benthic and echinoderm larvae in all regions in 2011. The presence of echinoderm larvae in 2011 is particularly interesting since this was the only year in which they were observed. The large copepod *C. glacialis*, one of the prey items of bowhead whales, was seen consistently only in the offshore region. *C. glacialis* is widespread on the Chukchi Shelf and is found also along the shelf break and along the slope of the Arctic Basin but is not considered to be a coastal species. Thus, its presence in the offshore regions of Barrow Canyon where the water may have originated either in the Canada Basin or in the Bering Sea water flowing through the Chukchi Sea is consistent with this known distribution. The ACC, with water of more coastal origin, should not be expected to be a source of *C. glacialis*. The presence of *C. glacialis* in the offshore water in Barrow Canyon also is consistent with known observations and takes of bowhead whales in the Canyon, many of which contain *Calanus* spp. in their guts (Moore et al. 2010, Sheffield and George Section VB: this volume).

Variability was observed also in the abundance, distribution, and size of euphausiids available to the bowhead whales. Overall abundance and size generally are determined by the characteristics of the upstream source of the euphausiids and the transit times and routes from a Bering Sea source to the Barrow region (e.g., Bérline et al. 2008). Alternatively, local abundance or patchiness and spatial distribution are determined by physical mechanisms that transport and concentrate the euphausiids, here embodied in the series of physical drivers described as the krill trap (Ashjian et al. 2010).

It is now thought that euphausiids are resident in the WW found at depth below the ACC and offshore. With the exception of periods when the krill trap had advected euphausiids onto the shelf, greatest abundances of euphausiids were found in the offshore regions (Figs. IIIB-15, -18, -19), presumably in the WW at depth. ADCP data from moorings at the shelf break have indicated that these euphausiids are upwelled onto the shelf along the Beaufort Shelf break from WW rather than from the shallower ACC (Okkonen Section IIIA: this volume).

The frequency of such wind-driven upwelling events, followed by sufficiently long periods of low winds or winds from the south during which the ACC flows along the eastern edge of Barrow Canyon, trapping water and euphausiids on the shelf, will determine if localized concentrations of euphausiids are present on the shelf and available as patches of prey for the bowhead whales. Multi-day periods of upwelling followed by periods when the krill trap was active were seen in all five of the field years. However, the proportion of days of upwelling relative to the days of active krill trap was much greater in 2007 and 2011 than in the other three years (multiple days of upwelling followed by relatively short periods of the krill trap being active; Fig. IIIB-9). This is reflected in the spatial distribution of euphausiids in those years, with relatively few euphausiids on the shelf in 2007 and particularly in 2011 (Figs. IIIB-18, -19). By contrast, 2009 had the greatest number/proportion of days with the krill trap operating and euphausiids were seen across the shelf during those periods.

The size of the euphausiids also determines the quality of the bowhead whale prey hotspot, in addition to the concentration and location of that prey. Juvenile and adult euphausiids provide a much greater biomass source for the feeding whales than do the smaller furcilia. A clear demonstration of this is seen in 2009 relative to 2010 (Fig. IIIB-20). Euphausiids in 2009 were overwhelmingly dominated by the large juveniles and adults, yielding much greater biomass of euphausiids on the shelf than in 2010. Based on the relative proportions of furcilia to juveniles/adults for the five years, 2008, 2010 and 2011 were years with very low proportions of the high-biomass older life stages while 2007 and 2009 were years with high proportions of the older life stages. These proportions likely are determined by Bering Sea source of the euphausiids, the timing of euphausiid reproduction at that location, and the advective pathways bringing the euphausiids to Barrow (e.g., Bérline et al. 2008).

The spatial distribution of bowhead whales on the shelf should be influenced by the availability of their euphausiid prey at different locations; bowhead whale distributions were documented systematically by the BOWFEST aerial surveys (Rugh et al. Section I: this volume) as well as being noted by boat crews during oceanographic and prey sampling. Both the relatively short periods when the krill trap was operating in 2011 and the very low proportion of large euphausiids in the population in that year appear to have had an important impact on the observed distribution of bowhead whales during the BOWFEST field sampling. Bowhead whales were present in 2011, but were concentrated in Barrow Canyon and not on the shelf, consistent with the relatively low abundances and small size of their euphausiid prey found on the shelf. Bowhead whales are known to feed and be successfully hunted in Barrow Canyon where they utilize copepods and, in 2011, euphausiids. In 2007, the other year in which protracted upwelling was followed by only very short periods when the krill trap was active, bowhead whales did not arrive in any abundance in Barrow until after the BOWFEST field season had been completed, so it is unknown if their spatial distribution would have been confined to regions offshore as was seen in 2011. During 2010, bowhead whales were seen across the shelf (Rugh et al. Section I: this volume), coincident with the presence of euphausiids on the shelf in that year (Figs. IIIB-18, IIIB-19, IIIB-21, IIIB-22) even though the euphausiids were dominated by the smaller furcilia stages. Echelon feeding by bowhead whales near the barrier islands of Elson Lagoon was observed in 2010 (Fish et al. 2012), with the whales presumably utilizing the furcilia present in the cold water on the shelf in that region (Fig. IIIB-22). During 2008 and 2009, the whales were observed primarily along the shelf break during the aerial survey although their euphausiid prey was present across the shelf. Bowhead whales were seen feeding off of Plover Point near Barrow in 2009, utilizing the juvenile/adult euphausiids that were present throughout the water column in that region (Fig. IIIB-21).

Summary

Despite the interannual variability in oceanographic and whale prey conditions, bowhead whales consistently utilized Barrow as a feeding hotspot during all five years of the BOWFEST study. The locations at which the whales found food differed between the years, depending on the efficacy of the physical mechanisms distributing and concentrating the whale prey and the upstream conditions that determined the character (abundance, size) of the euphausiid prey delivered to the Barrow region. The krill trap, identified during early years of work in this region (Okkonen et al. 2009, Ashjian et al. 2010) as the mechanism for delivering high concentrations of euphausiid prey to the shelf near Barrow consistently predicted the development of favorable feeding conditions for bowhead whales on the shelf. Of the five years of the study, 2009 provided the most favorable feeding conditions for the whales, with large, high-biomass euphausiids being delivered across the shelf. Other years, although providing concentrations of euphausiids, might be considered less favorable simply because the euphausiids were dominated by smaller life stages that provided lower biomass.

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Appendix IIIB-I. *Summary of event logs for the oceanographic field sampling from the R/V Annika Marie for 2007-2011.*

Year	Month	Day	Location	# Stations	Station #s	# CTDs	# Ring Nets	# Tucker
2007	8	22	Elson Lagoon	1	1	0	1	0
2007	8	22	Line 2	7	2-8	7	6	0
2007	8	23	Elson Lagoon	1	9	0	1	0
2007	8	23	Line 4	8	10-17	8	5	0
2007	8	25	Line 3	5	18-22	5	0	0
2007	8	25	Elson Lagoon	1	23	0	1	0
2007	8	28	Elson Lagoon	1	24	0	1	0
2007	8	28	Line 4	7	25-31	7	6	0
2007	8	28	Elson Lagoon	1	32	0	1	0
2007	8	29	Elson Lagoon	1	33	0	1	0
2007	8	29	Line 6	5	34-38	5	5	0
2007	8	30	Line 6	2	39-40	1	4	0
2007	8	30	Coastal-variable	4	41-44	0	5	0
2007	9	4	Elson Lagoon	2	45-46	0	3	0
2007	9	4	Line 6	8	47-54	8	9	0
2007	9	6	Elson Lagoon	1	55	0	1	0
2007	9	6	Line 2	4	56-59	4	2	0
2007	9	7	Line 2	3	60-62	0	4	0
2007	9	7	Elson Lagoon	1	63	0	1	0
2007	9	7	Line 2	1	64	1	3	0
2008	8	18	PrudhoeTransit	2	1-2	0	2	0
2008	8	19	PrudhoeTransit	3	3-5	0	3	0
2008	8	21	Line 2	4	6-9	4	4	0
2008	8	22	Line 2	4	10-13	4	2	0
2008	8	23	Line 4	7	14-20	7	6	0
2008	8	24	Line 4	2	21-22	2	3	0
2008	8	25	Line 4	10	23-32	10	7	0
2008	8	26	Line 2	5	33-37	5	0	0
2008	8	27	Line 2	6	38-43	2	6	0
2008	8	28	Along Elson	6	44-49	6	6	0
2008	9	5	Elson Lagoon	1	50	1	3	0
2008	9	5	Line 3	2	51-52	3	3	0
2008	9	5	Deadman's Island Pass	1	53	1	1	0
2008	9	6	Elson Lagoon	1	54	1	1	0
2008	9	6	Whale tracking	16	55-70	15	21	0
2008	9	8	Elson	1	71	1	1	0
2008	9	8	Line 4	2	72-73	2	2	0
2008	9	9	Line 4	7	74-80	2	2	0
2008	9	10	Elson Lagoon	1	81	1	1	0
2008	9	10	Cooper Island	1	82	1	1	0
2008	9	10	Along Beaufort Shelf	7	83-89	7	7	0

Year	Month	Day	Location	# Stations	Station #s	# CTDs	# Ring Nets	# Tucker
2009	8	18	Northstar	1	1	1	1	0
2009	8	21	Beaufort Shelf, Elson Lagoon	4	2-5	1	1	0
2009	8	22	Line 3	8	6-13	8	5	0
2009	8	23	Line 4	9	14-22	7	8	0
2009	8	25	Line 2	7	23-29	7	5	0
2009	8	26	Line 4	7	30-36	7	8	0
2009	8	28	Line 2	5	37-41	0	4	1
2009	9	2	Line 4	11	42-52	8	7	5
2009	9	7	Line 4	13	52-64	12	1	9
2009	9	11	Elson Lagoon	1	65	1	0	1
2009	9	11	Line 3	4	66-69	4	2	7
2009	9	11	Line 3 to 4	1	70	1	0	2
2009	9	11	Line 5	2	71-72	1	0	1
2009	9	11	Line 7	4	73-76	4	0	5
2009	9	12	11-m Isobath	5	77-81	5	1	10
2009	9	12	Line 4	5	82-86	5	0	5
2009	9	12	12-m Isobath	1	87	0	0	2
2009	9	13	Line 4	6	88-93	6	7	9
2009	9	13	Baumgartner CTD#5	1	94	1	0	1
2009	9	13	Transect north of Sta.94	4	96-99	5	0	6
2009	9	14	Mooring Location, Line 3	1	100	0	0	0
2009	9	15	Moorings, Line 6	3	101-103	0	2	0
2010	8	21	Line 2	9	1-9	9	4	0
2010	8	23	Line 4	12	10-21	12	5	2
2010	8	24	Line 1	11	22-32	11	7	2
2010	8	29	Line 2	9	33-41	9	4	3
2010	8	30	Line 6	7	42-48	7	5	4
2010	8	31	Line 6	1	49	1	1	1
2010	9	1	Line 2	4	50-53	4	0	4
2010	9	8	Line 4	10	54-63	9	6	7
2010	9	9	Line 5	7	64-70	7	0	6
2010	9	9	Line 6	5	71-75	5	0	4
2010	9	10	Line 6	1	76	1	1	1
2010	9	10	Zig-zag along Line 6	9	77-85	10	6	10
2010	9	11	Zig-zag along Line 6	1	86	1	0	1
2010	9	11	Line 5	9	87-95	10	0	10
2010	9	13	Line 3	1	96	1	0	0
2010	9	13	Line 4	1	97	1	0	1
2010	9	13	Beaufort Shelf	4	98-101	4	0	4
2010	9	13	Beaufort Shelf	3	102-104	3	0	3
2010	9	13	Beaufort Shelf	1	105	1	0	0
2010	9	13	Beaufort Shelf	3	106-108	3	0	4
2010	9	13	Elson Lagoon	1	109	1	0	0
2010	9	16	Whale tracking	9	110-118	9	0	12
2010	9	17	Line 4	5	119-123	5	0	4
2010	9	17	Whale tracking	3	124-126	3	0	4

Year	Month	Day	Location	# Stations	Station #s	# CTDs	# Ring Nets	# Tucker
2011	8	22	Line 4	7	1-7	8	4	3
2011	8	23	Line 2	8	8-15	8	5	4
2011	8	25	Line 4	11	16-26	11	4	5
2011	8	27	Line 2	6	27-32	6	0	4
2011	8	29	Line 6	12	33-44	12	5	5
2011	8	31	Along Beaufort Shelf	18	45-62	18	4	10
2011	9	1	Line 1	11	63-73	11	5	5
2011	9	3	Line 4	11	74-84	11	5	6
2011	9	5	Line 2	4	85-88	4	0	6
2011	9	8	Along Beaufort Shelf	16	89-104	16	4	10
2011	9	12	Along Beaufort Shelf	11	105-115	11	0	8
2011	9	13	Line 4	7	116-122	7	4	5
2011	9	14	Line 4	2	123-124	2	2	2
2011	9	14	Line 6	2	125-126	2	2	2
2011	9	17	Elson Lagoon	1	127	1	0	1

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SECTION IV - TAGGING AND FINE-SCALE OCEANOGRAPHY

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Abstract

The diving and foraging behavior of bowhead whales was studied on the western Beaufort Sea shelf to better understand the factors that influence the whales' feeding behavior and movements. Our specific objectives were to investigate associations among whale diving behavior, the distribution of prey in the water column, and the physical features that may contribute to the concentration of prey at particular depths. Diving behavior was monitored by attaching archival tags to bowhead whales for short periods of time (1-3 hours). Suction-cup attached tags were found to perform poorly owing to the whales' rough skin; therefore, a new dermal attachment tag was designed and used in the field project during 2009-2011. The short- and long-term behavioral and health effects of this tag were studied in humpback whales in spring 2009, and the tag was deemed to be sufficiently benign for use on bowhead whales. Tagged whales were tracked closely with the aid of a high-frequency acoustic transmitter incorporated in the tag. Oceanographic conditions and prey distribution were monitored as close in space and time to the tagged whales as possible using a profiling instrument package that measured temperature, salinity, chlorophyll fluorescence, and zooplankton abundance throughout the water column. Profiles with the instrument package were collected every 15 minutes along the tagged whale's track. Tagged whales traveled extensively while they were monitored; some remained at the surface during these traveling periods, while others made repeated and regular dives to near the sea floor. The regular diving behavior was very suggestive of prospecting or searching behavior. Zooplankton abundance, particularly that of the whales' putative primary prey (euphausiids and large copepods), was low in proximity to the tagged whales. Sampling both in the presence and absence of bowhead whales indicated no relationship between the occurrence of the whales and zooplankton abundance. In contrast, the occurrence of North Atlantic and North Pacific right whales, morphologically similar species to the bowhead, is very closely correlated with the abundance of their copepod prey. These results suggest that the western Beaufort Sea shelf may only be an occasional feeding area for bowhead whales, and that their presence in this region may be related to factors other than feeding, such as socializing or coordination during migration.

Introduction

The western Beaufort Sea shelf near Barrow, Alaska, is thought to be an important feeding area for bowhead whales (*Balaena mysticetus*). This area is transited by bowheads during both the spring and fall migrations between their winter habitat in the Bering Sea and their summer habitat in the Canadian Arctic (Moore and Clarke 1992, Moore and Reeves 1993, Moore et al. 2000). In addition to its ecological importance, this area is of particular importance to the native Iñupiat people of Barrow who harvest bowhead whales during both spring and fall subsistence hunts (Stoker and Krupnik 1993). Bowhead whales feed on zooplankton, especially copepods and euphausiids (Carroll et al. 1987, Lowry 1993, Lowry and Sheffield 2002, Lowry et al. 2004). While copepods appear to dominate the whales' diet in the Canadian Arctic during summer, euphausiids dominate the stomach contents of harvested whales on the western Beaufort Sea shelf near Barrow. To feed efficiently, balaenids (bowhead and right whales) must find highly concentrated aggregations of their prey (Baumgartner et al. 2007), yet the factors that promote such aggregations are poorly understood. The annual occurrence of bowhead whales near Barrow suggests that this region is an important feeding ground.

Variability in oceanographic conditions and prey abundance can have a significant impact both on the distribution of bowhead whales on the western Beaufort Shelf and their feeding behavior (e.g., dive patterns and duration). North Atlantic right whales, a temperate baleen whale that is closely related to the bowhead, targets vertically aggregated layers of the copepod *Calanus finmarchicus* (Baumgartner and Mate 2003), and processes that control the vertical positioning of these layers (e.g., bottom mixed layer) can influence the spatial distribution of the whales (Baumgartner et al. 2003). Right and bowhead whales are morphologically similar in that they both have large heads, long baleen with fine fringes, and a subrostral gap in the baleen that facilitates ram filter feeding on zooplankton. This similarity in their feeding apparatus implies that similar processes (e.g., ocean fronts, prey behavior) will likely govern their behavior and distribution. Like the right whale, a better understanding of both prey distribution and diving behavior can help to elucidate the factors that control bowhead whale distribution.

We report here on a study to characterize the diving and foraging behavior of bowhead whales on the western Beaufort Sea shelf off Barrow during the late summer. The study employed archival tags to monitor the whales' behavior and proximate oceanographic and zooplankton sampling to characterize oceanographic conditions and the distribution and abundance of the whales' prey. This tagging and fine scale sampling was designed to elucidate (1) the depths of feeding, (2) environmental conditions influencing the depth of prey layers, (3) foraging strategies, and (4) oceanographic processes that may influence the spatial distribution of bowhead whales.

Methods

Study design

Archival tags were attached to bowhead whales for 1-3 hours during which time oceanographic and prey sampling was conducted along the tagged whale's track. Tags were deployed from an aluminum- or fiberglass-hulled boat (~20 ft.) piloted by an Iñupiat driver. After tag attachment, the tagged whale was tracked at close range (< 1 km) from the tagging boat. Care was taken to track the tagged whale at sufficient distance to mitigate an overt behavioral response to the boat, but close enough to allow behavioral observations and to accurately collect surfacing locations. Upon the tagged whale's surfacing after a long dive or every few minutes for whales that surfaced more frequently, the tracking boat would stop at a surfacing location and record the position with a global positioning system (GPS) receiver. Roughly every 10-15 minutes, the most recent position would be transmitted by radio to the oceanographic vessel R/V *Launch 1273*, and the vessel would subsequently move to that location to conduct a cast with a vertical profiling instrument package (Fig. IV-1, described below). Tracking and sampling would continue until the tag's corrosive release mechanism detached it from the whale and the tag was recovered. In addition to conducting instrument casts in proximity to tagged whales, casts were also conducted opportunistically near non-tagged whales and in areas where whales were absent.

Figure IV-1. *(a) Oceanographic research vessel* Launch 1273*. (b) Deployment of vertical profiling instrument package from stern A-frame of* R/V Launch 1273*.*

Vertical profiling instrument package

The vertical profiling instrument package consisted of a conductivity-temperature-depth instrument (CTD; Seabird Electronics, SBE 19 plus), chlorophyll fluorometer (Wetlabs, WETStar WS3S), a video plankton recorder (VPR; Seascan model DAVPR; Davis et al. 1992, 1996), an altimeter (Benthos, PSA-916), and a bottom contact switch (WHOI custom built), which provided vertical profiles of temperature (CTD), salinity (CTD), chlorophyll fluorescence (fluorometer), and zooplankton abundance and community composition (VPR). The VPR captures digital images of a small volume of water 23-30 times per second, and is adept at estimating the abundance of large zooplankton. Regions of interest, defined as areas in the images with high brightness and contrast, were automatically extracted using AutoDeck software (Seascan) and visually inspected to identify and classify zooplankton. Taxon-specific abundance estimates were derived from the VPR using zooplankton counts from these manually classified regions of interest as well as empirical estimates of the image volume (327 ml). The vertical distribution and abundance of zooplankton were estimated over 2-m depth strata for the analysis and figures below.

Suction cup tag

During 2007 and 2008, a suction-cup attached tag consisting of a time-depth recorder (TDR; Wildlife Computers MK9), a pitch, roll, and pressure instrument (DST-PR, Star-Oddi), a high-frequency acoustic transmitter (V22P, VEMCO, Ltd.), and a radio transmitter (CHP-1P, Telonics) was used during fieldwork (Fig. IV-2). The TDR measured depth at 0.5 m resolution.

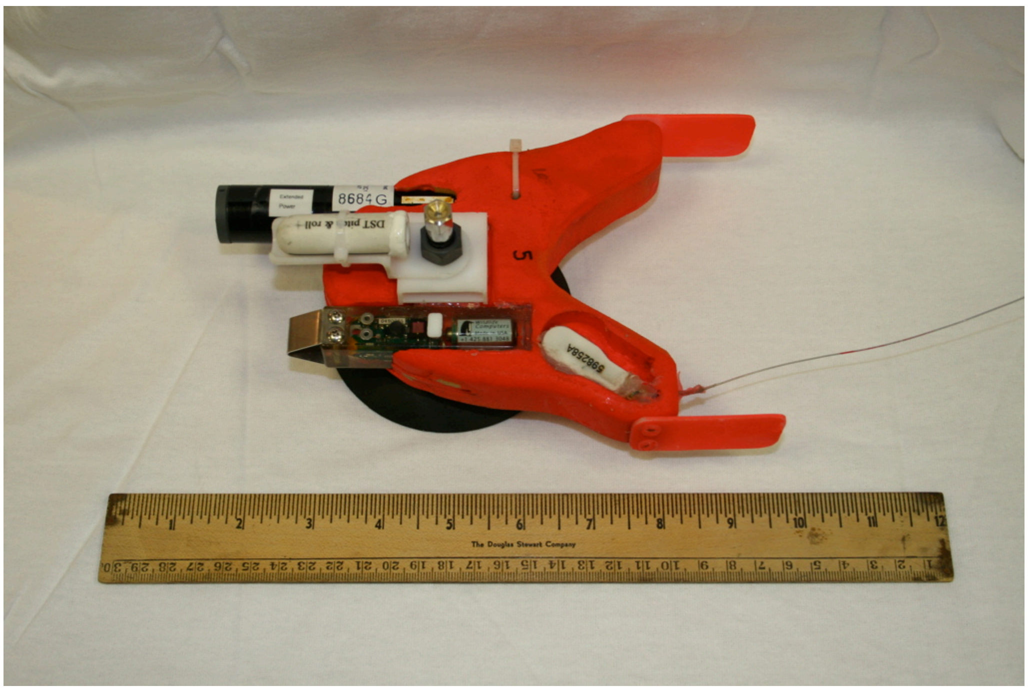

Figure IV-2. *Suction-cup tag used in 2007-2008 field seasons.*

The acoustic transmitter facilitated tracking submerged whales at close range (< 1 km) using a hand-held directional hydrophone and an acoustic receiver. We have found this tracking method to be superior to radio tracking for our study, since it did not require tags to be placed high on the back (i.e., good radio antenna exposure was not needed) and it allowed environmental sampling to occur much closer in space and time to the whale than when radio tracking. Each acoustic transmitter emitted a 10-ms 36-kHz pulse at 165 dB (re 1 μP at 1m) roughly once every second. The frequency response of the transmitter, data on the behavior of right whales tagged with and without the transmitter, and justification for the use of this active acoustic source on baleen whales can be found in Baumgartner and Mate (2003) and Baumgartner et al. (2008). Tags were deployed using a 9-m long telescoping aluminum pole, and attached to the whale's skin via a suction cup. Detachment was controlled using a zinc foil plug in the suction cup that corroded over 1-3 hours and eventually allowed seawater to flood the suction cup. Upon detachment, syntactic or PVC foam incorporated in the tag provided buoyancy so that the tag could return to the surface and be recovered for data retrieval.

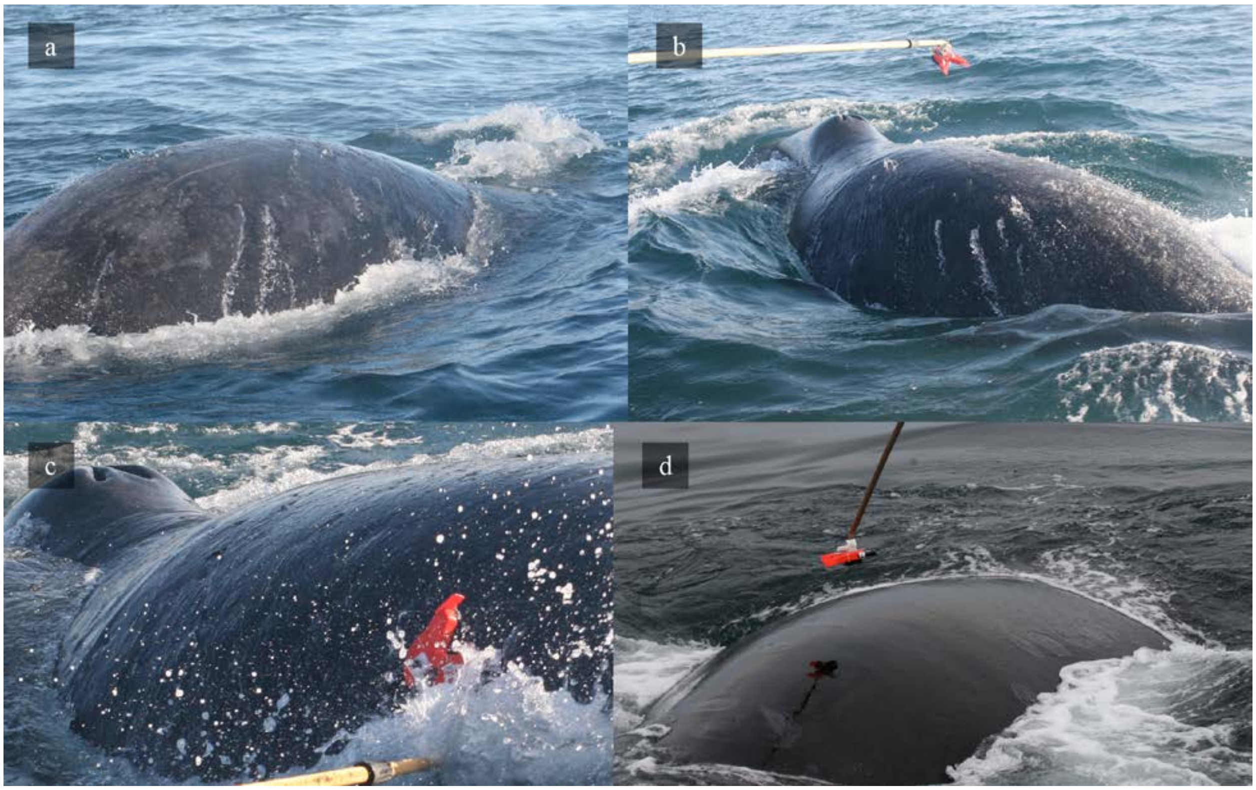

Figure IV-3. *(a) First bowhead whale approached and tagged on September 13, 2008. (b) Second bowhead whale approached on September 13, but tagging was unsuccessful. (c) Close up of skin of the whale in (b). (d) Tagging of a North Atlantic right whale. Note the irregularities in the bowhead whale skin that cause uneven water sheeting in (a) and (b). In contrast, the North Atlantic right whale skin is much smoother.*

Dermal attachment tag

We found whales extremely difficult to approach within 10 m to allow deployment of the suction-cup attached archival tags during 2008 (no whales visited the study area in 2007, so there were no tagging attempts that year). In general, whales surfaced for short intervals, remained submerged for long periods of time, and moved long distances between surfacings. We were only successful in approaching 2 whales during our last day on the water of the 2008 field season. An analysis of the photos taken during close approaches revealed that the bowhead whales we attempted to tag had particularly rough skin (Fig. IV-3). We observed numerous small divots, bumps, and scrapes on the skin that interrupts water sheeting off of the animal's back when it surfaces (Fig. IV-3a,b). These irregularities can be clearly seen in close-up shots of the animals' back (Fig. IV-3c), and are particularly evident when compared to the relatively smooth skin of the North Atlantic right whale (Fig. IV-3d), upon which we have had good success deploying tags. We concluded from these photographs that the skin of bowheads off Barrow was so rough that suction-cup attachment was impossible. To overcome these challenges, we developed a short-term dermal attachment that was tested during May 2009 on humpback whales (*Megaptera novaeangliae*) near Cape Cod, Massachusetts and used with success during the late-summer 2009, 2010, and 2011 field seasons in Barrow.

The dermal attachment consists of a single stainless steel needle and a hemispherical delrin "stop" that prevents full implantation of the needle and subsequent inward migration (Fig. IV-4). The needles used in the studies described below were 6.5-cm (humpback and bowhead

Figure IV-4. *Needles used in humpback whale field trials. Needle at left features 4 tapered cupped rings rising 0.16 cm above the needle shaft, while the needle at right features 4 curved 316 stainless steel pins. Each needle is attached to a white hemispherical delrin "stop". Inset shows cross design of needle tip with 4 cutting blades and side vents.*

whales) or 7.5-cm (bowhead whales) long with a 0.635-cm diameter shaft, and each was machined from 316 surgical stainless steel. The design of the needle tip was originally based on the cupped blade of Watkins (1979); however, after testing on a beach-cast fin whale carcass, we found that this point removed a plug of skin upon entry and carried the plug into the blubber. The introduction of this skin and associated surface contaminants into the blubber was unacceptable, so we redesigned the point to prevent this. The new point consists of four cutting blades arranged as a cross with side vents to prevent any skin or surface contaminants from entering the wound (Fig. IV-4). Testing of this new point on a second beach-cast fin whale carcass indicated that, unlike the Watkins-style point, the cross design preserves the skin initially cut during entry to presumably facilitate better healing of the wound after the needle is shed. Moreover, the cross design allows penetration of the skin and blubber at more oblique entry angles than would be allowed by a point (Watkins 1979), such as that used by Goodyear (1993); consequently, the tag does not need to be implanted while perpendicular to the whale's flank, but instead can be launched while the tagging boat is slightly behind and to the side of the whale (at the "quarters," in naval terms, which is the safest direction to approach a whale). Two anchoring designs providing different degrees of holding power were used: (1) tapered cupped rings rising 0.16 cm above the needle shaft, and (2) curved 316 stainless steel pins pulled through the needle shaft and blunted (Fig. IV-4). Prior to use, both the needle and "stop" are steam sterilized in an autoclave, and are removed from the sterile autoclave bag in the field only immediately before loading the tag in the launcher. The needle is not touched during this process, and it is subsequently protected from incidental contact and sea spray while inside the barrel of the launcher.

The tag housing is a 40.6-cm long by 3.2-cm diameter hollow cylinder constructed of polyethylene, and the TDR (LAT1500, Lotek), VHF radio transmitter (MOD-050, Telonics) and acoustic transmitter (V22P, VEMCO, Ltd.) are imbedded in a buoyant PVC foam core (DIAB Global Divinycell HCP060) that inserts into the polyethylene housing (Fig. IV-5). As with the suction-cup attached tag, the acoustic and radio transmitters were included in the tag to facilitate tracking of the whale and recovery of the tag, respectively. Venting holes were drilled into the housing to allow it to freely flood as well as to allow the signal produced by the acoustic transmitter to radiate outside of the housing. Attenuation of the acoustic pulse by the housing and foam core was tested by VEMCO and found to be negligible. The "stop" of the dermal anchor was designed to fit seamlessly into the endcap of the housing. The needle and the tag housing were attached by a monofilament or braided polyethylene (Spectra) tether that passed through a piece of zinc foil in the endcap. This foil corroded over the period of several hours and weakened until a knot and bead at the end of the tether was pulled through the foil, at which point the tag housing parted from the dermal anchor (which remained attached to the whale, but was shed within a few days; see below), floated to the surface, and was recovered. During deployment, the force of initial recoil after anchor attachment can easily pull the knot and bead through the zinc foil; only 8 lbs of force is required to do this. A dissolvable washer made of a folded strip of Solvy (Sulky), a water-soluble stabilizer used in sewing applications, was used to absorb the force associated with the recoil. This dissolvable washer can withstand over 25 lbs of force when dry (i.e., upon initial deployment), but less than 2 lbs of force after being submerged in water for 5 min. Since the tag housing was not implanted, the dissolution of the Solvy occurred well away from the wound site.

The anchor and tag housing fit together to make a single projectile (Fig. IV-5) that was fired using a compressed air launcher called the Air Rocket Transmission System (ARTS; Heide-

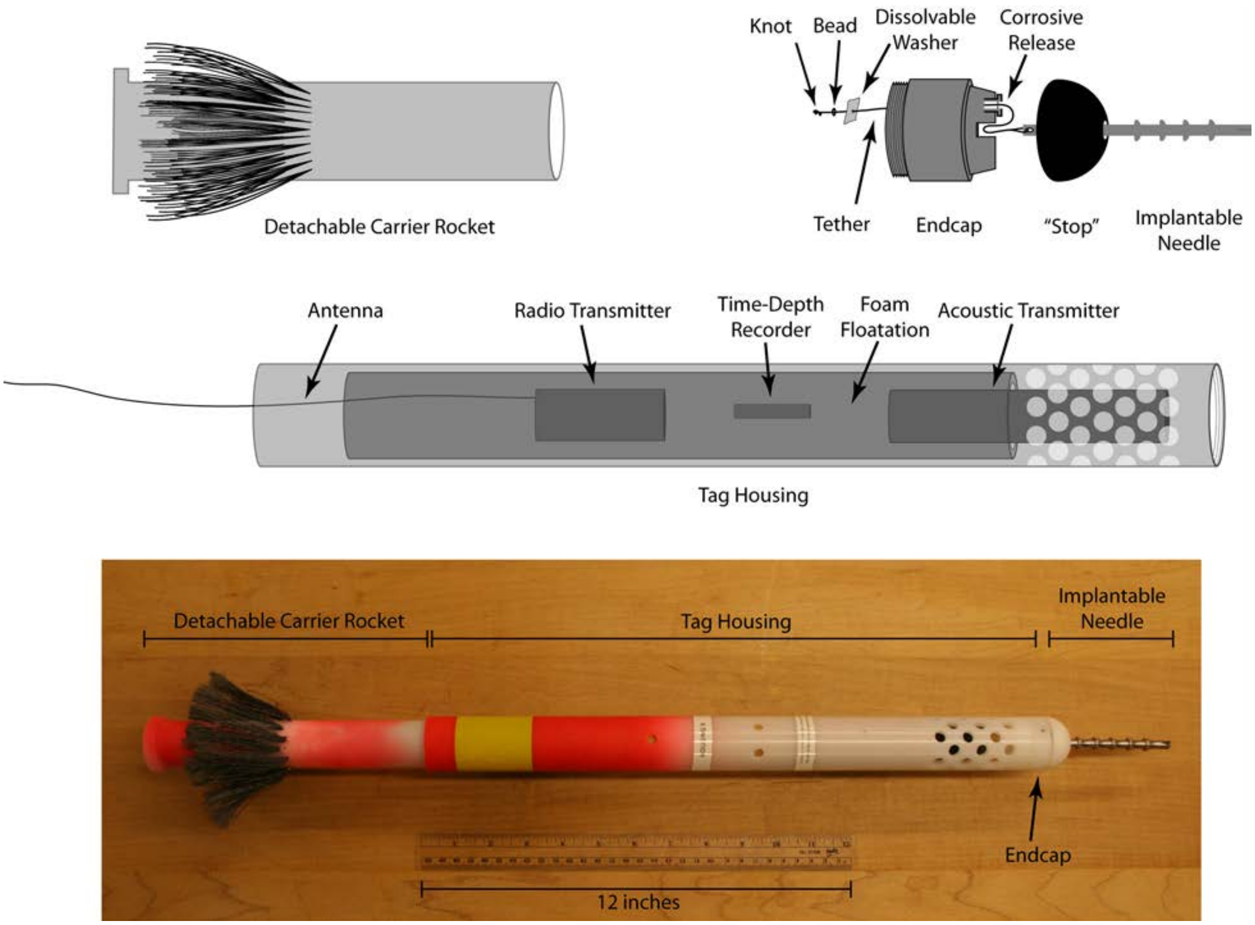

Figure IV-5. *Dermal attachment tag components, including tag housing, foam floatation, time-depth recorder (TDR), radio transmitter, acoustic transmitter, detachable carrier rocket with flu-flu fletching, and endcap with needle, black deldrin "stop", and zinc foil corrosive release mechanism. Photograph shows tag assembled for launch with the carrier rocket fitted into the end of the tag housing at the left, endcap screwed into the tag housing at right, and the sterilized needle fitted into the endcap.*

Jorgensen et al. 2001), which is a modified line thrower (Restech, Inc.). To provide stability in flight, a "carrier rocket" was inserted into the end of the tag housing opposite the dermal anchor (Fig. IV-5). Several designs of this carrier rocket were tested, including many with traditional vanes. Because it was difficult to find materials for the vanes that could be compressed in the barrel of the launcher, yet resume their shape after exiting the barrel, we designed a carrier rocket with flu-flu fletching borrowed from a style of arrow used to hunt birds. Flu-flu arrows have an excessive amount of fletching to provide greater stability and to slow the velocity of the arrow. Our recoverable carrier rocket was made of a hollow polyethylene cylinder with a buoyant PVC foam insert and fletching made of plastic strands.

Results

Effects of dermal attachment: humpback whales

Prior to use, we thought it extremely important to examine the short- and long-term effects of the dermal attachment on both the health and behavior of the whales to insure that the tag was sufficiently benign. Because there is no systematic effort to monitor individual bowhead whales off Barrow, Alaska, a longitudinal study of tagging effects on this species was not feasible. Instead, we examined the effects of the dermal attachment in a much better monitored population: Gulf of Maine humpback whales. This population was chosen because (1) individuals in this population have been studied for more than three decades, (2) animals can be individually identified from fluke and dorsal fin photographs, and (3) follow-up photographs after tagging can be obtained by researchers and naturalists aboard whale watching boats from spring through early fall.

Initial deployments of the dermal attachment tag were conducted on humpback whales near Cape Cod, Massachusetts during late May 2009 from the bow of the 18.3 m oceanographic research vessel *Tioga*. From May 25-29, 2009, 5 attempts were made to tag 4 whales a few miles northeast of Provincetown, Massachusetts (Table IV-1). This sample size was deliberately

Table IV-1: *Summary of humpback whale field trials with the dermal attachment in the southwestern Gulf of Maine*
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Event	Date, Time & Position	Needle	Individual ID	Reaction	Comments
1	5/25/09 15:00 42°N 03.8′ 69°W 53.0′	cupped rings	“Clothesline”	None	Upon deployment, tether separated from tag at corrosive link
2	5/27/09 11:58 42°N 05.7′ 70°W 16.3′	cupped rings	“Ventisca”	None	Carrier rocket was stuck in barrel, so tag not launched with appropriate force; needle only partly implanted, and detached after 5 min
3	5/27/00 12:35 42°N 05.4′ 70°W 16.3′	cupped rings	“Ventisca”	None	Upon deployment, tether separated (cut) from needle because of sharp edge where tether inserts into needle.
4	5/27/09 13:23 42°N 05.3′ 70°W 17.3′	stainless steel pins	“Ragweed”	Tail flick	Successful tag attachment; tag remained attached for 1.5 hours; detachment caused by breaching
5	5/29/09 13:08 42°N 07.9′ 70°W 12.3′	cupped rings	“Whisk”	None	Successful tag attachment; tag remained attached for 3.5 hours; detachment caused by breaching

small to be precautionary. Tag attachment durations were variable: 0 minutes (events 1-3; owing to early problems with the tether that were solved during subsequent deployments), 1.5 hours (event 4) and 3.5 hours (event 5). In all but one of the 5 tagging events, the whales showed no immediate reaction to being tagged (Table IV-1). The first tagged whale (event 1) was observed feeding at the surface prior to tagging, and continued feeding without interruption during and after tag deployment. This animal also tolerated close boat approaches to obtain follow-up photographs of the tag site for one hour after tagging. Only during event 4 was a reaction to tagging observed. The tag was launched from behind the animal and attached at an oblique angle forward of the dorsal fin on the left flank. The animal reacted with a strong tail flick (similar to those reported for biopsying; Weinrich et al. 1992, Clapham and Matilla 1993). On rare occasions, we have observed similar tail flicks when approaching humpback whales in a 4.5 m rigid hulled inflatable boat for suction-cup tagging.

All of the whales were monitored for at least 30 minutes after tagging to obtain photographs of the tag site and to observe both behavior and swim speeds. Swim speeds were assessed using the ship's track (derived from a GPS) and the times of photographs of the whales taken in proximity to the ship (the camera's clock was synched to GPS time prior to use). The tagged whales traveled at speeds comparable to humpback whales that were suction-cup tagged in the same area during July and August of 2005 and 2006 (Baumgartner et al. 2008): the mean swimming speed of the dermal attachment tagged whales was 0.55 m s^{-1} (n = 5, SD = 0.17 m s^{-1}, 95% CI: 0.34 – 0.76 m s^{-1}) and the mean swimming speed of the suction-cup tagged whales was 0.74 m s^{-1} (n = 6, SD = 0.22 m s^{-1}, 95% CI: 0.51 – 0.96 m s^{-1}). On average, suction-cup tagged whales swam slightly faster than dermal attachment tagged whales, but not significantly so (two-sample two-tailed *t*-test, $t = 1.57$, $p = 0.1517$).

Photographs were obtained of the tag site immediately after tagging in 4 of the 5 events (the exception being event 2 where the tag site was well below the water line). The tag site in each of these cases looked very good in the short-term (i.e., in the few hours following tagging), with the delrin "stop" resting snugly against the skin with no sign of swelling, bruising, protruding tissue, or damage to nearby skin. Over the week following tagging, additional photographs were taken of 2 of the 4 tagged individuals (events 3 and 5). The animal tagged during event 3 shed the needle within 2 days of tagging (Fig. IV-6), and the wound appeared to be healing well at that time with no signs of trauma. Follow-up photographs over the course of the next 3 months indicated complete healing with no long-term swelling or depression at the wound site (Fig. IV-6d). The whale tagged during event 5 was photographed 4, 5, and 9 days after tagging (Fig. IV-7). The needle was migrating cleanly out of the skin on day 4, and was completely shed by day 5. By day 9, the wound site was virtually undetectable (Fig. IV-7e), and follow-up photographs collected over the next 2 months indicated complete healing (Fig. IV-7f).

Over the 3 months following tagging, all of the whales were re-sighted within 30 km of the location at which they were originally tagged. Confirmed re-sightings of 3 of the 4 individuals persisted within 30 km of the tagging location for nearly 5 months after tagging. All were re-sighted in the same area the following year (2010). Two of the tagged whales were reproductively mature females, and both produced calves in years following the tagging. One of these females calved during 2010 and was therefore pregnant when tagged.

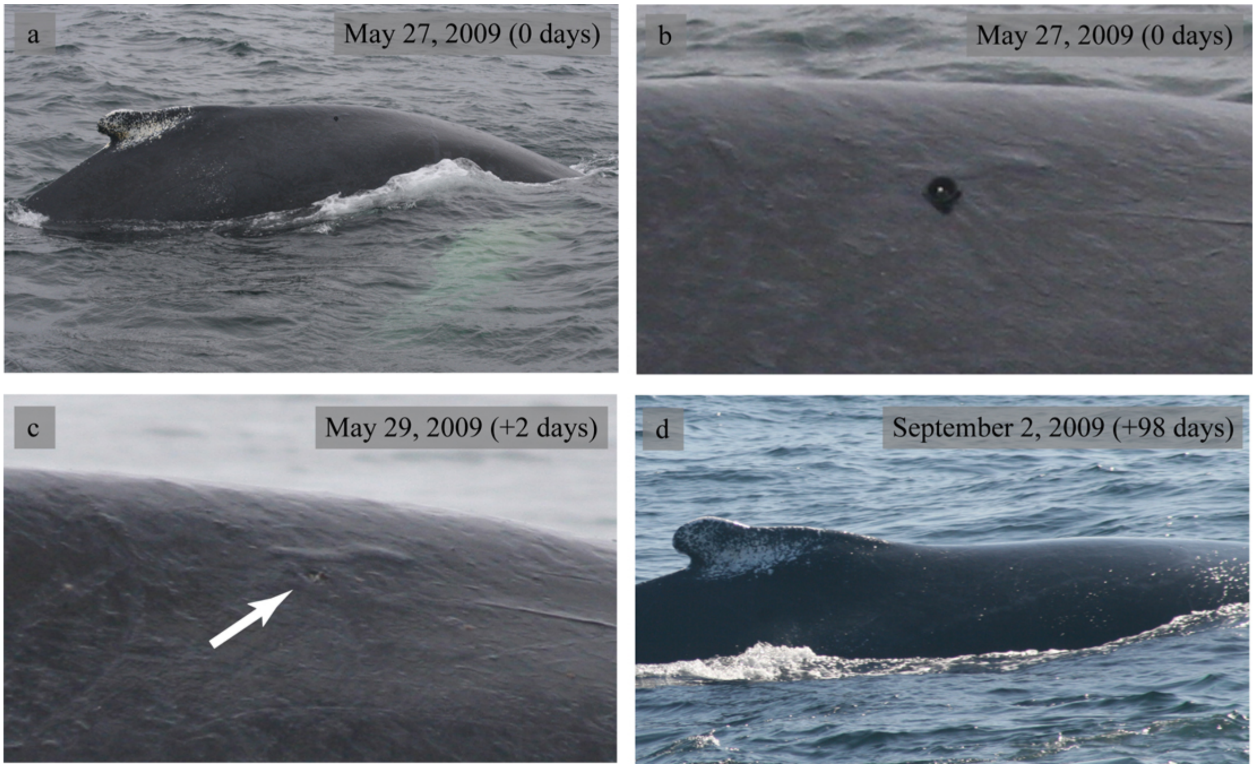

Figure IV-6. *Photographs of a humpback whale tagged in the Southwestern Gulf of Maine during event 3. Panels show the tag attachment site (a, b) and progression of wound healing (arrow in panel (c) points to wound, panel (d) shows the tag site is no longer visible by day 98). Photo credits: (a-c) Woods Hole Oceanographic Institution, and (d) Whale and Dolphin Conservation Society. Note that a black delrin "stop" (shown in Figure IV-5) was used in event 3.*

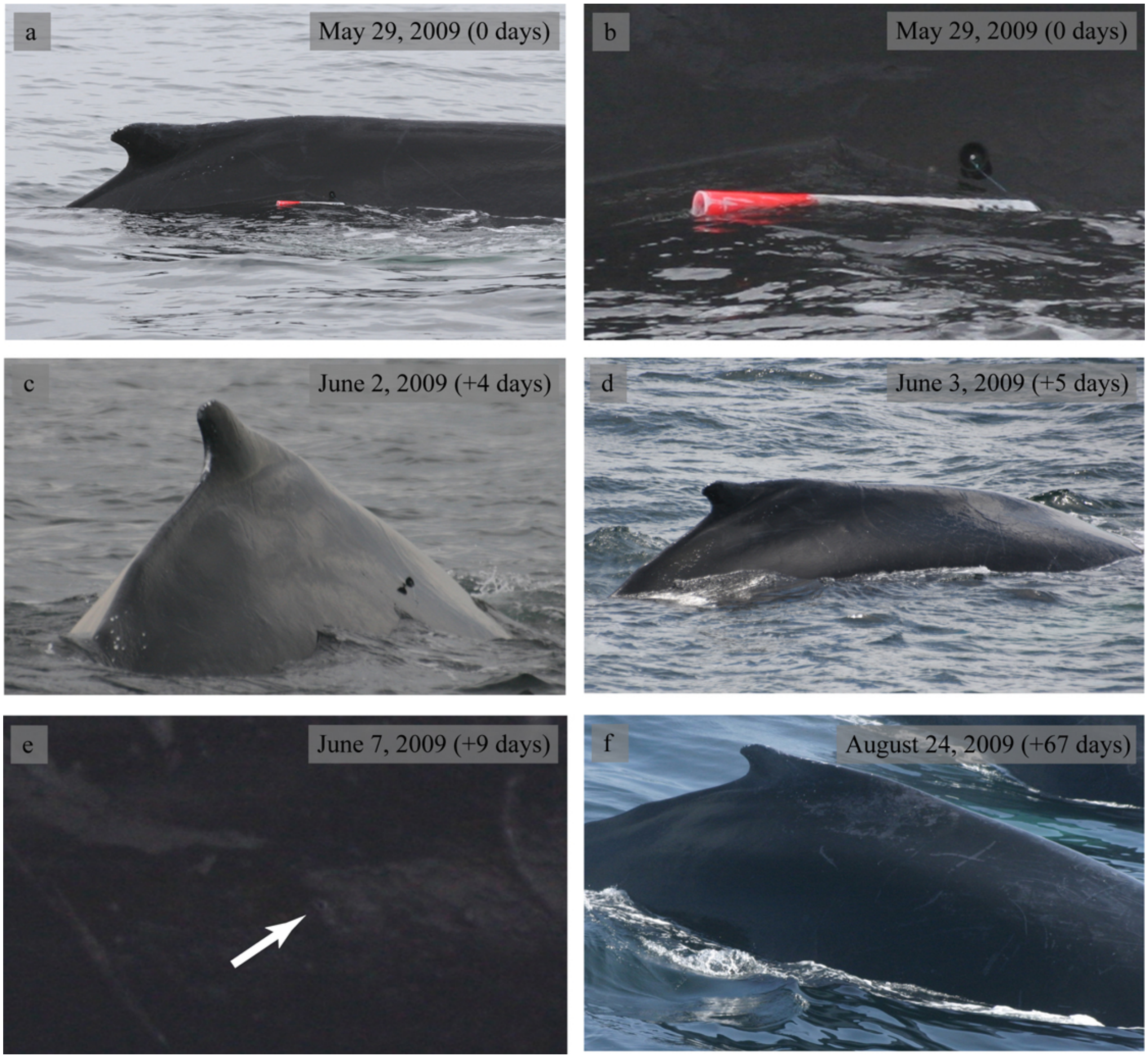

Figure IV-7. *Photographs of a humpback whale tagged in the Southwestern Gulf of Maine during event 5. Panels show the tag attachment site (a, b) and progression of wound healing (arrow in panel (e) points to wound, panel (f) shows the tag site is no longer visible by day 67). Photo credits: (a, b) Woods Hole Oceanographic Institution, (c, d) Whale Center of New England, (e) Provincetown Center for Coastal Studies, and (f) Dolphin Fleet. Note that a black delrin "stop" (shown in Figure IV-5) was used in event 5.*

Effects of dermal attachment: bowhead whales

From late August to mid-September during 2009-2011, we used the dermal attachment tag to study the diving and foraging behavior of bowhead whales on the western Beaufort Sea shelf off Barrow. A total of 13 whales were tagged (Table IV-2; Fig. IV-8). During 2009 and the first half of the 2010 field season, needles with cupped rings ranging in length from 6.5 to 7.5

cm were initially used on bowhead whales with variable, but generally quite poor, results (Fig. IV-9a-f). During some deployments, this needle was observed to fully penetrate and then immediately exit the skin and blubber (note that this same design was used on humpbacks with far better anchor retention). Six bowhead whales were tagged with this needle design, and tag attachments ranged from 11 min to 271 min (median = 30 min). During the later half of the 2010 field season, we switched to 7.5-cm needles with stainless steel pins, and attachments became extremely reliable (Fig. IV-9g-m). Six whales were tagged with the needle featuring the stainless steel pins, and tag attachments ranged from 45 min to 137 min (median = 116 min); all of these tags detached as planned via the corrosive release. The original study design called for tag attachments of 1-2 hours (after Baumgartner and Mate 2003), so these deployments were considered successful. All tag deployments were made at faster approach speeds or longer distances than that which is feasible for pole deployment of suction cup tags.

Table IV-2: *Results for each bowhead whale tagged in 2009-2011, including attachment duration (in minutes), total distance traveled (in kilometers), average swimming speed (in kilometers per hour), and the number of casts conducted near the tagged whale with the vertical profiling instrument package. Note that the tag did not attach properly during Event 3 in 2009, and Events 1 and 2 in 2010 were gray whales.*

Event	Date/time	Needle type	Duration (min)	Distance (km)	Speed (km/hr)	No. casts
2009						
1	09/02/09 15:21	Rings	30	4.9	9.8	4
2	09/07/09 12:48	Rings	35	3.7	8.9	3
4	09/13/09 13:49	Rings	21	1.8	10.2	2
5	09/13/09 18:34	Rings	271	38.5	8.5	15
2010						
3	09/09/10 13:20	Rings	12	1.9	12.5	2
4	09/16/10 09:12	Rings	11	1.4	8.7	2
5	09/16/10 10:48	Pins	65	10.3	9.0	5
6	09/17/10 13:56	Pins	137	21.3	9.3	10
7	09/17/10 17:09	Pins	45	6.2	9.1	5
8	09/18/10 12:23	Pins	88	13.2	9.7	6
9	09/18/10 14:53	Pins	129	17.5	8.3	7
10	09/19/10 15:28	Pins	116	13.0	7.0	5
2011						
1	09/13/11 12:36	Pins	97	14.7	9.1	5
Average			81	15.4*	8.8*	5.5

* *Calculated only for tagging events with durations over 30 minutes*

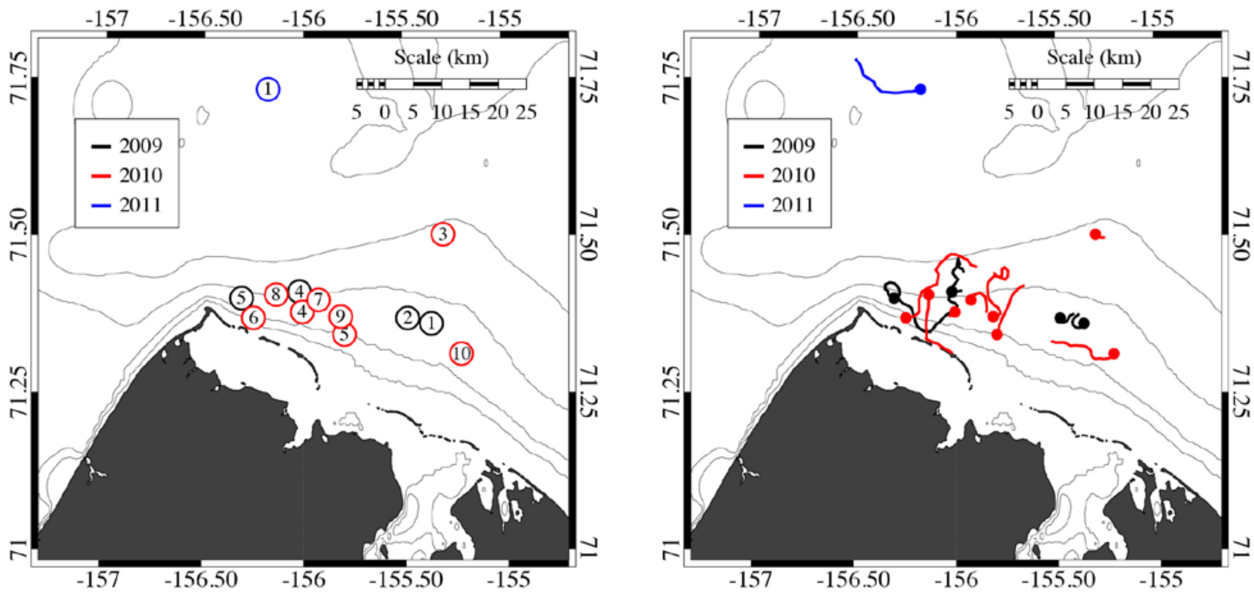

Figure IV-8. *Maps of (left) tagging locations and (right) tracks for all bowhead whales tagged in 2009-2011.*

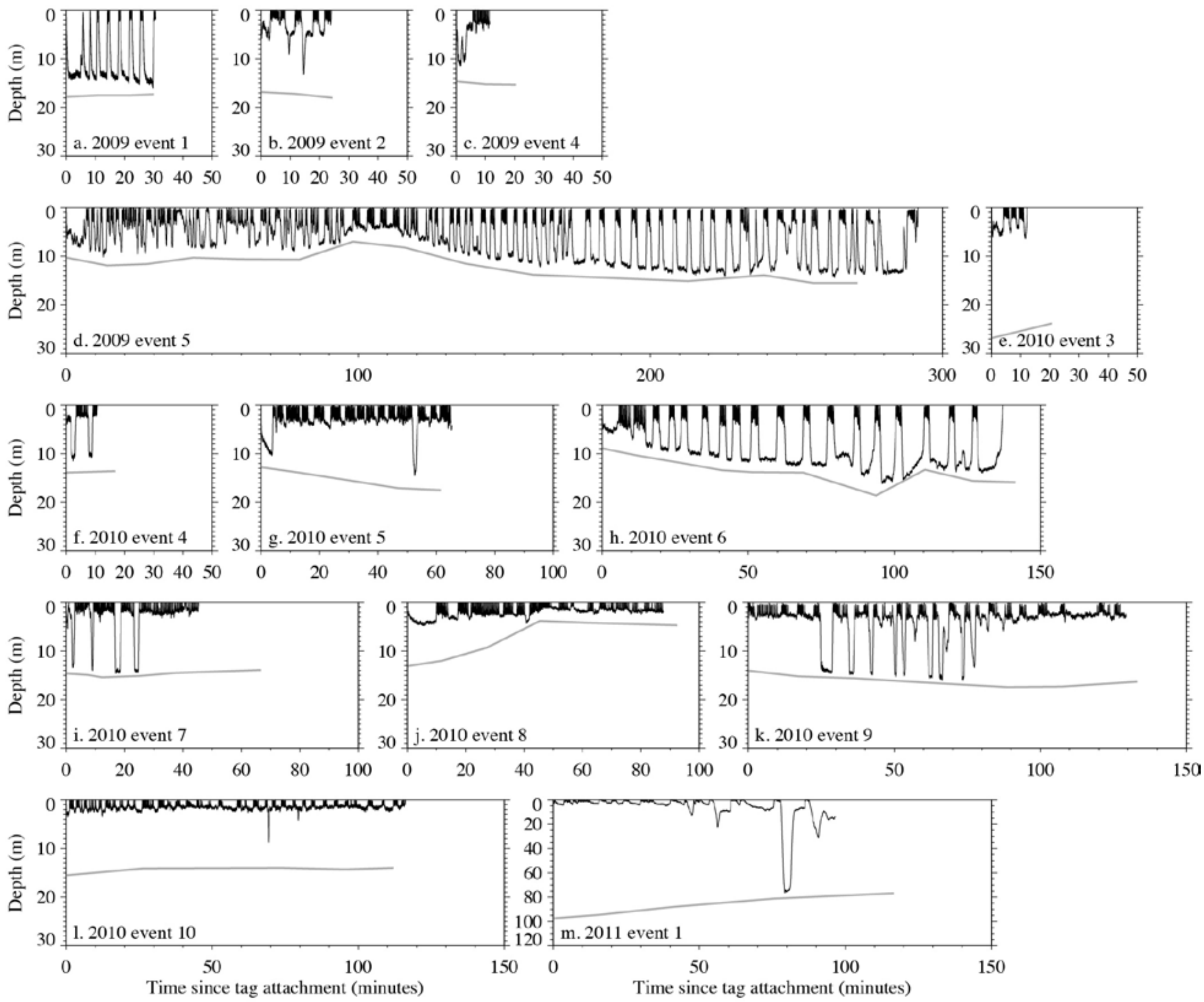

Figure IV-9. *Bowhead whale dive profiles. Sea floor shown as light gray line. Note change in depth scale in (m). Time scale is identical in all plots.*

There were very few reactions to the tagging process; on one occasion, the tagged whale made a tail flick in response to the carrier rocket falling on its peduncle, and on another occasion the tagged whale resurfaced within a minute of tagging and slapped the sea surface with a pectoral fin. In all other cases, the whales showed no overt reaction to tag deployment. However, many whales made a long dive immediately after tagging. Of the 8 whales that carried the tag for 30 minutes or more, five spent 4.0-10.0 min submerged immediately after tagging, whereas the remaining 3 whales had first dive times of only 0.3-1.2 min. Of the 5 whales that had long first dives, 3 of these first dives were significantly longer than subsequent dives observed over the course of the first hour. These results suggest that the immediate reaction to small boat approach and tagging is relatively mild and varies among individuals.

To assess the response to tagging over the first few hours of attachment, respiration rates were measured for each tagged whale using surfacing data from the TDR. These rates were then compared between the first and second hour of attachment. The surfacing during which the tag was attached was not included in these calculations. Respiration rates for the tagged animals were also compared to the respiration rates of undisturbed bowheads. Undisturbed rates were observed for 4 bowheads on 10 September 2010 over the course of an hour from a stationary small boat whose engines had been shut down for 30 min prior to respirations being recorded. Undisturbed individuals were each monitored for 5.5-22 min. For the five whales tagged for roughly 1.5 hours or more, respiration rates for the first hour of attachment were significantly higher than for the second hour of attachment (paired one-sample two-sided *t*-test: n = 5, average difference = 0.39 blows min^{-1}, $t = 5.55$, $p = 0.0052$). Respiration rates for the tagged whales averaged 1.79 blows min^{-1} during the first hour (n = 5, SD = 0.336 blows min^{-1}) and 1.41 blows min^{-1} during the second hour (n = 5, SD = 0.327), whereas undisturbed bowheads averaged 1.29 blows min^{-1} (n = 4, SD = 0.191 blows min^{-1}). Respiration rates during the first hour of tag attachment were significantly higher than those of the undisturbed whales (two-sample two-tailed *t*-test: $t = 2.65$, $p = 0.0328$), but there was no significant difference between respiration rates for the undisturbed animals and those observed during the second hour of tag attachment (two-sample two-tailed *t*-test: $t = -0.633$, $p = 0.5470$; note low power of this test). After 1.5 hours had elapsed since tag attachment, average respiration rates for the tagged whales and the undisturbed whales were nearly identical (tagged: n = 4, average = 1.24 blows min^{-1}, SD = 0.300; undisturbed: n = 4, average = 1.29 blows min^{-1}, SD = 0.191; two-sample two-tailed *t*-test: $t = 0.310$, $p = 0.7669$). These results suggest that the response of bowhead whales to close approach and tagging lasts for up to 1-1.5 hours, but afterward, the whales behave (at least physiologically) like undisturbed whales. This time scale of response appears to be longer than that observed for suction-cup tagged North Atlantic right whales (*Eubalaena glacialis*), whose first feeding dive immediately after tagging is an average 15% shorter than subsequent dives (average duration is 12.2 min), but no response is apparent afterward (Baumgartner and Mate 2003).

After tag attachment, we found bowhead whales difficult to approach without disturbing their behavior, and because the goal of our study was to observe natural behavior, no follow-up photographs were collected of the tagged whales or the tag site. Moreover, owing to the remoteness of their habitat, there is no concerted photographic monitoring of this population. Therefore, we were unable to conduct a follow-up study to determine the duration of needle attachment or the condition of the wound site over time.

Zooplankton community composition

The most common taxa imaged by the VPR were euphausiids, copepods, naked pteropods, ctenophores, hydromedusae, and jellyfish (Fig. IV-10). Zooplankton community composition was dominated by euphausiids in 2009 with small contributions from both gelatinous taxa (ctenophores, hydromedusae, and jellyfish) and copepods (Fig. IV-11). Gelatinous zooplankton dominated nearly all the casts in 2010 and 2011 (Fig. IV-11), with smaller contributions from euphausiids and copepods. Chaetognaths and naked pteropods were less common than all the other taxa. With the exception of 2009, the abundance of euphausiids and large copepods was generally low both in the presence and absence of bowhead whales (Fig. IV-12). For all zooplankton taxa except euphausiids, abundance in the presence of whales was highest in 2010 (Fig. IV-12). The abundances of large copepods, naked pteropods, and chaetognaths were comparatively very low in 2009 and 2011. In contrast, the abundance of gelatinous zooplankton was quite high, particularly in 2010 (tens to hundreds of organisms m^{-3}, and one nearshore sample peaking at 5400 organisms m^{-3} – not shown in Fig. IV-12).

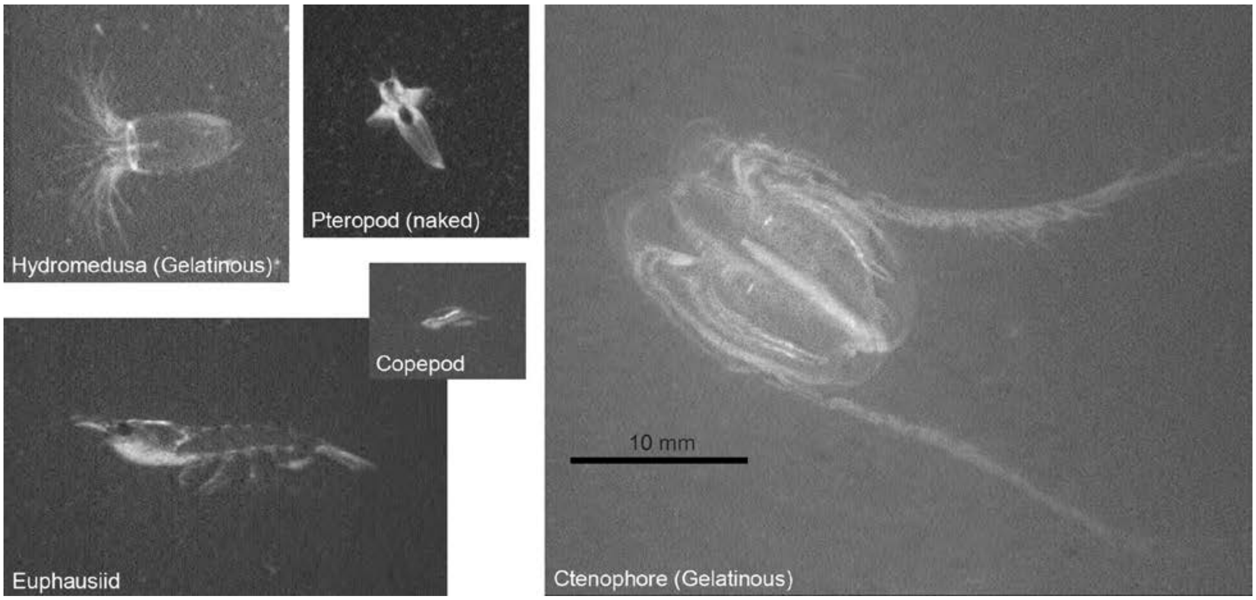

Figure IV-10. *Video plankton recorder (VPR) images of different zooplankton taxa collected in the Beaufort Sea off Barrow, Alaska. All images share the scale bar shown in the ctenophore image.*

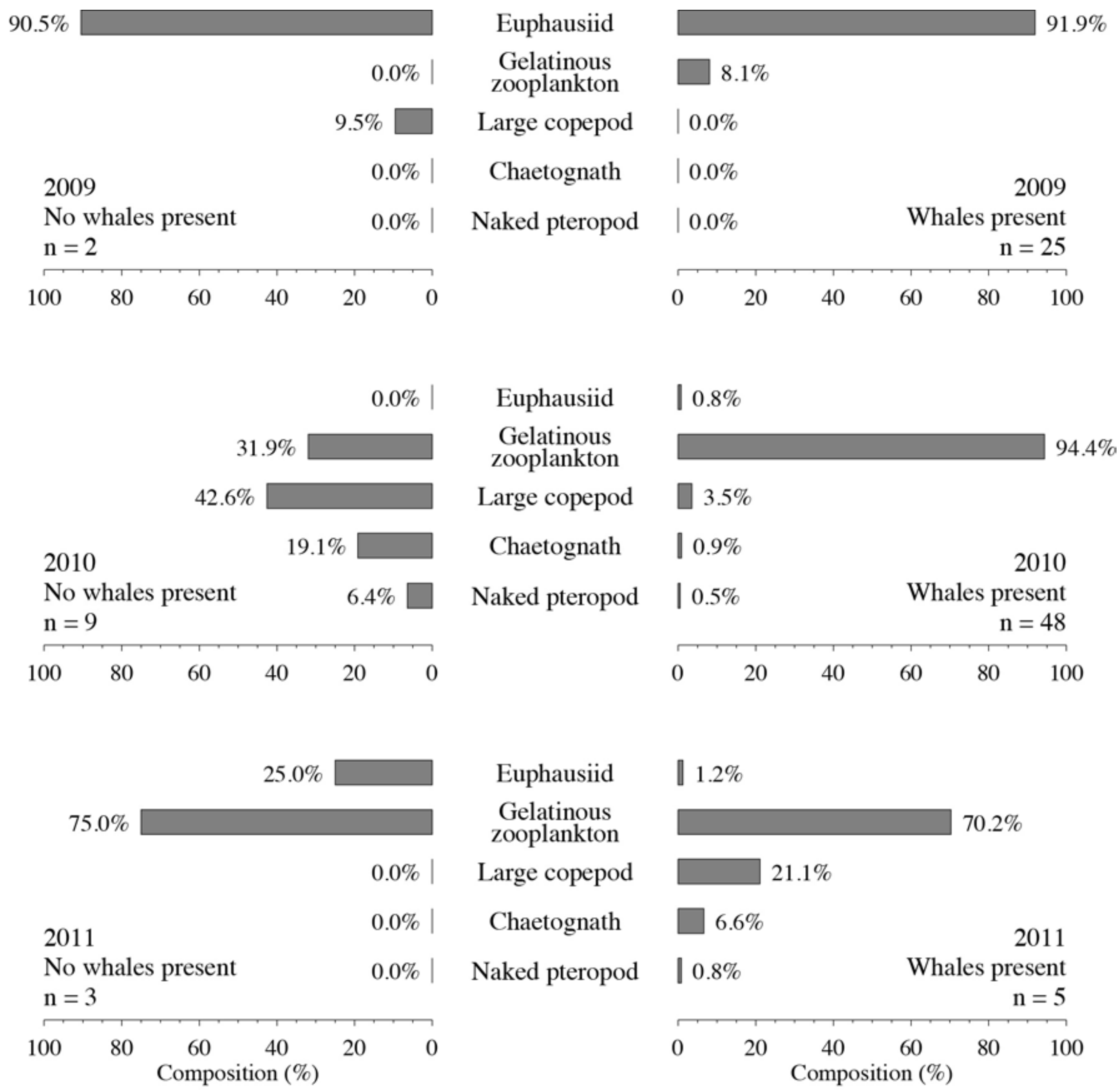

***Figure IV-11.** Zooplankton community composition in the absence (left panels) and presence (right panels) of bowhead whales in years 2009 (top), 2010 (middle) and 2011 (bottom). Sample size indicates number of VPR casts analyzed. Gelatinous zooplankton include hydromedusae, ctenophores, and jellyfish.*

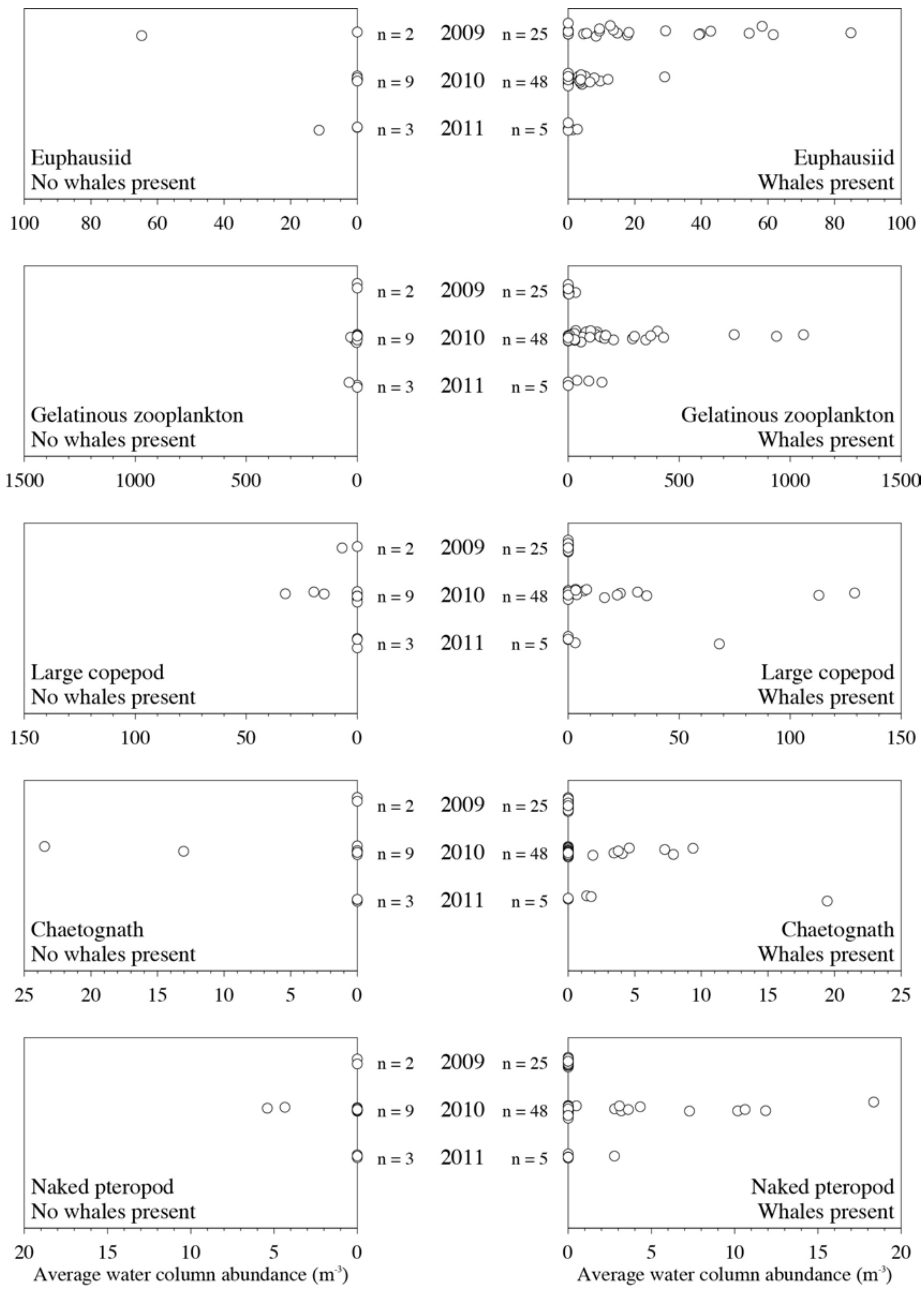

Figure IV-12. *Zooplankton abundance by taxa in the absence (left panels) and presence (right panels) of bowhead whales. Ordinate values jittered. Sample size indicates number of VPR casts analyzed. Gelatinous zooplankton include hydromedusae, ctenophores, and jellyfish.*

Diving behavior

Tagged bowhead whales exhibited highly variable diving behavior, both between and within individuals. Several whales conducted U-shaped dives at regular intervals to within a few meters of the sea floor while traveling (Fig. IV-9a,d,h) which is highly suggestive of prospecting. Other whales engaged in surface traveling behavior with only sporadic dives to within a few meters of the sea floor (Fig. IV-9g,i,k,m), while some remained near the sea surface while traveling for the entire time they were tagged (Fig. IV-9j,l). For whales with sufficiently long attachment durations, diving behavior changed over time; for example, the whale tagged in 2009 during event 5 (Fig. IV-9d) engaged in highly variable diving behavior during the first 2 hours of the attachment, but dives became more regular as it moved offshore into deeper waters.

There was no apparent association between the diving behavior of the whales and the vertical distribution of either euphausiids or large copepods, the two putative prey species of bowhead whales in the Beaufort Sea (Fig. IV-13, IV-14). Only on two occasions were reasonably high abundances of euphausiids observed in proximity to the tagged whales (Fig. IV-13b,d), yet in each instance the whale seemingly ignored these prey patches. Elevated copepod abundance was also observed in proximity to tagged whales on only two occasions (Fig. IV-14l,m), but again, these were seemingly ignored by the whales. Moreover, the actual abundance of copepods in these patches were at least an order of magnitude lower than that observed near feeding North Atlantic right whales (Baumgartner and Mate 2003, Baumgartner et al. 2003).

The predominant movement behavior observed during the tagging events was traveling. Tagged bowhead whales covered significant distances at an average speed of 8.8 km hr^{-1} (Table IV-2). During this traveling behavior, some whales predominantly remained near the sea surface (Fig. IV-9g,j,l,m), while others made repeated dives to the sea floor (Fig. IV-9a,d,h,k).

Bowhead whale presence and zooplankton abundance

To assess the relationship between bowhead whale occurrence and zooplankton abundance, euphausiid and large copepod abundance was estimated for VPR casts conducted in both the presence ($n = 24$) and absence ($n = 20$) of whales during 2007-2011. Repeated casts near tagged whales were ignored; only the first cast for each tagging event (i.e., at the tagging location) was used for this analysis. Using logistic regression, no relationship was found between the relative probability of whale occurrence and either euphausiid abundance ($p = 0.4029$) or large copepod abundance ($p = 0.8167$) (Fig. IV-15). Similar results as these can also be obtained using non-parametric tests, such as the Mann-Whitney test.

For comparison, an identical analysis was conducted using zooplankton abundance estimated in the presence/absence of North Atlantic and North Pacific right whales (*Eubalaena japonica*) (data from Baumgartner et al. 2003, Baumgartner et al. submitted, and unpublished data). Both of these species feed on large calanoid copepods of the Calanidae family (specifically, *Calanus finmarchicus* for North Atlantic right whales, and *Calanus marshallae/glacialis* for North Pacific right whales). Even when using different methods to assess zooplankton abundance (nets, optical plankton counter, VPR) and right whale presence (sighting and acoustic surveys), a strong relationship was detected between the probability of right whale occurrence and copepod abundance (Fig. IV-16; $p = 0.0010$ for North Atlantic right whale sighting surveys and optical plankton counter data, $p < 0.0001$ for North Atlantic right whale sighting surveys and net samples, $p = 0.0151$ for North Atlantic right whale sighting surveys and VPR data, and $p = 0.0026$ for North Pacific right whale acoustic surveys and VPR data).

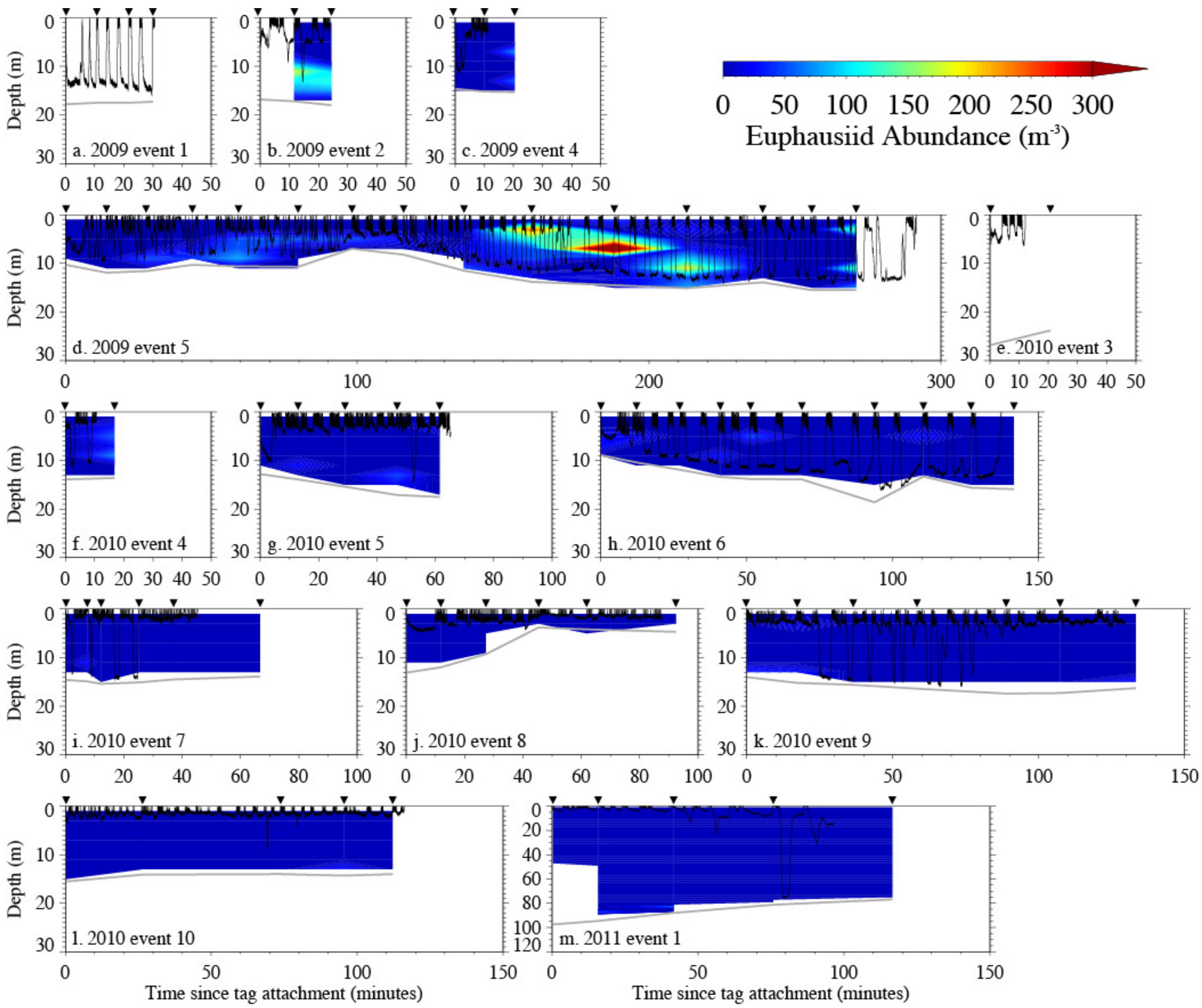

Figure IV-13. *Bowhead whale dive profiles (black line) with respect to the abundance of euphausiids observed with the video plankton recorder (VPR). Sea floor shown as light gray line. Inverted triangles indicate the times when casts were made along the whale's track with the vertical profiling instrument package. Note change in depth scale in (m). The VPR failed in (a), the first cast of (b), and (e). Time scale is identical in all plots.*

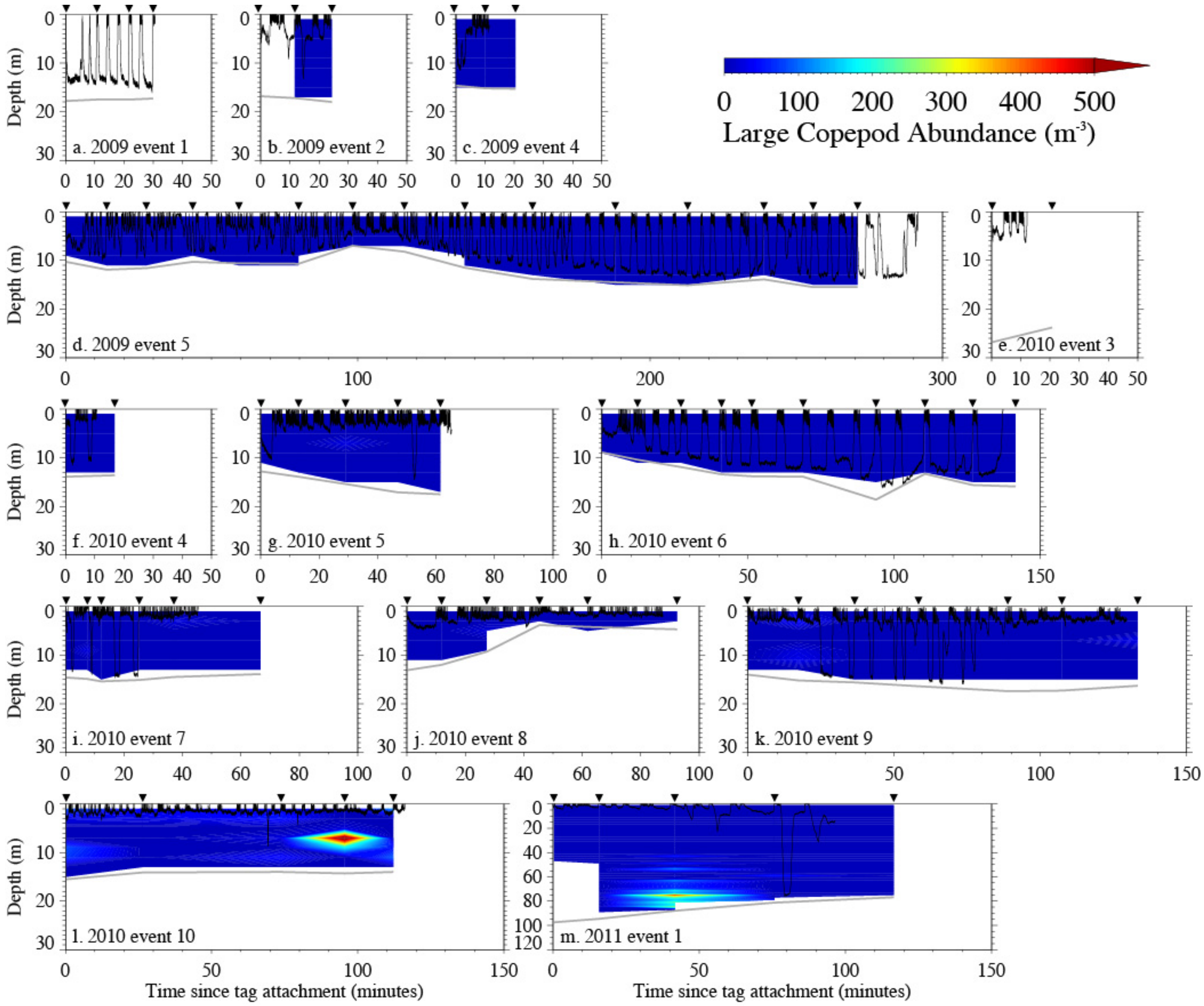

Figure IV-14. *Bowhead whale dive profiles (black line) with respect to the abundance of large copepods observed with the video plankton recorder (VPR). Sea floor shown as light gray line. Inverted triangles indicate the times when casts were made along the whale's track with the vertical profiling instrument package. Note change in depth scale in (m). The VPR failed in (a), the first cast of (b), and (e). Time scale is identical in all plots.*

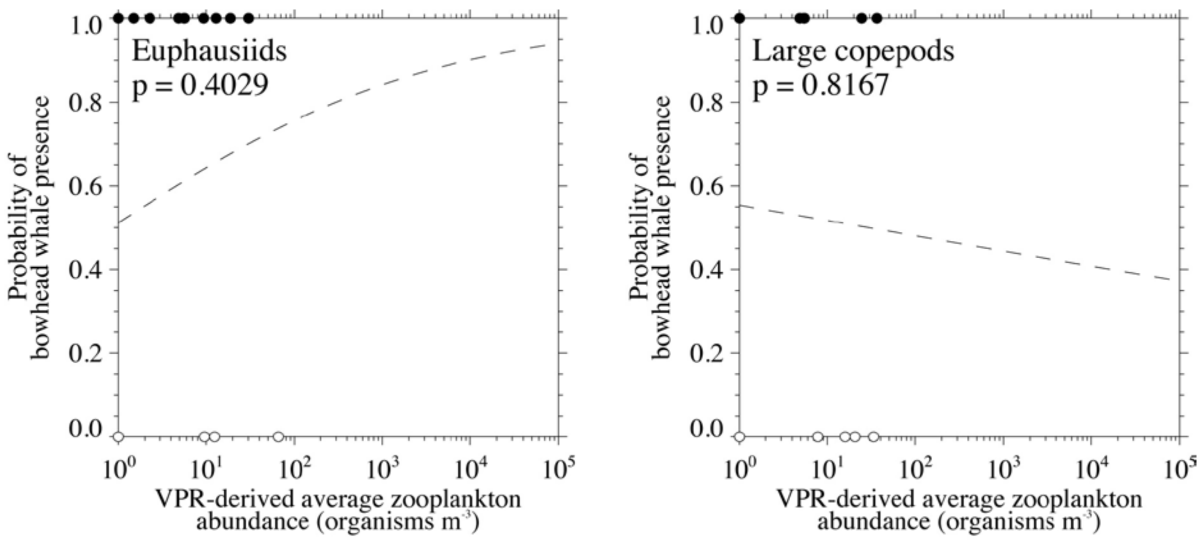

Figure IV-15. *Relationship between bowhead whale occurrence and (left) euphausiid and (right) large copepod abundance modeled with logistic regression. Filled and open circles represent casts with and without whales nearby, respectively, and the dashed (non-significant) logistic regression line indicates how the relative probability of occurrence changes with zooplankton abundance. The significance of the regression is reported as a p-value.*

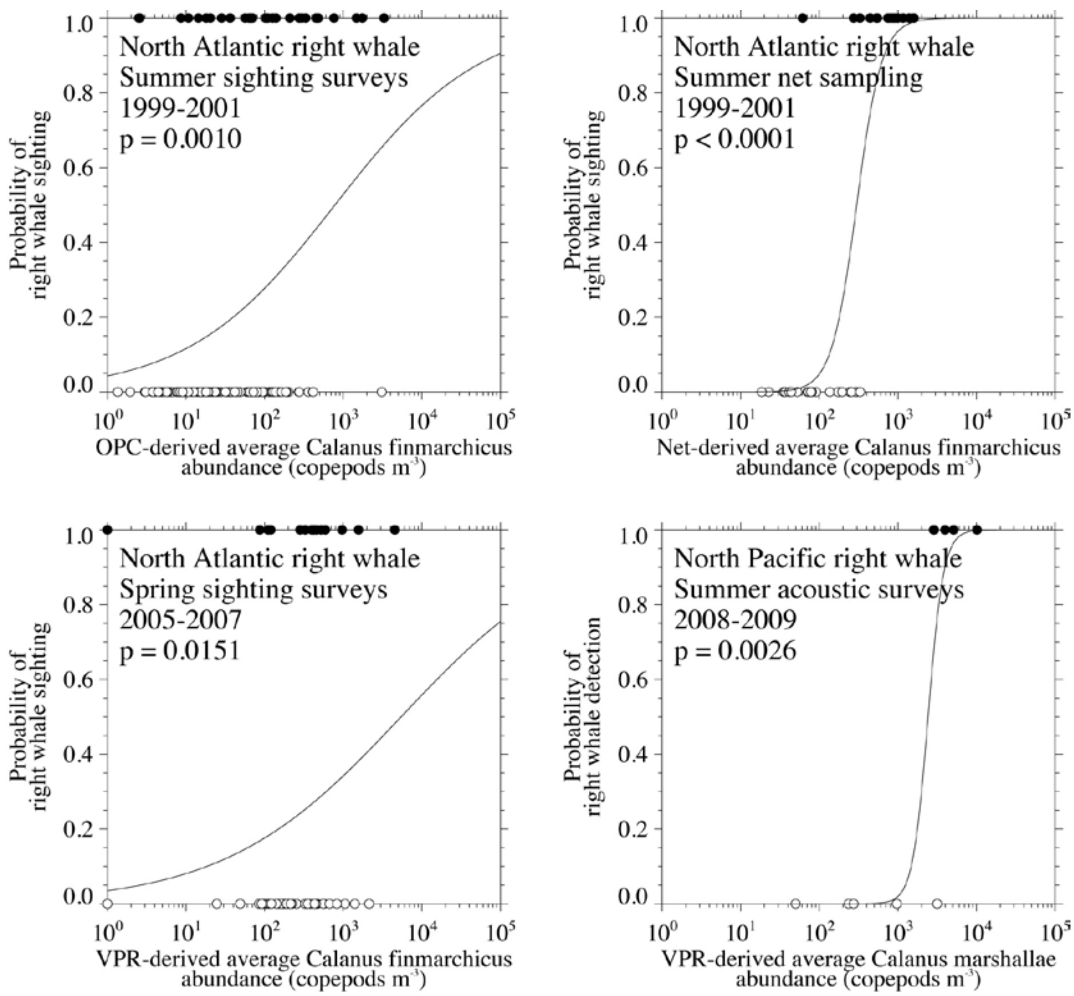

Figure IV-16. *Relationship between right whale occurrence and copepod abundance modeled with logistic regression for (upper left, upper right) North Atlantic right whales in the Bay of Fundy during 1999-2001, (lower left) North Atlantic right whales in the southwestern Gulf of Maine during 2005-2007, and (lower right) North Pacific right whales in the Bering Sea during 2008-2009. Filled and open circles represent survey units with and without whale detections, respectively, and the logistic regression line indicates how the relative probability of detection changes with copepod abundance. The significance of the regression is reported as a p-value.*

Discussion

From our field trials with humpback whales and the subsequent photographic documentation of the tag site, the dermal attachment appears to be reasonably benign. Our selection of a well-studied humpback whale population off Massachusetts and the small sample size was by design, allowing us to proceed cautiously by closely monitoring the outcome of a few trials. In the two best-monitored cases, needles were shed in 2 and 5 days, and the wound site appeared in very good condition over time scales of days to months after tagging. Re-sightings for all humpback whales and calving events for known mature females indicate that the dermal attachment has no discernable effect on long-term behavior and reproduction. While it is nearly impossible to study the wound site in detail, we believe that the needle design (cutting blades with vents that may preserve epidermal tissue) and sterilization of the needle prior to use may improve health outcomes for the tagged whales.

Reactions to boat approach and tagging varied widely between individuals and species. Both humpbacks and bowheads appeared to tolerate tag deployment well; overt reactions were uncommon, and when observed, were mild. Immediately after tagging, we observed long submergences and increased respiration rates in some bowhead whales, which suggests that the tagging process may be stressful for this species. However, respiration rates returned to levels observed in undisturbed animals within 1-1.5 hours of tagging. In contrast to the bowheads, the behavior of humpback whales appeared to be unchanged by the tagging process. The differences between the two species may be related more to the animals' experience with boats than to the attachment of the tag itself. Off of Massachusetts, humpback whales are regularly approached by a variety of vessels, including commercial whale watch vessels and pleasure boats. Bowhead whales have no such experience with boats, small or large, except perhaps those used in the subsistence hunt by the Alaskan Iñpuiat Eskimos. It is plausible, therefore, that bowheads would be more reactive to any close boat approach, so future studies that seek to study natural behavior should use tag attachments of sufficient duration to allow whales time to recover from the initial stress of the tagging process.

It is likely that none of the tagged whales actually fed during the period they were tagged. This conclusion is based on (1) no apparent relationship between the whales' diving behavior and the vertical distribution of their prey (Fig. IV-15, IV-16), (2) the relatively low abundance of both euphausiids and large copepods observed in proximity to the tagged whales with the VPR (Fig. IV-12), and (3) the large distances traveled by the tagged whales (Table IV-2). The combination of travel and repeated dives to the sea floor is indicative of prospecting or searching behavior (e.g., Fig. IV-9a,d,h), further supporting the notion that the tagged whales were not encountering prey patches of sufficient concentration to warrant feeding. In contrast to our bowhead observations, the diving behavior of North Atlantic right whales is closely coupled to the vertical distribution of their copepod prey (Baumgartner and Mate 2003), and movements of feeding whales over hourly time scales are often constrained to a very small area; tagged right whales that are feeding typically remain within a 1-km radius circle for periods of at least 1-2 hours (Baumgartner unpublished data). This area-restricted movement behavior was not observed in the tagged bowhead whales (Fig. IV-8).

The observed traveling behavior may have been induced by the stress of the tagging process or as a consequence of being followed by a small boat for an extended time; therefore, our observations may simply be an artifact of our study methods. The comparison of respiration rates in undisturbed and tagged whales certainly suggests behavioral differences that are likely related to the tagging process. However, these differences were highly variable, with some individuals showing little reaction, and others showing stronger reactions. The fact that some whales engaged in putative prospecting behavior argues that behavioral disturbance did not prevent some whales from foraging. If behavioral disturbance did prevent the tagged whales from feeding, we would *still* expect to sample high abundances of their zooplankton prey in proximity to the whales if the area is a significant feeding area. The probability of bowhead whale occurrence was unrelated to the abundance of euphausiids and large copepods, indicating that even undisturbed whales were not associated with high abundances of prey. This further suggests that neither the tagged whales nor undisturbed whales were encountering prey patches sufficiently concentrated to warrant feeding.

Given the absence of whales in our tagging operation area during 2007 and 2011, it appears that there is significant interannual variability in prey abundance that influences the occurrence of the whales in the waters off Barrow. Even in years with moderate prey concentrations (2009), bowheads appear to travel extensively on the Beaufort Sea shelf and do not occur solely in areas with high prey abundance (e.g., Fig. IV-13d). It is likely that the waters off Barrow are not always a rich feeding ground; however, variability in prey abundance makes these waters worth visiting on the chance that zooplankton abundance will be high. Since the fall migration corridor includes the waters off Barrow, whales must pass over the western Beaufort Sea shelf to reach the Chukchi Sea and ultimately the Bering Sea. Pausing in this area may be motivated not only by potential feeding opportunities, but perhaps also by an opportunity to socialize or coordinate migration movements with conspecifics.

Acknowledgements

This study was conducted by a dedicated team of researchers, including Billy Adams, Lewis Brower, Michael Donovan, H. Carter Esch, Craig George, Nadine Lysiak, Sarah Mussoline, and Kate Stafford. Significant help was provided by the following people: Nadine Lysiak processed all VPR data and conducted taxonomic analysis of the resulting VPR images, Terry Hammar led the design and development of the dermal attachment tag, Jooke Robbins coordinated collection and analysis of the humpback whale photographs, Ken Houtler provided ideas for improving flight stability of the dermal attachment tag, Matthew Holland and Chad Murphy of VEMCO verified the efficacy of the acoustic transmitter in the tag housing, Michael Moore and Sea Rogers Williams provided advice on sterilization of the dermal anchor, and Bruce Mate allowed the use of his federal permit to conduct part of this work. The following naturalists provided photographs of tagged humpback whales: Regina Asmutis-Silvia (Whale and Dolphin Conservation Society), Jenn Tackaberry (Whale Center of New England), Carole Carlson (Dolphin Fleet) and Carol Carson (Captain John and Sons). This work could not have been done without the assistance and support of the North Slope Borough Department of Wildlife Management, Barrow Arctic Science Consortium, Barrow Whaling Captains Association, and Alaska Eskimo Whaling Commission. Special thanks goes to Chuck Monnett of the Bureau of Ocean Energy Management for his sustained support of the BOWFEST project. Testing on fin whale carcasses was conducted under permit #932-1489 issued to Teri Rowles, and all tagging work was conducted under permits #369-1757 issued to Bruce Mate and #1058-1733 issued to Mark Baumgartner.

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SECTION V - NORTH SLOPE BOROUGH RESEARCH
A - LOCAL BOAT SURVEYS

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[2] Delongview Enterprises, Fairbanks, Alaska

Abstract

The North Slope Borough Department of Wildlife Management (DWM) coordinated small-boat surveys during the BOWFEST study from 2008 to 2012. The study area spanned the nearshore waters (to ~15 miles offshore) from approximately Cape Simpson to 25 miles SW of Barrow. The vast majority of the surveys were conducted by chartering local hunters and their boats. For all five years, a total of 1,427 marine mammals were recorded (469 sightings) of which 650 were bowheads (175 sightings). Total effort was about 1,400 hours. We found that bowhead whales summer in the study area in low numbers but show considerable annual variation. Local knowledge and results of our surveys suggest that numbers may have increased over the last 30 years. Gray whales consistently feed near Barrow during summer. While their relative abundance varies annually, gray whale occupancy is more predicable in local feeding areas during summer than bowhead whales. Bowhead and gray whales show clear spatial segregation in the study area with gray whales using deeper waters to the west associated with Barrow Canyon and bowheads targeting shelf waters to the east, with some overlap north of Point Barrow. For the entire study period, about 50% of the bowheads sighted were scored as feeding but there was considerable variation by year. The largest aggregations of bowheads seen were near the barrier islands. Sighting rates (whales seen/hour) were higher in the study area in 2009 and 2010 (July to September) than other years. Sighting rates tended to be higher for bowhead whales than gray whales, but surveys were more often conducted in areas frequented by bowheads. Sighting rates for bowheads in August and September 2011 were very low despite the highest survey effort of any season. Possible explanations include a delayed migration from Canada associated with high prey abundance, delayed sea ice development, low prey densities near Barrow, or some combination of these factors. Locally-operated boat surveys proved to be an effective, relatively low-cost method to locate whales, support community-based science, and estimate distribution and relative abundance.

Introduction

Multidisciplinary studies of bowhead whales (*Balaena mysticetus*) feeding near Barrow during summer/fall have been ongoing since 2005, beginning with the National Science Foundation's (NSF) SNACs program[1]. Examinations of bowhead stomach contents have been ongoing for over 30 years, beginning in the 1970s under the National Oceanic and Atmospheric Administration-National Marine Mammal Laboratory (NOAA-NMML), and since 1981 by the North Slope Borough (NSB) (e.g., Lowry et al. 2004; Sheffield and George Section VB: this volume). The Bureau of Ocean Energy Management (BOEM) funded a multi-year bowhead whale feeding study (BOWFEST) via NMML starting in 2007.

[1] SNACs began in 2004, but the first field season was 2005.

Its purpose was to expand and continue the feeding ecology research begun under the NSF. Besides some basic scientific contributions, the information from the BOWFEST study will be used by BOEM for pre- and post-lease analysis and documentation under the National Environmental Policy Act (NEPA) for Beaufort Sea and Chukchi Sea Lease Sales.

Several authors have noted that the Barrow area is important for whale hunting and as a feeding area for bowheads (Moore et al. 2010). However, the mechanisms which promote this feeding area and quantification of its biological oceanography were poorly understood. The migration of the Bering-Chukchi-Beaufort seas (BCB) bowhead whales past Point Barrow has been subject to a hunt by Iñupiat whalers for roughly 2,000 years (Stoker and Krupnik 1993). Bowheads commonly feed during their westward fall migration (Lowry et al. 2004; Sheffield and George Section VB: this volume) through the Beaufort Sea, and fall hunting is likely facilitated when whales linger to feed near Barrow. Hunters, and NSB unpublished observations, indicate that feeding whales tend to be less wary and more easily approached. Aerial surveys indicated that bowhead densities during fall near Barrow were among the highest reported in the Beaufort (see Monnett and Treacy 2005, Clarke et al. 2011). Prior to these studies, timing of bowhead whale arrival and residency in waters near Barrow was not well understood or documented. Moore (1992) noted that "opportunistic records show that bowheads were seen near Barrow throughout summer during the 1980s, but reports were sporadic and whale numbers low." Hunters often reported summertime bowhead sightings near Barrow; however, it was unclear whether these whales arrived from the eastern Beaufort Sea or resided near Barrow during summer (Moore et al. 2010). New evidence from telemetry studies suggests that both conditions may occur. Bowheads show greater mobility than previously thought with whales making long east-west movements across summer feeding areas from Canada to Russian waters (Quakenbush et al. 2010a,b).

NSB Department of Wildlife Management (DWM) coordinated small-boat surveys during the BOWFEST study from 2008 to 2012. The observational skill of local hunters is well documented (Bee and Hall 1956, Albert 2001, Noongwook et al. 2007) in the literature, but "traditional knowledge" (TK) and local knowledge has not routinely been collected (Huntington and Quakenbush 2009, Quakenbush and Huntington 2010) in many communities. This project was also intended to engage hunters in scientific studies and document local knowledge.

Objectives

1. Use local hunters in field surveys to locate cetaceans and other marine mammals.
2. Gather distribution data on bowhead whales in the study area (Barrow to Cape Simpson and offshore ~30 km) via local boat-based surveys <u>before</u> the intensive oceanographic sampling and aerial surveys initiated on ~15 August.
3. Document locations and basic behavior of feeding whales from a small boat-based platform.

Methods

Local boat captains with whaling experience in the Point Barrow area were hired to conduct BOWFEST surveys. All were Iñupiat Eskimo, and some were registered whaling captains with the Alaska Eskimo Whaling Commission (AEWC). Additional observations were collected from the *R/V Annika Marie*, *R/V Launch 1273*, and NSB-DWM boats used for the oceanographic and tagging portions of BOWFEST. About 85% of the effort was from hunter charters and opportunistic sightings by marine mammal hunters not directly associated with the project. In some cases, data were included from other projects not specifically part of BOWFEST, such as DWM seal surveys. Bowhead sightings from some seal and walrus hunters that had global positioning systems (GPS) were used as well. Our approach was somewhat novel in that local hunters conducted the bulk of the surveys. They also assisted with several other science projects such as whale tagging, deploying acoustic recorders, and deploying and retrieving oceanographic equipment.

Prior to each field season, DWM staff attended both the AEWC and the Barrow Whaling Captains' Association (BWCA) meetings to: a) describe the study logistics and objectives, and b) seek permission to conduct surveys in the Barrow fall whaling grounds. The BWCA responded with general interest and support but asked that all activities cease one week prior to the locally designated start of fall whaling, usually around 1 October.

Before the initial survey, DWM identified boat captains with fall whaling experience via the Barrow Arctic Science Consortium (BASC) and from our personal knowledge of local captains. We held an orientation meeting with captains and support staff to discuss the overall goals of the project and review the field protocol. Critical points for completing data sheets, such as the importance of recording bowhead feeding behavior and data codes, were reviewed. Boat captains were asked to review the safety equipment list and confirm they had all the necessary safety gear. DWM personnel determined the survey area the prior day with some waypoints to define the border of the survey area. Boats were sent out in pairs, if there were no other boats working in the area, but were separated as much as possible so that they did not observe the same whales. Formal transects were used occasionally. More often hunters were sent to areas (e.g., SW of Barrow and ENE of Point Barrow) where they had been successful finding bowheads while whaling. Instructions for a survey might be "survey from the Point (Point Barrow, *Nuvuk*) to the Martin Island waypoint and offshore to the about the 60 ft (20 m) line; be safe." Surveys were about eight hours in duration. Detailed survey protocols are listed in Appendix VA-1.

Data were hand-recorded on forms affixed to clipboards. Binoculars were used when possible when ocean conditions permitted. A GPS was used to record the ship track and location of each marine mammal sighting. A small Canon camera was supplied to take digital images and film clips of whales for documentation.

The onboard observers (most had years of whaling experience) were asked to record all cetacean sightings (e.g., bowhead, gray (*Eschrichtius robustus*), beluga (*Delphinapterus leucas*), minke (*Balaenoptera acutorostrata*), fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*) whales, and harbor porpoise (*Phocoena phocoena*)) and, where possible, note observations of seals, birds, and other marine mammals. If possible, the behavior of all large whales was noted, particularly when whales were thought to be feeding.

Once back on-shore, data were retrieved each evening by DWM personnel. Photographs, GPS tracks and waypoints were downloaded, and the data were entered into a database. The following morning, entries were reviewed with the observers.

Analysis

Data were entered into and analyzed in MS Excel. The types of data collected are listed below. Sightings were summarized and presented as raw counts with no correction for visibility, detection probability, or distance. Therefore, the sighting data in these reports should be considered an index of relative abundance and not an estimate. Sighting (or catch) per unit effort was estimated as the number of animals seen as a function of survey effort (hours) on a weekly and seasonal (year) basis. Behavioral data were calculated as the sums of whales seen in a specific behavior category by year.

Data Forms

A basic data form was devised for use during the surveys. After some field testing, we decided on the form in Figure VA-1. In recording sightings of groups of whales, the size and behavior of individuals had to be recorded separately, which could be an inconvenience for observers. Whale size was estimated by the observer based on their hunting experience. Codes used on the form are given in Table VA-1.

BOWHEAD FEEDING STUDY WHALE SIGHTING FORM

DATE ______________ START: ______ END: ______

WEATHER __________________________________ **GPS#** ______

CAPTAIN & CREW __________________________________

RECORDER __________________________________

TIME	WPT#	LATITUDE	LONGITUDE	SPECIES	# SEEN	SIZE	VIS	BEHAVIOR

Figure VA-1. *Example of data form used for the small boat surveys. In 2012, a sea state column was added. Observations of all cetacean sightings and other marine mammals also were recorded.*

Table VA-1. *Codes used during the BOWFEST local boat surveys.*

WEATHER	SPECIES	BEHAVIOR
PC - PARTLY CLOUDY	BH – BOWHEAD WHALE	F – FEEDING
CL – CLEAR	GW – GRAY WHALE	M – MIGRATING/TRAVELING
OV - OVERCAST	BW- BELUGA WHALE	B – BREACHING
LR - LIGHT RAIN	KW – KILLER WHALE	I – INTERACTING
HR- HEAVY RAIN	HB – HUMPBACK WHALE	FL – FLUKE-UP DIVES
LF - LIGHT FOG	MW – MINKE WHALE	U – UNKNOWN
HF - HEAVY FOG	FW – FIN WHALE	O – OTHER (DESCRIBE-INCLUDING
SEA- Beaufort Sea state		DIVING, MILLING, AND RESTING)
	RS – RINGED SEAL	
VISIBILITY	SS – SPOTTED SEAL	
P – POOR	BS – BEARDED SEAL	**GPS NOTES**
F – FAIR		HOLD TO MAKE WAYPOINT
G – GOOD	PB – POLAR BEAR	TURN ON GPS BEFORE TAKE OFF
VG – VERY GOOD		
E – EXCELLENT	WR – WALRUS	

Results and Discussion

Intermittent small boat surveys were conducted from late June through mid-September from 2008 to 2012, with most survey effort focused during August and September. The surveys summarized here were largely conducted by local experienced whale hunters employed by the BOWFEST project and included observations from other vessels associated with the project. The most abundant species seen were bowheads (n = 650), gray whales (n = 501), and beluga whales (n = 184). Other cetacean sightings included low numbers of harbor porpoise, possible minke whales, and possible humpback whales. The sighting numbers reported here are raw counts and are not corrected for visibility conditions. A brief summary of each year is provided herein followed by a summary for all years of the study.

2008

A total of 18 surveys were conducted from 15 August to 13 September in 2008. Six of the 18 surveys were hunting forays conducted by hunters associated with BOWFEST, prior to being hired (15 August) on the study (Fig. VA-2, Table VA-2). These surveys were included because reliable GPS tracks existed and the hunters were confident about their recollection of bowhead sightings. With the inclusion of earlier hunting forays, the surveys spanned from 20 July to 13 September. During the July and early August surveys, only sightings of bowhead whales were documented and no other species were recorded.

During the period from 20 July to 13 September, a total of 59 bowhead whales were seen plus 4 additional "possible" bowhead sightings. Gray whales were the most commonly seen whale with 61 recorded sightings; however, this is a minimum as not all gray whales were recorded during the surveys. All gray whales were seen west of 156° W longitude. Other marine mammal sightings included two possible minke or humpback whales, two walruses (*Odobenus rosmarus*), and four swimming polar bears (*Ursus maritimus*) (a single animal and a sow with 2 cubs). Seals were ubiquitous through the area and were not consistently recorded.

Sea ice was mostly absent in the study area after 15 August. The sea ice in the area before 15 August appeared to consist of entirely first-year ice; no multiyear ice was seen.

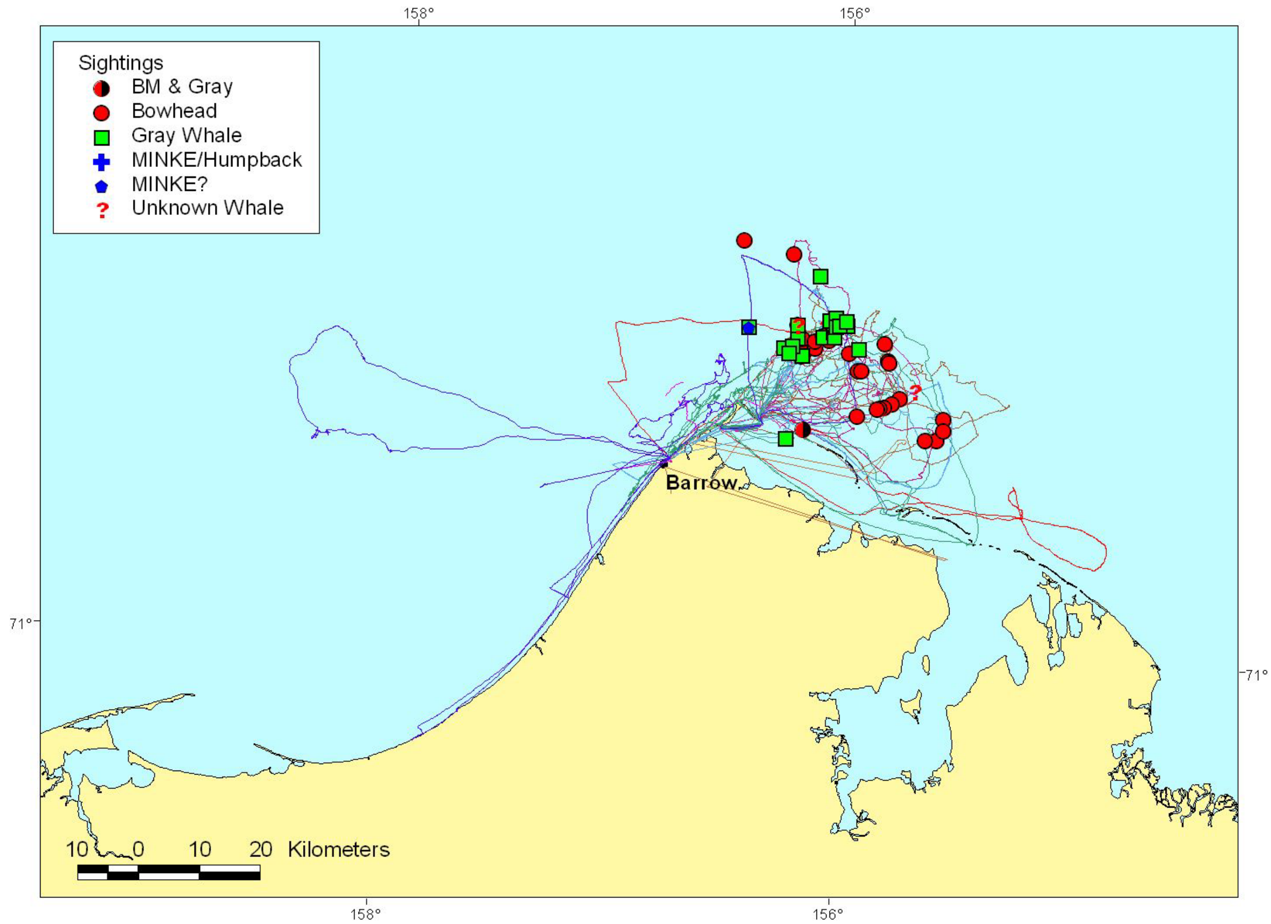

Figure VA-2. *Locations of cetacean sightings and effort tracks during local boat-based surveys, 20 July - 13 September 2008.*

Table VA-2. *Number of individuals and sightings of cetaceans during small boat surveys, 20 July - 13 September 2008.*

Cetaceans	No. Seen	No. Sightings
Bowhead whale	59	30
Bowhead or gray whale	4	2
Gray whale	61	23
Harbor porpoise	0	0
Minke or humpback whale	1	1
Possible minke	1	1
Unknown cetacean	4	3
Beluga whale	0	0

2009

We have records for 26 boat surveys in 2009. These surveys included opportunistic hunter observations and BOWFEST-funded surveys, which provided the bulk of the sightings. Survey data were available from 1 July to 16 September (Fig. VA-3, Table VA-3).

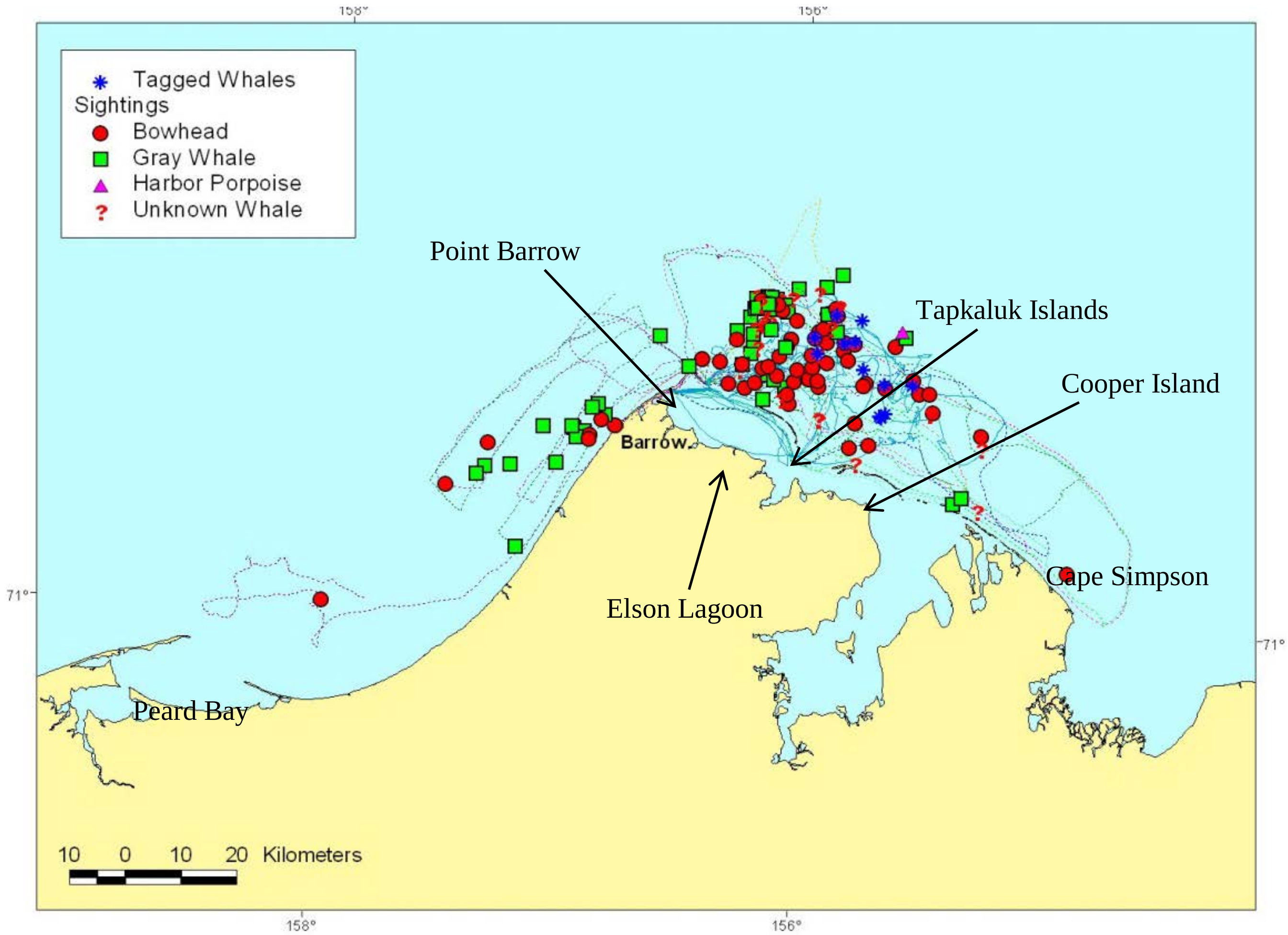

Figure VA-3. *Locations of cetacean sightings and effort tracks during local boat-based surveys, 1 July to 16 September 2009. Use this map as a general reference for place names used in this report.*

Table VA-3. *Number of individuals and sightings of cetaceans during small boat surveys, 1 July to 16 September 2009.*

Cetaceans	No. Seen	No. Sightings
Bowhead whale	289	70
Bowhead or gray whale	34	23
Gray whale	81	39
Harbor porpoise	1	1
Minke or humpback whale	0	0
Possible minke	0	0
Unknown cetacean	0	0
Beluga whale	0	0

During the period from 1 July to 16 September, a total of 289 bowhead whales were seen as well as an additional 34 unidentified large whale sightings that may have been either bowhead or gray whales (Table VA-3). Unlike 2008, bowhead whales appeared to be more common than gray whales in the survey area; however, not all gray whale sightings were recorded. As in 2008, most gray whales were seen west of the 156° W longitude line. Other species, incidental to the large whale surveys, included one harbor porpoise, numerous ringed (*Phoca hispida*), spotted (*P. largha*), and bearded seals (*Erignathus barbatus*), and sea bird observations. Neither humpback nor minke whales were recorded, nor were swimming polar bears recorded in the survey area in 2009. It is possible that polar bears were seen in some surveys but not recorded. Walruses were reported as abundant on the 1 July survey but numbers were not recorded. Seals were generally ubiquitous through the area but not consistently recorded.

Sea ice was mostly absent in the study area during August, all of September, and most of October. Bowheads were almost continuously observed and reported by subsistence hunters and also during boat surveys through summer 2009. On 1 July, nine bowheads were reported by Captain Harry Brower about 40 miles southwest of Barrow during an unrelated project. Most of these whales were very large and their behavior indicated they were feeding. On the evening of 24 July 2009, we observed 4-5 bowheads in the Chukchi Sea (71° 17.476 N; 156° 48.445 W) only 0.5 km from the city of Barrow. These whales appeared to be feeding and had mud plumes associated with them. Local whalers found this unusual, as did we, since bowheads have not previously been observed feeding nearshore off Barrow during July. Also unusual was that the whales were fluke-up diving in only 5.5 to 6 m water (Fig. VA-4).

Figure VA-4. *Photograph of feeding bowhead whale offshore of Barrow on 24 July 2009. Several whales appeared to be feeding with mud plumes associated with them. Local whalers did not recall ever seeing feeding bowheads during July off Barrow. Note the whales were fluke-up diving in only 5.5 to 6 m water. Photo: Dave Thoreson.*

On 11 August 2009, three boats went out on formal BOWFEST surveys and over 30 bowheads (including a cow/calf pair) and gray whales were observed from Point Barrow and east to Cape Simpson. Some exceptionally large bowheads were observed in deep waters NNE of Point Barrow by DWM personnel (Fig. VA-3). Behaviors recorded included both feeding and migrating.

Following a period of bad weather that prevented any boat surveys from being conducted, crews went out again on 20 August, and several bowheads were seen. From 20 August through 11 September, when formal BOWFEST boat surveys ended, whales were regularly seen on every survey with one exception. On 27 August, despite considerable effort by several boats, no bowheads were seen in the study area.

Generally bowheads were concentrated east of Point Barrow, and most were observed feeding. Water column, bottom (mud plumes evident near Cooper Island), and surface skim feeding were observed. There was a paucity of sightings between Tapkaluk (71° 19’N, 156° 05’W) and Cooper Island (71° 14’N, 155° 43’W) (see Fig. VA-3), but densities increased again east of Cooper Island. Also, many whales were seen by the tagging crew (see Baumgartner Section IV: this volume) within the area north of Cooper Island; however, they did not record individual whale locations. Note that during later satellite-tagging operations on 14 October, “dozens” of whales were observed north of Cooper Island and four whales were successfully tagged with satellite transmitters. The previous day (13 October), Bowhead Whale Aerial Survey Project (BWASP) aircraft found record numbers of bowheads just a few miles east. Janet Clarke (*pers. comm.*) reported:

> “*On 13 October 2009, BWASP completed transects in Block 12, again under very good survey conditions. There were 25 sightings of 297 bowhead whales. Six of the sightings, of groups ranging from three to 186 whales, were recorded as feeding. Sediment was noted in the water, along with birds. Some surface feeding was noted (and photographed).*”

The last boat survey was conducted on 16 September under poor visibility conditions, and only three bowheads were seen (from *R/V Launch 1273*). Per our longstanding agreement with the BWCA, we ceased research operations at least one week prior to the fall hunt, which began on 1 October.

Euphausiid “wash-ups” occurred on 7 August and 19 September on the beach in Elson Lagoon (Fig. VA-5). Such events are fairly uncommon and only occur when significant amounts of krill have been entrained in nearshore waters (see Ashjian et al. Section IIIB: this volume). The event was accompanied by high densities of Sabine’s Gulls (*Xema sabini*) and Arctic Terns (*Sterna paradisaea*) within the Lagoon and near Cooper Island (C. George, pers. observation).

Figure VA-5. *Photograph of a euphausiid (krill) wash-up along the beach inside Elson Lagoon on 19 September 2009 along its western shore* (71° 22'N, 156° 29'W). *Two events were reported in 2009 (7 August and 19 September) suggesting high concentrations of euphausiids in the area. Note the large number of phalaropes feeding near shore presumably on euphausiids (photo: C. George).*

2010

In 2010, 64 surveys were conducted by the boats associated with the study; however, tracks were not collected for every survey. These included surveys by locally chartered boats by the DWM, BOWFEST vessels such as *R/V Launch 1273* and *R/V Annika Marie*, and vessels used for the NOAA/NSB gray whale biopsy study. While bowhead sightings were recorded as early as 28 June, BOWFEST-funded local boat surveys were initiated on 27 July and continued through 17 September. Note that a short cruise was conducted on 24 September to retrieve the acoustic equipment and was not included in the sighting data. These surveys accounted for approximately half (30 of 64) of the survey effort.

Cetacean counts included: 215 bowhead whales (n = 41 sightings); 149 gray whales (n = 60 sightings), and more belugas were seen (125) than in past years (Fig. VA-6, Table VA-4). Belugas were seen inside Elson Lagoon in late July, August, and September. In fact, on 25 July, Robert Suydam (*pers. comm.*) reported seeing over 500 belugas near Point Barrow, mostly inside the Lagoon, that were likely feeding. Gray whales were consistently seen throughout the study period at predicable locations (Fig. VA-6). More harbor porpoise (n = 10) were seen in 2010 than in any year.

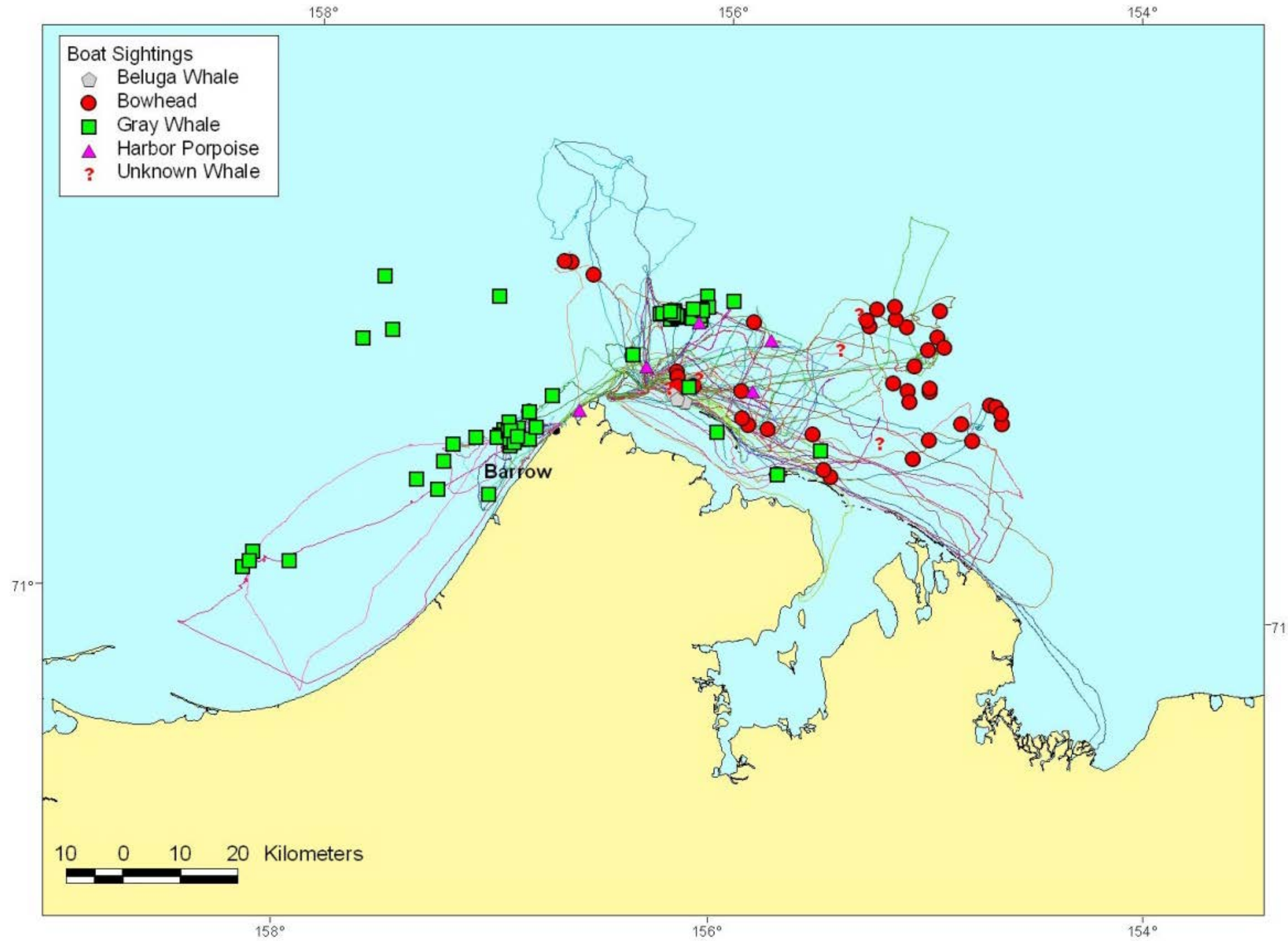

Figure VA-6. *Locations of cetacean sightings and effort tracks during local boat-based surveys, 28 June - 17 September 2010.*

Table VA-4. *Number of individuals and sightings of cetaceans during small boat surveys, 28 June – 17 September 2010.*

Cetaceans	No. Seen	No. Sightings
Bowhead whale	215	41
Gray whale	149	60
Harbor porpoise	10	5
Minke or humpback whale	0	0
Possible minke	0	0
Unknown cetacean	4	4
Beluga whale	125[1]	3

[1]Shore-based sighting of 500 belugas (by R. Suydam) is not included in this table.

The first bowhead sighting for the open water season was reported on 28 June by local seal hunters among ice floes just west of Barrow. Similarly, two bowheads were seen on 11 July by NOAA and NSB seal biologists north of Point Barrow. After these initial sightings, there was a long period without any bowhead sightings (essentially all of August). Bowhead whales were not seen again until 1 September. Bowheads were seen on essentially every survey in September. The highest densities of bowheads occurred in mid-September, and most whales were feeding. While there was some uncertainty about the availability of strikes for the fall hunt due to a successful spring hunt, surveys were ended on 24 September based on our agreement with the BWCA to stop work a week before the hunt start date of 1 October.

Despite increased effort in 2010, the relative distribution and abundance of bowheads in the Barrow area was lower during the summer period (July and August) than in 2009. In 2009, some bowheads were seen essentially all summer. Unlike 2009, there were no reported euphausiid wash-ups in 2010 and the plankton tows indicated lower euphausiid densities which might explain the low bowhead numbers in the area during summer (see Ashjian et al. Section IIIB: this volume).

2011

In 2011, surveys started in June (Fig. VA-7; Table VA-5) and included surveys by locally chartered boats by the NSB, vessels associated with BOWFEST such as *R/V Launch 1273* and *R/V Annika Marie*, hunters, and vessels used for a gray whale tagging study. We have records for a total of 77 surveys – the most of any year (tracks were not collected for every survey). Boat survey data were collected from 28 June to 30 September. More survey data were collected and the duration was longer than in any previous season.

Despite the increased effort, tallies indicate only 41 bowhead whales were seen (Table VA-5). This is remarkably low compared with past years, e.g., 215 bowhead whales were seen during the previous 2010 season. A total of 163 gray whales and 59 belugas were seen, which was consistent with other years.

The effort for the 2011 surveys (623 hours) was much greater than any previous season (see Summary section below). However, based on comparative data from past seasons and hunter assessments, bowhead numbers were exceptionally low in summer/fall 2011. Aerial surveys also indicated low occurrence of bowheads (see Rugh et al. Section I: this volume).

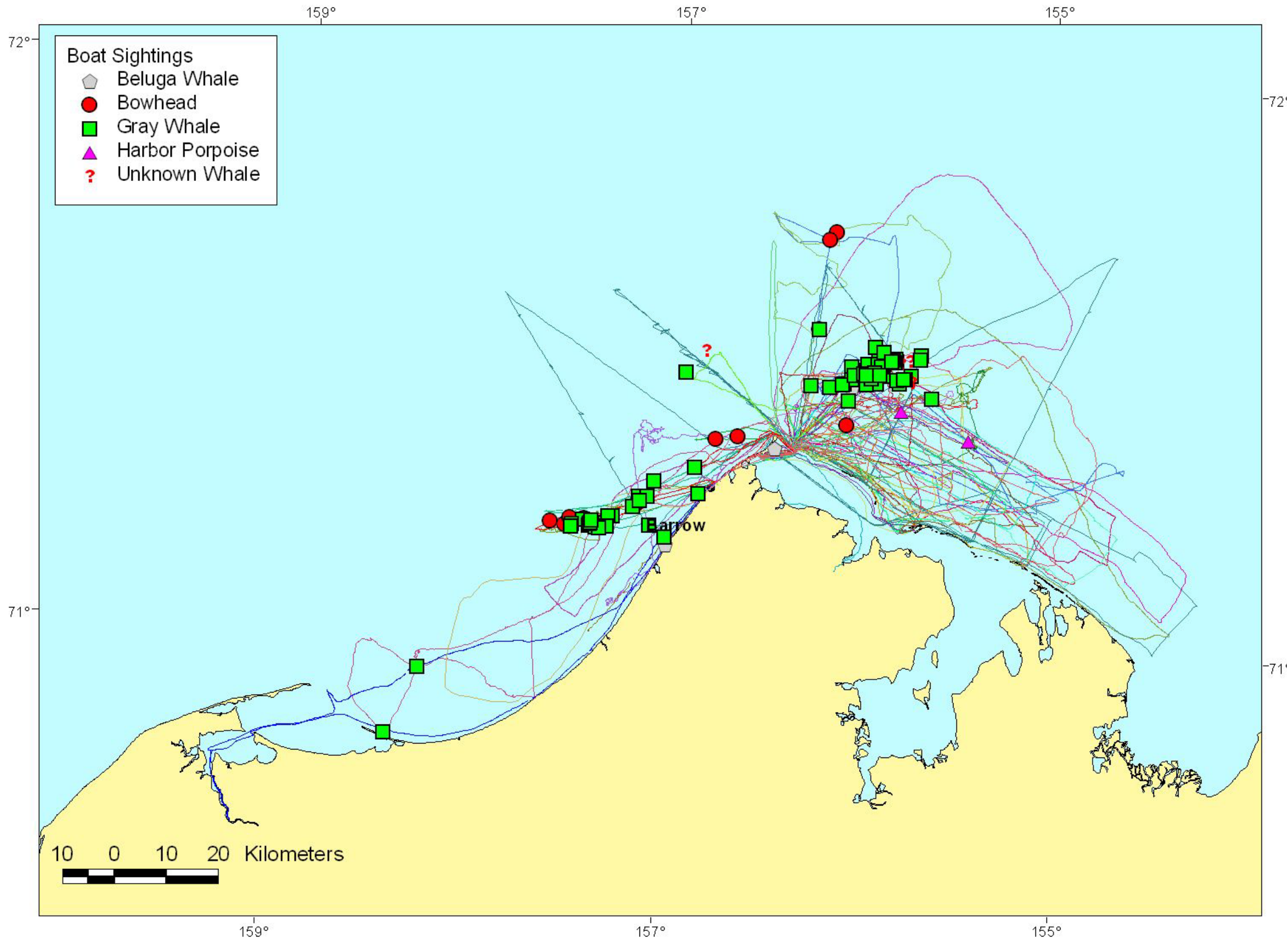

Figure VA-7. Locations of cetacean sightings and effort tracks during local boat-based surveys, 28 June to 30 September 2011.

Table VA-5. Number of individuals and sightings of cetaceans during small boat surveys, 28 June to 30 September 2011.

Cetaceans	No. Seen	No. Sightings
Bowhead whale	41	13
Gray whale	163	77
Harbor porpoise	3	3
Minke or humpback whale	0	0
Possible minke	0	0
Unknown cetacean	14	7
Beluga whale	59	6

2012

During 2012, limited surveys were conducted due to logistical constraints associated with BASC. Data collection methods were similar to past years. The surveys were conducted by the NSB seal tagging program, from local vessels in the Alaska Department of Fish and Game (ADF&G)/NSB

bowhead tagging study, NSB BOWFEST boat surveys, and the vessel *R/V Okpik* associated with BOWFEST. We have records for a total of 18 surveys conducted by the boats associated with the study (Fig. VA-8); however, tracks were not collected for every survey. Boat survey data were collected from 25 June to 21 September. The 2012 season was a relatively modest effort (137 hours) compared with past seasons (see Summary section below).

In contrast to 2011, some bowheads were seen intermittently through the summer of 2012. A total of 46 bowheads plus two large whales that were likely bowheads were seen. Gray whale sightings totaled 47 whales plus one possible gray whale. These were included in the "Bowhead or gray whale" data row in Table VA-6. Ten unidentified large whales were seen as well (Table VA-6).

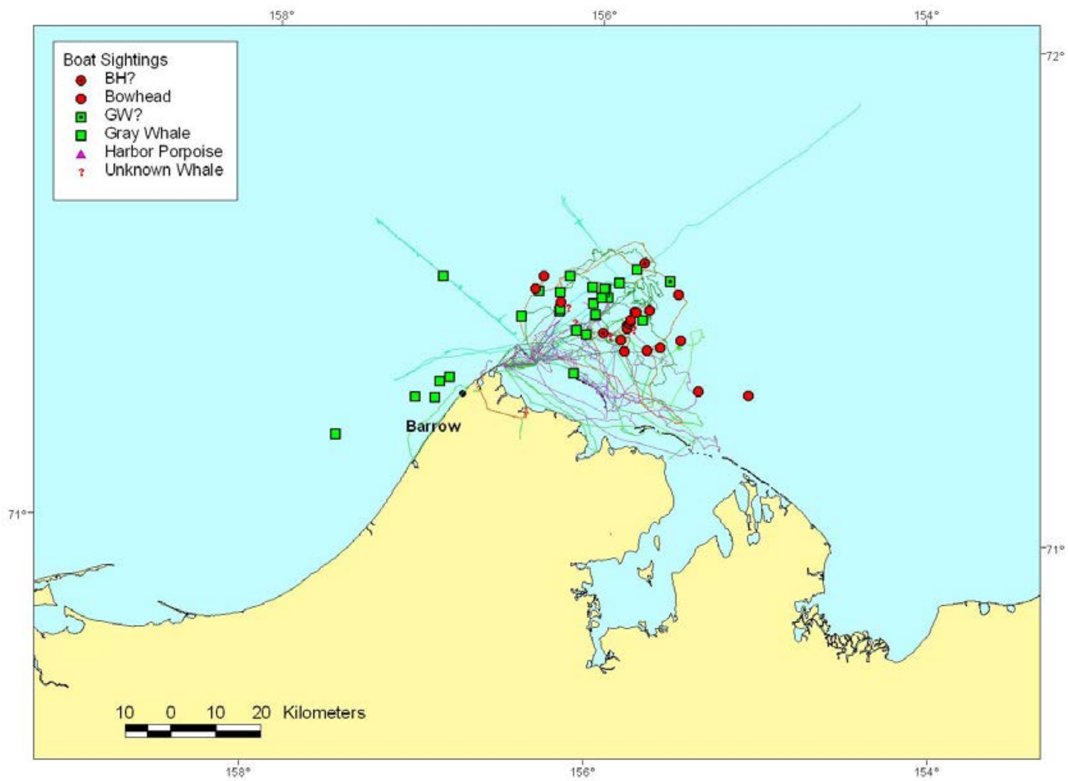

Figure VA-8. *Locations of cetacean sightings and effort tracks during local boat-based surveys, 25 June to 21 September 2012.*

Table VA-6. Number of individuals and sightings of cetaceans during small boat surveys, 25 June to 21 September 2012.

Species	No. Seen	No. Sightings
Bowhead whale	46	21
Bowhead or gray whale	3	3
Gray whale	47	26
Harbor porpoise	3	1
Minke or humpback whale	0	0
Possible minke	0	0
Unknown cetacean	10	6
Beluga whale	0	0

Summary of Results: 2008 to 2012

Surveys conducted by local hunters proved to be an effective, relatively low-cost method for surveying nearshore areas for large cetaceans in the Barrow area. The survey methodology used a semi-structured approach whereby observers were assigned to areas where they typically find whales during the fall whale hunt. Fixed transects were only occasionally used. Useful information on presence, location, relative densities, and behavior, particularly feeding bowheads, were gathered and is summarized here.

Observers saw a total of 1,427 cetaceans in 469 sightings in approximately 1,360 hours of effort over the five-year period of the study in the Barrow area (Table VA-7; Table VA-8).

***Table VA-7**. Total number of cetaceans seen and numbers of sightings (in parentheses) during local boat surveys 2008 to 2012 in the Barrow area.*

Cetaceans	2008	2009	2010	2011	2012	Totals
Bowhead whale	59 (30)	289 (70)	215 (41)	41 (13)	46 (21)	650 (175)
Bowhead or gray	4 (2)	0 (0)	0 (0)	0 (0)	3 (3)	7 (5)
Gray whale	61 (23)	81 (39)	149 (60)	163 (77)	47 (26)	501 (225)
Harbor porpoise	0 (0)	1 (1)	10 (5)	3 (3)	3 (1)	17 (10)
Minke or humpback	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
Possible minke	1 (1)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)
Unknown whale	4 (3)	34 (23)	4 (4)	14 (7)	10 (6)	66 (43)
Beluga whale	0 (0)	0 (0)	125 (3)	59 (6)	0 (0)	184 (9)
Totals	130 (60)	405 (133)	503 (113)	280 (106)	109 (57)	1427 (469)

Table VA-8. *Total survey effort (hours) by year for the BOWFEST small boat surveys.*

Year	Total hours
2008	81.8
2009	193.7
2010	321.6
2011	622.5
2012	137.5
Total	1357.1

Comparison of Sighting Rates

Sighting rates of bowhead and gray whales were computed based on raw counts uncorrected for visibility and detection. Hence, these data can only be used to examine relative differences in sighting rates. One apparent pattern in the data was that bowhead numbers and sighting rates (whales seen/survey hour), and presumably whale densities, varied markedly between years (Fig. VA-9). Particularly interesting years were the 2011 season which had the highest effort yet the lowest sighting rates; and the 2009 season with bowheads seen consistently in modest numbers all summer. The low number of bowheads in 2011 was consistent with the aerial surveys (see Rugh et al. Section I: this volume) and hunter observations. In fact, the fall subsistence bowhead hunt did not open until 7 October 2011 (typically it opens 1 October or earlier), in part due to low abundance of whales in the area. Even then, 33 whaling boats went out in calm weather and only one whale was taken. On the following day (9 October), 26 boats went out hunting but no whales were seen. The hunters said the lack of whales was very unusual (or even unprecedented) for this date (NSB-DWM unpublished data).

The highest sighting rates for bowheads occurred in September in all years, with the exception of 2011 when few whales were seen (Fig. VA-10). Presumably the buildup of whales near Barrow in September is from the influx of whales migrating west from feeding areas in Canada (e.g., Quakenbush et al. 2010a,b).

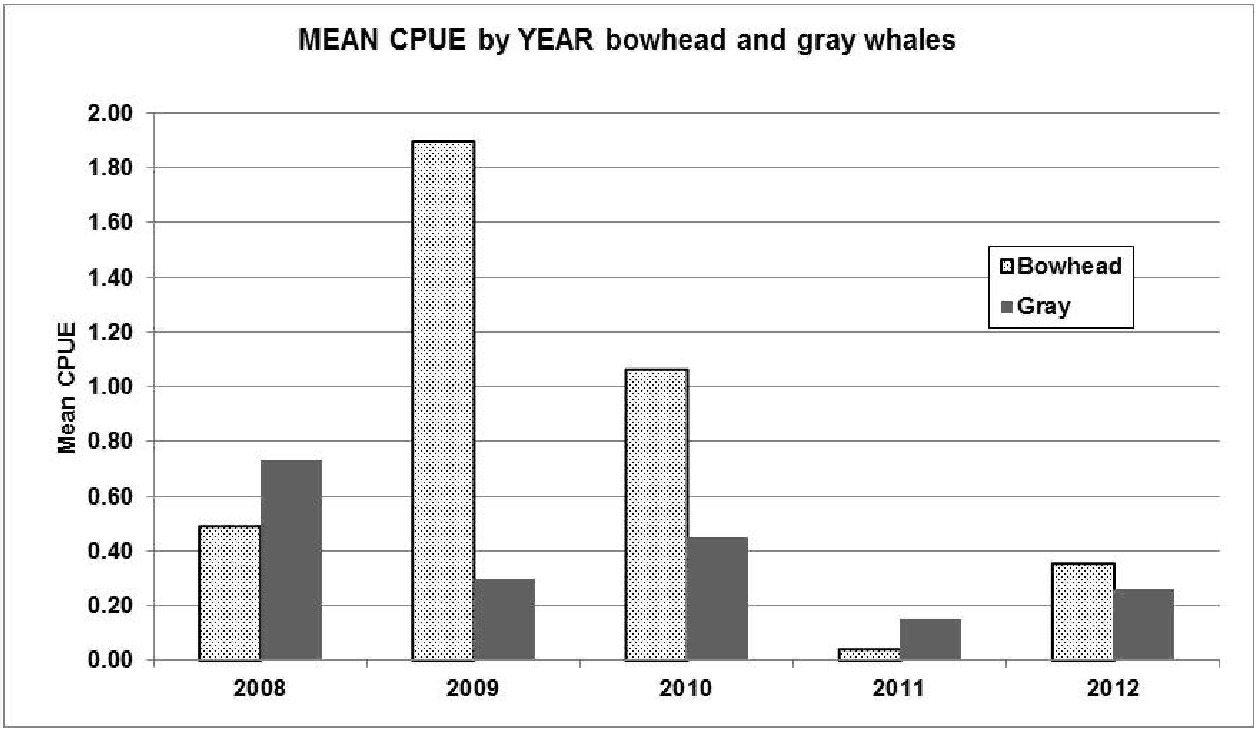

Figure VA-9. *Mean "catch" per unit effort (CPUE) for bowhead (light gray bars) and gray whales (dark gray bars) 2008 to 2012. Note that CPUE is relatively low (<1 whale/hr) in most years. Rates were highest in 2009, and lowest in 2011.*

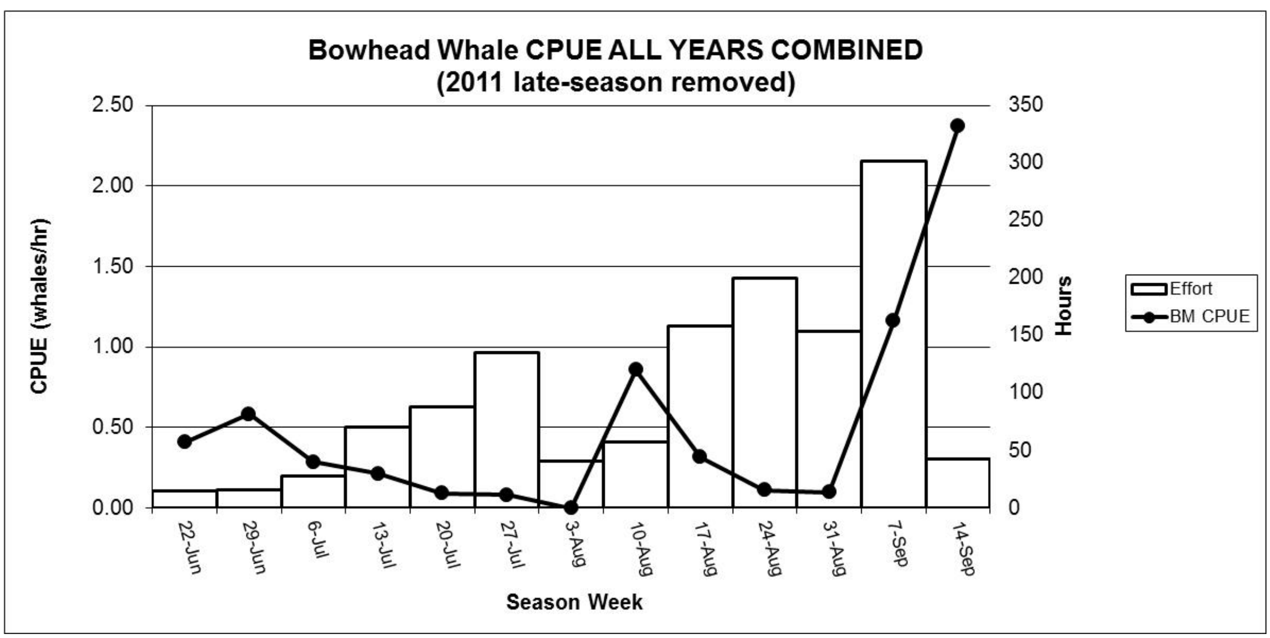

Figure VA-10. *Bowhead CPUE by week and sighting effort for all years combined. Bowhead sightings increased in September but a few were seen in all periods of the summer. This plot excludes the late-season 2011 data (21 and 28 September) as it was the only year with surveys after 21 September.*

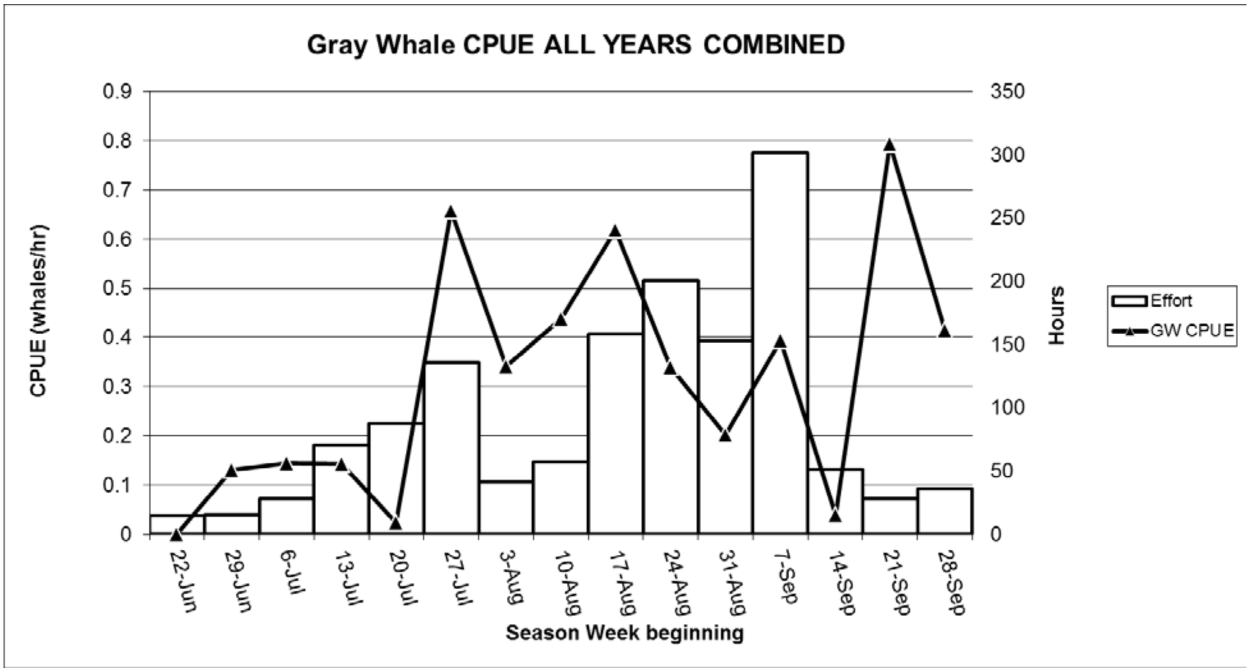

Figure VA-11. *Gray whale CPUE by week and sighting effort for all years combined. Gray whales were observed late in the study season.*

Gray whale numbers were fairly consistent through summer and fall (Figs. VA-9 and VA-11). Gray whales were mainly seen in the waters north of Point Barrow (near the shoal) and along the Chukchi coast. Nearly all gray whales were reported as feeding. Comparison of CPUE between these two species indicates that bowhead sighting rates were actually higher but more variable (Fig. VA-9). This difference in sighting rates should be viewed with caution. CPUE was estimated for the entire study region and because our surveys were targeting bowheads, more were conducted in areas where bowheads are commonly seen, such as east of Point Barrow. Hence, it is not unexpected that sighting rates of gray whales would be lower.

Visibility Conditions

Visibility was not scored on all surveys. If the weather or visibility was very poor at the start of the day, surveys were not conducted, so surveys were biased towards good weather and visibility. In some years, such as 2012, wind precluded surveys for periods of a week or longer. Strong winds greatly hampered observation efficiency, and boats did not survey in wind speeds over 13 knots. About 70% of the bowheads were observed under acceptable visibility conditions (Fair to Excellent; Fig. VA-12). It is likely that some bowheads were missed in poor visibility conditions which would lead to a downward bias in the counts. Corrections for visibility, however, were not made.

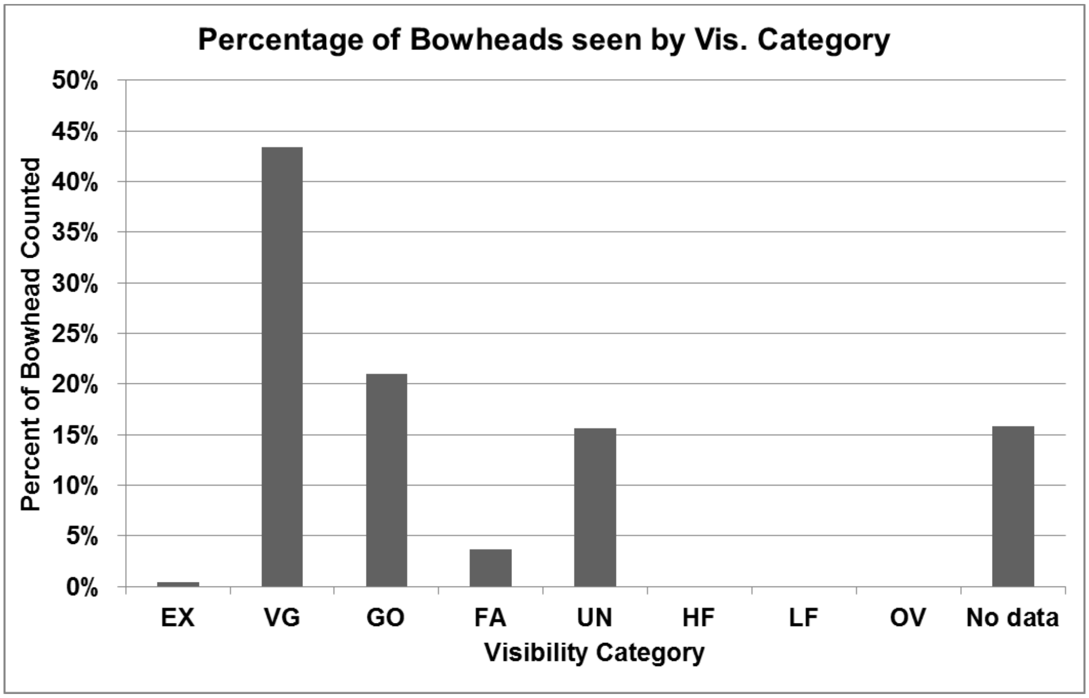

Figure VA-12. *Percentage of bowheads seen by visibility conditions (n = 63) during small boat surveys for the period 2008-2012. About 70% of the surveys had acceptable visibility (EXcellent, Very Good, FAir, GOod) suggesting counts of whales had a downward bias. Visibility codes are defined in Table VA-1. If the visibility was poor at the start of the day, a survey was <u>not</u> conducted.*

Bowheads in Summer

A specific objective of the project was to determine if bowheads were present in the Barrow study area during summer. The BCB population of bowhead whales is known to migrate annually from wintering areas in the northern Bering Sea to summering areas in the Canadian Beaufort Sea (Moore and Reeves 1993). Moore (1992) noted scattered reports of a few bowheads summering near Barrow in the 1980s. Moore et al. (2010) noted that hunters reported increasing summertime bowhead sightings near Barrow but that it was unclear whether these whales arrived from the eastern Beaufort Sea or resided near Barrow during summer. New evidence from telemetry studies suggests that both may be occurring. Telemetry studies indicate that bowheads show higher mobility in summer than previously thought, and east-west movements across feeding areas (Russia to Canada) are not uncommon (Quakenbush et al. 2010a,b). Therefore, some of the bowheads we observed in July and August in summer may well have come either from the Canadian Beaufort Sea or perhaps from the Russian Chukchi Sea. Also, it is the general impression of local hunters that bowhead numbers are increasing in summer in the Barrow region.

The new estimate of BCB bowhead whale abundance for 2011 is 16,892 (95% CI: 15,704 - 18,928) %) (Givens et al. 2013). This suggests that this population is near a full recovery from Yankee commercial whaling (1848-1915). In those years, bowheads were frequently captured in the Chukchi Sea in July and August, so one might expect bowheads in the Barrow area to be more frequent given their population status (Bockstoce et al. 2005).

Habitat Partitioning

One of the more conspicuous patterns in the data is the spatial separation of gray and bowhead whales near Barrow. Bowheads tend to feed in the shallower shelf waters while the gray whales tend to use the deeper Barrow canyon and adjacent shelf (Barrow shoal) in the extreme western Beaufort Sea (Fig. VA-13). As a consequence, gray whales were sighted over significantly (*t*-test; $p = 0.006$) deeper waters (mean = 75.9 m; SD = 22.0) than bowheads (mean = 38.5 m, SD = 13.2) for all years combined (Table VA-9).

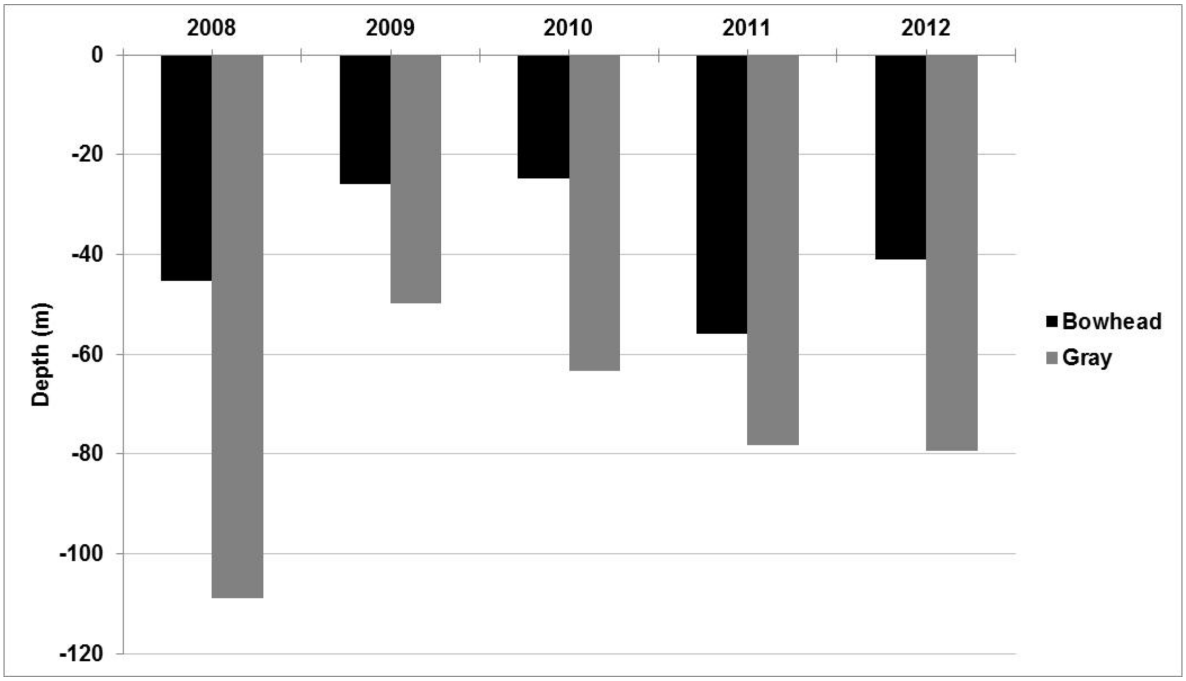

Figure VA-13. *Plot of mean water depth for sightings of bowhead and gray whales observed during small boat surveys, 2008-2012.*

Table VA-9. *Mean water depth (m) of sightings of bowhead and gray whales by year during small boat surveys, 2008-2012.*

Year	Bowhead	Gray
2008	-45.3	-108.9
2009	-25.9	-49.9
2010	-24.8	-63.4
2011	-55.8	-78.1
2012	-41.0	-79.2
Average	-38.5	-75.9
SD	13.2	22.0

By the third year of this project, it became evident that gray whales and bowheads appear to partition feeding locations within the BOWFEST study area (see also Rugh et al. Section I: this volume). Gray whales were consistently seen scattered in small groups primarily north of Point Barrow and west of the Barrow village throughout the summer. In all years, few gray whales were seen east of 156° W longitude (about 10 miles east of Point Barrow) whereas bowheads commonly fed in these waters (Fig. VA-14). Bowheads likely feed in waters east of Point Barrow due to oceanographic factors that entrain euphausiids in these areas (Ashjian et al. 2010, see also Ashjian et al. Section IIIB: this volume). Why gray whales feed in specific areas is not well understood but is likely associated with the availability of benthic prey.

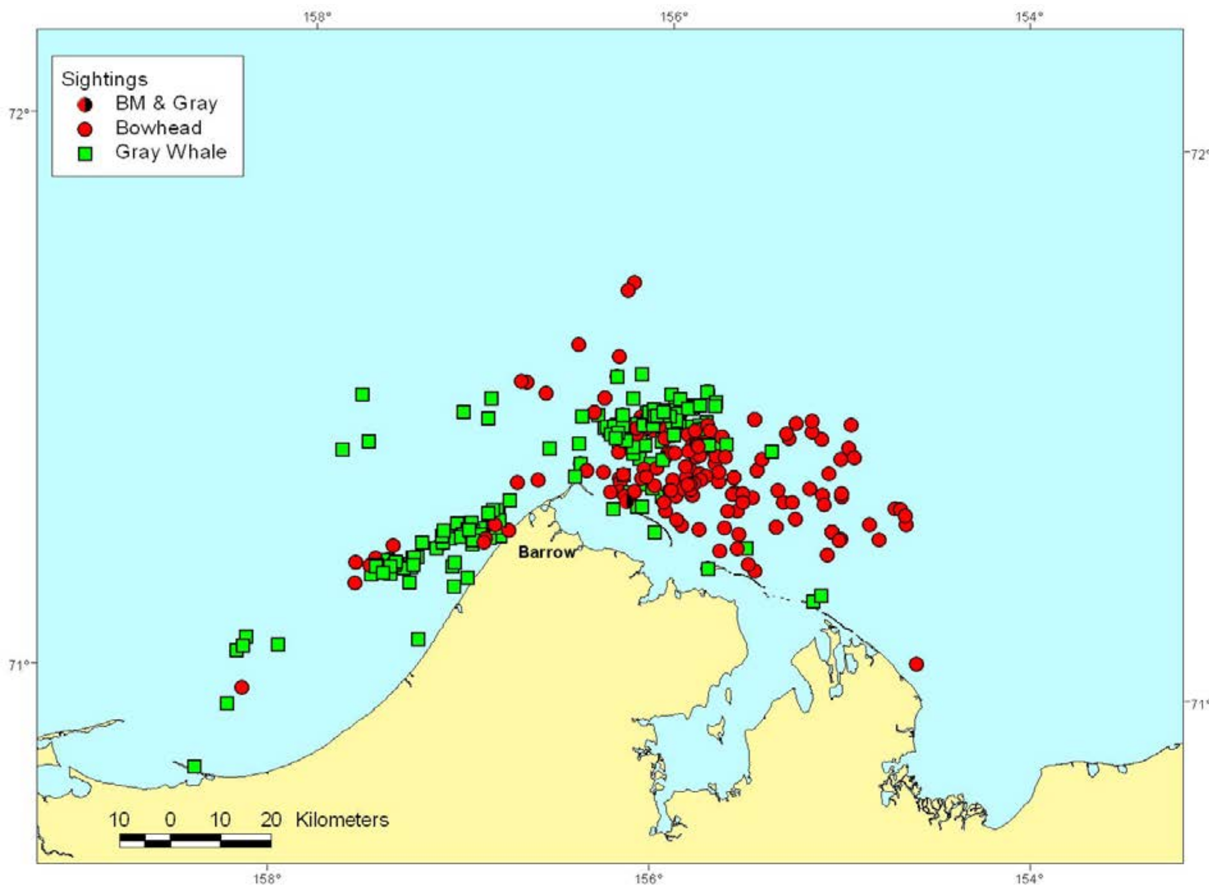

Figure VA-14. *Gray and bowhead whale locations during local boat surveys, 2008-2012. Note the separation east of Point Barrow. Gray whales prefer the Barrow Canyon waters and are uncommon in the shelf waters to the east. Bowheads use the entire study area but were more abundant in the relatively shallow shelf waters east of the Point.*

Bowheads appear to be targeting the shelf waters east of Point Barrow where the hypothesized "krill trap" occurs concentrating prey such as euphausiids and mysiids (Ashjian et al. 2010, Okkonen et al. 2011, see also Section IIIA and IIIB: this volume). Copepods, an important food for bowheads, occur mainly in Barrow Canyon. Copepods are probably not in high concentrations near Barrow in most years, based on examinations of the stomachs of landed whales (see Sheffield and George Section VB: this volume) and net surveys (Moore et al. 2010; Ashjian et al. Section IIIB: this volume). Gray whales primarily feed on benthic invertebrates; therefore, it makes sense that they would target the highly productive benthic waters of the Barrow Canyon and adjacent waters.

Bowhead Behavior

The observers recorded behavior for about 80% of the bowhead sightings. The types of behavior scored were similar to other cetacean studies, e.g., migrating, feeding, interacting, fluke-up dive, breach, etc. (Table VA-1). Determining whether a whale is feeding is difficult in most cases, particularly for distant whales, unless they are seen engaged in obvious surface feeding/trawling (Fig. VA-15).

Figure VA-15. *Bowhead whales surface feeding in nearshore waters off of Cooper Island. Photograph by: Billy Okpeaha.*

Observers based their assessment of feeding mainly on the rate and direction of travel. If a whale was west-bound at a typical migratory speed, it was scored as a migrating (non-feeding) whale. Whales making vertical dives (e.g., fluke-up dives) were either scored as feeding or just fluke-up dive. For a number of reasons we only present the feeding behavior data; regardless, these data should be *viewed with caution*. Nonetheless, these limited data suggest that feeding was more common in 2009 and 2010 than other years (Fig. VA-16). This finding is consistent to some degree with the oceanographic work (see Ashjian et al. Section IIIB: this volume). For all years, ~52% (range 26% - 67%) of the bowhead whales seen were reported as engaged in "feeding or surface feeding." If "fluke-up diving" is included as a feeding behavior, then ~54% of bowheads were scored as engaged in feeding.

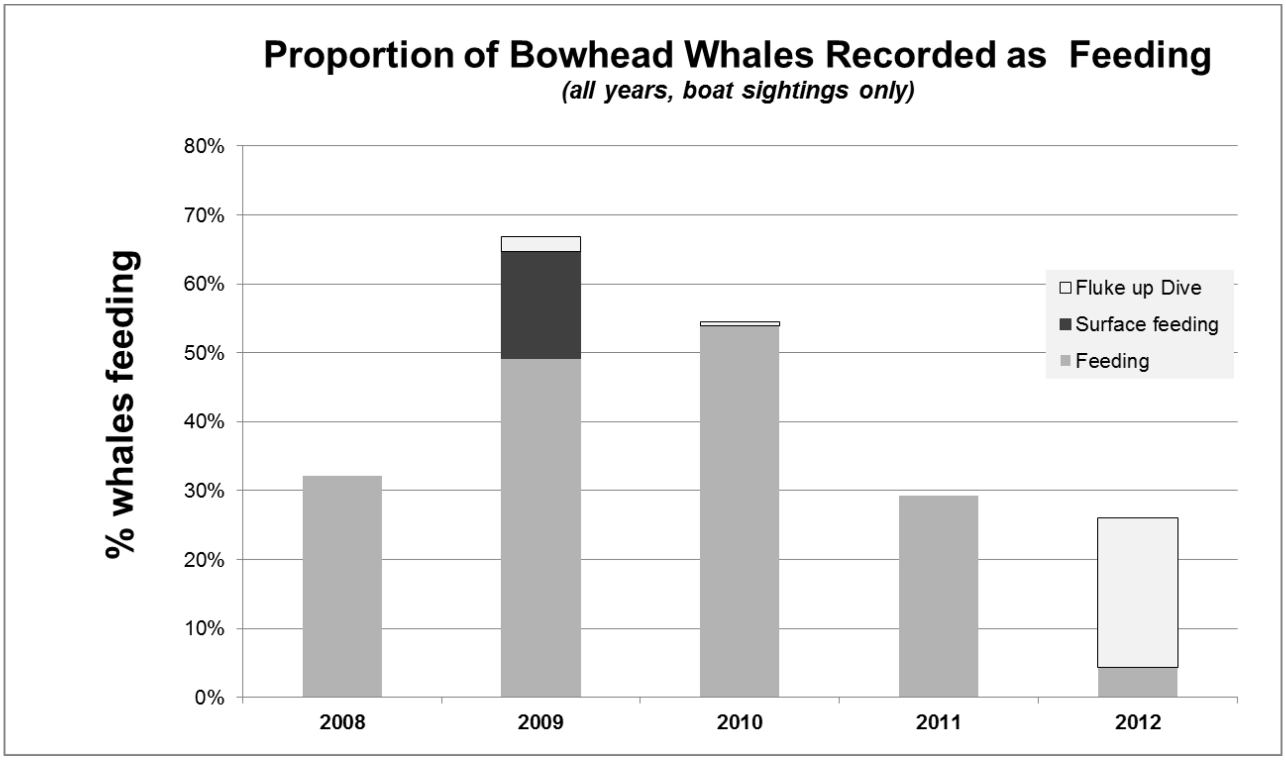

***Figure VA-16**. Proportion of bowhead whales seen engaged in feeding or feeding-type behaviors. We included 'fluke-up' dives here since bowheads generally do not fluke-up while migrating but often do when engaged in water column feeding. Surface trawling is an unmistakable indication that the whale is feeding. Scoring consistency between seasons for the behavioral observations varied so these data should be viewed with some caution.*

The aerial component of BOWFEST (Rugh et al. Section I: this volume) indicated that 33% of bowheads sighted were involved in feeding behavior. Lowry et al. (2004) summarized bowhead feeding based on examinations of stomachs from harvested whales. They estimated the proportion of animals feeding during the fall hunt (1969-2000) to be 75% at Barrow and 83% at Kaktovik. As a partial explanation of the differences, it could be that feeding whales are more likely to be harvested as hunters have told us that feeding whales tend to be less wary of them.

For the BOWFEST period (2007-2012), Sheffield and George (Section VB: this volume) estimated that 92 % of whales had been feeding at Barrow at the time of capture.

Group Size

Aggregations of bowhead whales swimming or feeding within several body lengths of each other were seen on some occasions (Fig. VA-17). All large whale groups (> 10 whales) were scored as feeding. Generally the largest feeding groups were near the barrier islands. This could be due to the fact that prey aggregate in these areas. The two surface feeding groups that were observed from survey boats were estimated to consist of 20 and 25 animals, respectively.

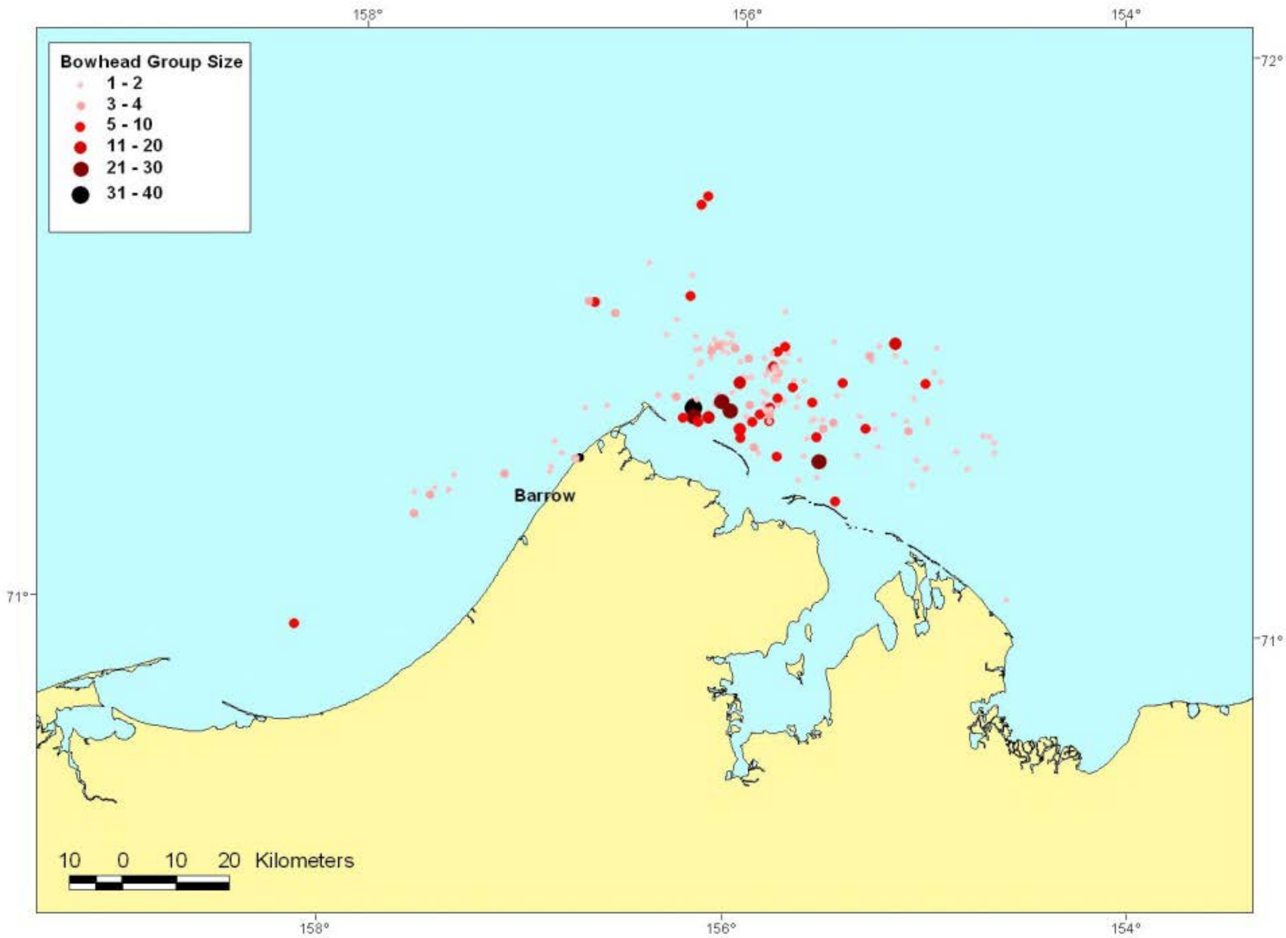

Figure VA-17. *Bowhead whale sightings made during small-boat surveys, 2008-2012 (scaled to indicate group size). Note that the largest groups tend to be near the barrier islands in areas where euphausiids presumably are concentrated.*

Other Marine Mammals

Birds, and marine mammals other than cetaceans, were sighted during the surveys and intermittent records were kept (Table VA-10, Fig. VA-18). There were 18 polar bears observed, several of which were seen swimming at sea (Fig. VA-19). The bears may have been transiting to and from offshore pack ice which was located many miles offshore in some years and periods. Walruses were seen hauled out on ice floes and occasionally in open water. These species were consistently recorded by hunters. Counts of ringed and spotted seals were not consistently recorded and should be viewed with considerable caution.

Table VA-10. *Total number of non-cetacean marine mammals and number of sightings (in parentheses) during small boat surveys, 2008-2012. Seal sightings were* <u>*not*</u> *consistently collected, so these numbers should be viewed with caution. Most walrus and polar bear observations were recorded.*

Year	Polar bear	Ringed seal	Spotted seal	Walrus
2008	4 (2)	2 (2)	0 (0)	2 (1)
2009	0 (0)	4 (4)	5 (3)	0 (0)
2010	6 (2)	12 (10)	3 (3)	1 (1)
2011	7 (6)	140 (49)	60 (57)	3 (2)
2012	1 (1)	29 (22)	0 (0)	59 (5)
Totals	18 (11)	187 (87)	68 (63)	69 (9)

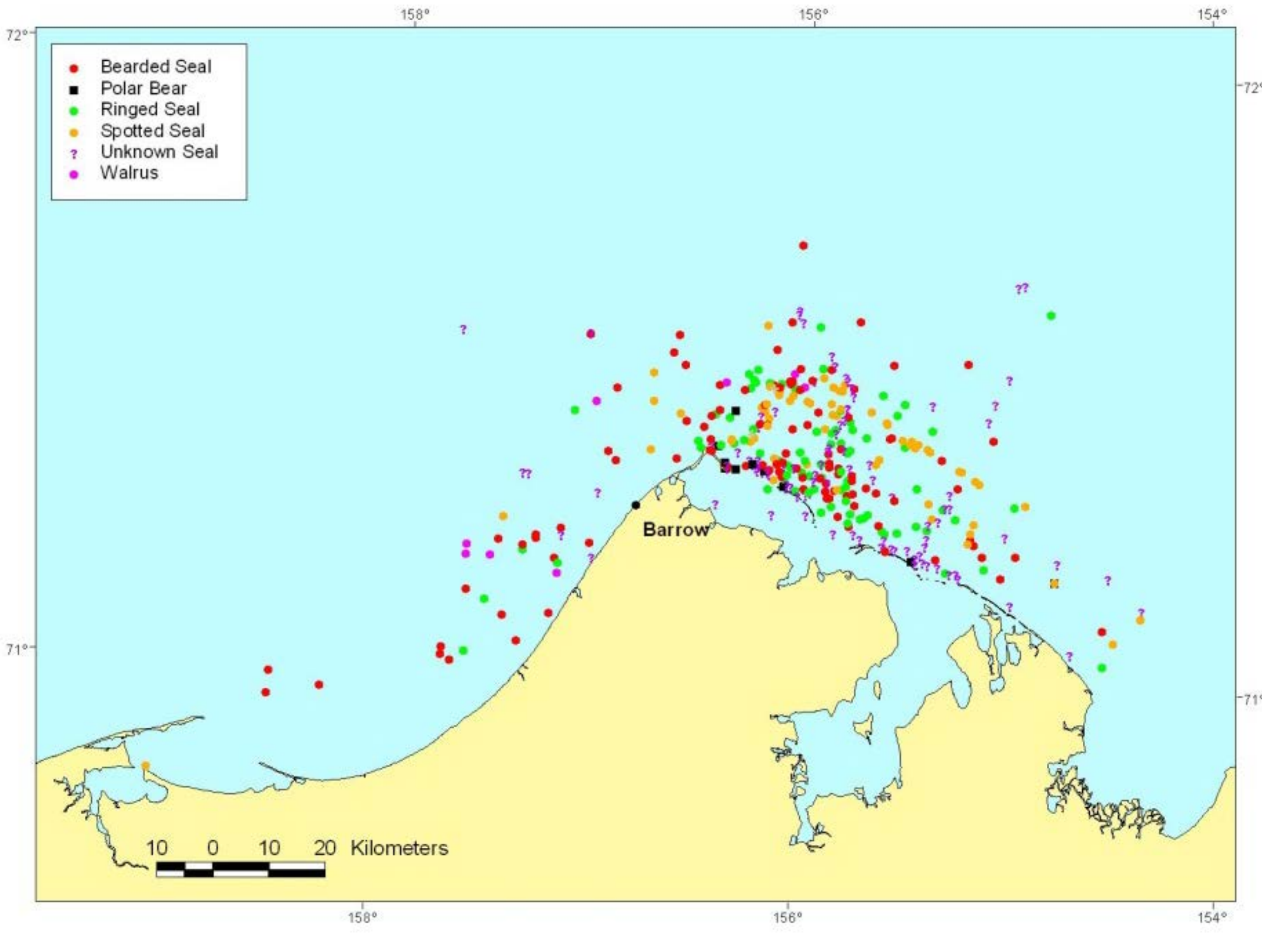

Figure VA-18. *All non-cetacean marine mammal sightings made during small boat surveys, 2008-2012. The black squares show where polar bears were seen, some of which were at sea in open water.*

Figure VA-19. *A single polar bear seen swimming in open water north of the barrier islands during a survey in September 2012. Bears sightings were rare but were seen at sea in all years except 2009.*

Effectiveness of Local Boat Surveys

Our results indicate the utility of using local boat-based surveys and local hunters to conduct nearshore surveys. These types of surveys can provide information on nearshore bowhead distribution and behavior and be used to deploy scientific instruments.

Positive aspects of using locally-chartered boats:

1) Local hunters are familiar with the region and distribution of marine mammals,
2) Local hunters understand the regional safety hazards and can operate safely,
3) Local hunters can put their observations in context with a large body of traditional knowledge,
4) Data from boat-based hunting forays can be included,
5) Survey costs are modest compared with aircraft and large vessel charters, and
6) Surveys engage local hunters and the community in science projects.

Local hunters were integral to the success of BOWFEST not only for completing small boat surveys but for their work on other parts of the project, including: spotting whales and piloting the tagging boat for the tagging project (Baumgartner Section IV: this volume), deploying acoustic recorders (Berchok et al. Section II: this volume), and assisting with the ADF&G/BOEM satellite telemetry program (Quakenbush et al. 2010b). Their years of hunting and experience in arctic conditions proved extremely useful.

This approach also has limitations. The use of small boats (most are < 8 m) confined surveys to nearshore waters (< ~25 miles offshore), so offshore areas were not surveyed. Space for crew and scientific equipment was limited on small boats. Data quality varied among crews as some were not familiar with standard recording processes. Because many of the boat captains were active hunters, subsistence activities sometimes took precedence over surveys. Improvements and modifications for future surveys could include: a) use of structured transects, b) more robust data collection techniques and training, and c) use of enhanced GPS data-capture methods.

Summary Points

- Bowheads summer in the study area in low numbers; abundance varies by year. Numbers may have increased over the last 30 years based on local knowledge and survey results.
- Gray whales consistently summer (and feed) near Barrow but numbers vary somewhat by year.
- Bowheads and gray whales show fairly strong spatial segregation in the Barrow region. Bowheads tend to use shelf waters east of Point Barrow and gray whales target benthic prey in and near Barrow Canyon.
- In 2009 and 2010, bowheads were more frequent in the study area, from July to early September, than in the other years of the study.
- On 24 July 2009, bowheads were seen feeding within 0.5 km off the village of Barrow. Local whalers found this quite unusual, as did we, since bowheads have not previously been observed feeding nearshore off Barrow during July.
- Few bowheads were observed in the study area in August and September 2011, despite highest survey effort of any year of the study. Explanations include a delayed migration from Canada associated with high prey abundance there, low prey abundance near Barrow, late sea ice development, or some combination of these and other factors.
- Locally-operated boat surveys are an effective relatively low-cost method to locate whales, support community-based science, and estimate relative abundance.

Acknowledgments

We thank the Barrow Whaling Captains Association for supporting and participating in this study. We thank BOEM for funding and the NSB DWM staff for their assistance. We thank Charles Monnett for his guidance and encouragement as well as Jeff Denton. We appreciated the assistance of Frederick Brower, Shawn Brower, Billy Adams, Floyd Suvlu, James Ahsoak, Lewis Brower, Henry Kignak, Harry Brower, Jr., Harry Brower III, Billy Okpeaha, Wayne Toovak, and Eugene Brower for the surveys. We also thank Billy Okpeaha for taking some excellent photographs of feeding bowheads and for conducting a major proportion of the local boat surveys. Cyd Hanns (unsung hero), Glenn Sheehan, and Nok Acker of BASC were extremely helpful with logistical matters and essentially made this project possible given contracting constraints and other issues. We appreciate editorial comments by Amy Van Cise and Gay Sheffield.

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Appendix VA-1. Details of the approach used for the local boat surveys at Barrow.

For someone interested in conducting local boat surveys elsewhere or at Barrow in the future, the following are some guidelines that worked well in Barrow. These are basically common sense guidelines but may be useful.

1. DWM (Department of Wildlife Management) chooses the route and sets schedule.
2. DWM will notify captains when they are scheduled. Give captains advance notice of at least 2 days.
3. Boats are always sent out in pairs if there are no other boats out in the area.
4. Before initial survey, boat captains must review safety equipment list and confirm that they have all necessary safety gear.
5. Before heading out for the day, captains will check-in at DWM/ARF and complete the Boat Activity Log and pick-up the following survey equipment:
    a. Clipboard with Data sheets
    b. GPS and extra batteries
    c. Binoculars
    d. Camera (with freshly charged battery)
6. Captains will arrive with their boat fueled. Re-fueling by DWM will take place at the end of the day, after the boat has returned from the survey.
7. Notify contracting entity (in this case the Barrow Arctic Science Symposium BASC) by e-mail that BOWFEST boats are out for the day. Include captain's name and route.
8. Boats will check in with Rescue Base when heading out and returning on channel 68. Boats will also check-in periodically with other BOWFEST boats as well as with BASC and/or DWM (DWM on channel 1A).
9. Some important points for completing data sheets:
    a. Sightings of bowheads and gray whales are of primary importance.
    b. Note any feeding behavior by bowheads in particular.
    c. When recording a group of the same species, make separate line entries for different size animals.
    d. Take as many photographs as possible.
10. When boat returns to shore, DWM will meet to fuel and collect completed data sheets and equipment.
11. DWM will fuel the boat at the gas station.
12. At the office, download waypoints and tracks, save to project directory.
13. Enter the raw data (from field forms) in the database. Delete waypoints and tracks at the end of each day from the GPS.
14. Download images from the camera. Label photos with date and captain's name immediately. After downloading and saving images, delete photos from camera. Recharge the camera battery for the next survey.
15. Write a brief daily summary (weather conditions, # of boats, captains, rough locations, #s of whales, fuel, anything else).
16. Each week, complete the Weekly Time Records for each boat captain.

SECTION V- NORTH SLOPE BOROUGH RESEARCH
B - DIET STUDIES

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[2]North Slope Borough, Dept. of Wildlife Management (Barrow, Alaska)

Abstract

This study examined the diet of bowhead whales (*Balaena mysticetus*) harvested by Alaska Natives at Barrow (western Beaufort Sea) and Kaktovik (eastern Alaskan Beaufort Sea) during 2007-2012. We additionally describe prey identified from stomach and/or fecal samples from bowhead whales harvested near Saint Lawrence Island in the northern Bering Sea. Our objectives were to: 1) identify the proportion of harvested whales that had been feeding; and 2) describe diet based on ingested prey samples. Field examinations of 149 whales were conducted to determine the status of feeding as well as describe the diet. During the fall, a higher proportion of animals had been feeding near Barrow (92%) than at Kaktovik (54%) during the study period. A higher proportion of animals had been feeding near Barrow during the fall (92%) than the spring (10%). During the spring, a larger proportion of bowhead whales near Saint Lawrence Island (73%) were feeding than at Barrow (10%). There was no difference in the proportion of harvested whales feeding seasonally (spring 73% vs. fall 75%) near Saint Lawrence Island.

For whales harvested near Barrow, amphipods and mysids occurred more frequently in whales harvested during the fall than for whales harvested during the spring. During the fall, amphipods, fish, and euphausiids occurred more frequently in bowhead whales harvested near Barrow than whales harvested near Kaktovik. Near Saint Lawrence Island, euphausiids were the only prey taxa with a seasonal difference with euphausiids occurring more in fall harvested whales. During the fall at Barrow, percent by volume during 2007-2009 were dominated by euphausiid prey (82%). During 2010, the dominant prey by volume switched to copepods (88%). A diversity of prey types dominated the fall 2011-2012 samples from Barrow and included isopods, mysids, copepods, amphipods, and fish. Our results agree with previous works that indicate bowhead whales fed regularly in the Alaskan Beaufort Sea during the fall and that the diet samples of bowhead whales in the northern Bering Sea indicate bowhead whales feed commonly in the northern Bering Sea before and after their annual migration to the Beaufort Sea.

Introduction

Bowhead whale (*Balaena mysticetus*) studies have been ongoing at Barrow for over 30 years beginning with the National Science Foundation's (NSF) SNACs (Study of the Northern Alaskan Coastal System) program in 2004 and Bureau of Ocean Energy Management (BOEM, formerly MMS) funding intensive studies of bowhead whales. The purpose of this project was to expand and continue the feeding ecology research begun under the NSF, to better understand the oceanographic mechanisms and ecology of bowhead feeding in this area, and contribute to the broader knowledge of the feeding ecology of bowhead whales and other large cetaceans. This report describes the University of Alaska Fairbanks (UAF) Marine Advisory Program (MAP) and the North Slope Borough (NSB) Department of Wildlife Management's (DWM) activities with the BOWFEST study during 2007-2012.

The bowhead whale is a long-lived large baleen whale that spends its life in cold northern waters and forages on zooplankton. In Alaska during spring, bowhead whales migrate over 3,000 km from their northern Bering Sea wintering ground to their eastern Beaufort Sea summering area. The return migration occurs in the early fall as the whales travel westward into the Chukchi Sea, along the northeast coast of the Chukotka peninsula, through Bering Strait, and finally return to the northern Bering Sea (Moore and Reeves 1993, Quakenbush et al. 2010).

Research on the diet of bowhead whales has primarily been conducted in the Beaufort Sea (Carroll et al. 1987, Lowry 1993, Lowry et al. 2004, Moore et al. 2010) and bowhead whales commonly feed during their fall westward migration (Lowry et al. 2004). Regional and seasonal differences exist in the diet of bowhead whales harvested in the Beaufort Sea (Lowry et al. 2004). Neither sex of the whale nor total length/size of the animal was shown to influence frequency of occurrence of prey items in the diet of subsistence-harvested whales (Lowry et al. 2004).

In the northern Bering Sea, relatively little has been documented regarding the feeding habits and ecology of bowhead whales although they spend a large portion of the year there. Traditional knowledge of Alaska Native whalers on Saint Lawrence Island indicates that bowhead whales regularly exhibit feeding behavior near the island during spring and fall and reports of food in the stomach are not unusual (Hazard and Lowry 1984, Noongwook et al. 2007, Sheffield 2008, Sheffield and George 2009).

The annual harvest of bowhead whales by Alaska Natives (Stoker and Krupnik 1993, Suydam et al. 2012) allows an opportunity for the study of bowhead diet by directly examining prey items via stomach contents or fecal analysis. At Barrow, bowhead whales are typically harvested during the spring (late April–June) migration to the eastern Beaufort Sea and during their fall (September-October) westward migrations. At Kaktovik, bowhead whales are typically harvested during the westward migration from the eastern Beaufort Sea during September. In the northern Bering Sea, bowhead whales are typically harvested near Saint Lawrence Island at the start of the spring (April–May) northward migration and during end of the fall (November-December) migrations. Working collaboratively with coastal communities, our objectives were to: 1) identify the proportion of harvested whales that had been feeding; and 2) describe diet based on stomach and/or intestinal samples.

Methods

Field records and feeding status

We classified bowhead whales harvested by Alaska Native subsistence whalers during 2007–2012 as either 'feeding', 'not feeding', or 'uncertain' based on descriptive field records and laboratory data on stomach contents. If field records indicated that a substantial amount (i.e., at least 10 items or 1 liter) of prey was present in the stomach, the whale was classified as feeding. If field records indicated that the stomach was empty, the whale was classified as not feeding. If field records recorded the presence of only a small amount of prey (i.e. less than 10 items or less than 1liter), or that food was present but no quantity was indicated, the feeding status of the whale was recorded as uncertain. For some whales, field records did not provide any information about prey items, but collected samples were available for laboratory analysis. In those instances, a whale was classified as feeding if the sample contained 10 or more identifiable prey items, not feeding if there were no identifiable prey items, and uncertain if the sample contained fewer than 10 prey items. Items such as baleen hairs, algae, and pebbles were not considered to be food items. If a stomach contained milk, the animal was excluded from all analyses. Data were grouped by harvest location and harvest season. The proportions of feeding whales from different harvest locations and seasons were compared using chi-square tests. Whales with feeding status classified as uncertain were not included in these comparisons.

Collection and analysis of stomach content / fecal samples

Subsistence-harvested bowhead whales were examined for evidence of feeding during spring and fall 2007-2012 at four locations that included: Barrow (western Beaufort Sea), Kaktovik (eastern Beaufort Sea), and the Saint Lawrence Island communities of Gambell and Savoonga (northern Bering Sea) (Fig. VB-1). The stomach of each whale landed was examined, if possible, within a few hours after the animal was brought to shore. An estimate was made of the total stomach contents volume and a sample of contents was collected from the forestomach, when possible. Stomach contents samples were kept frozen until examined in the laboratory. If the stomach was not accessible, a fecal sample was collected, usually within a few hours after the animal was landed, and kept frozen until subsequent laboratory analysis.

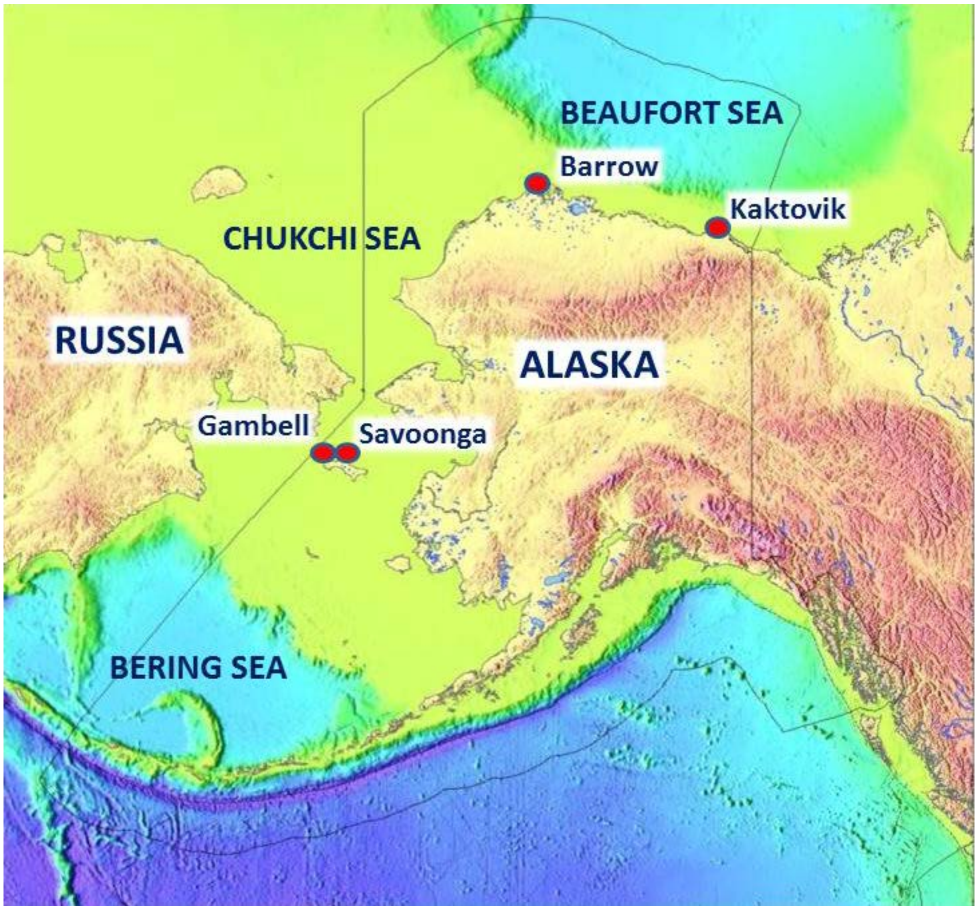

Figure VB-1. *Coastal communities from which postmortem examinations were conducted and diet data were collected from subsistence harvested bowhead whales during 2007-2012.*

In the laboratory, stomach samples were gently rinsed in fresh water on a 1.0 mm screen with a 0.5 mm screen layered underneath. Prey items were sorted macroscopically into major taxonomic groups, examined microscopically, and identified to the lowest taxonomic level possible by the authors and species taxonomy experts at the University of Alaska. The volume of sorted prey items was measured to the nearest 0.1 ml by water displacement in graduated cylinders and or weighed on an electronic scale to the nearest 0.1 gm. Voucher specimens of prey items were stored in 70% isopropyl alcohol. Volumes were recorded as measured with no correction for state of digestion. These methods were similar to those used in the collection and analysis of bowhead whale stomach contents in previous years (e.g., Lowry and Frost 1984, Lowry et al. 2004, Moore et al. 2010).

Frozen fecal samples were thawed, placed in glass beakers appropriate to sample volume, and sieved through 505 micron mesh and subsequently through 150 micron mesh to remove the finer particles (i.e., copepod mandibles, etc.) from the more fluid fecal component. All subsamples were examined microscopically and prey items were identified to the lowest taxonomic level. Prey items were preserved with preserved in Streck (non-toxic tissue preservative) and archived. The fluid portion of each fecal sample was discarded.

Prey data from individual whales that were earlier classified as feeding were grouped into major prey types (i.e., copepod, euphausiid, etc.) and the frequency of occurrence of major prey types was calculated as the number of samples containing that prey divided by the total number of samples examined.

The frequencies of the top eight prey types consumed were compared using 2x2 contingency tables with an experiment wise error rate of $\alpha = 0.05$ using Bonferroni's procedure (Neter et al. 1990) between Barrow (spring vs. fall), Barrow (fall) vs. Kaktovik (fall), and Saint Lawrence Island (spring vs. fall).

Volumetric prey data from individual bowhead whales were summarized and described by region and season.

Results

Field examinations and samples 2007-2012

Postmortem examinations of stomach contents and/or feces of subsistence-harvested bowhead whales that included field notes and/or diet samples were conducted on a total of 153 whales during 2007-2012 at the Beaufort Sea coastal communities of Barrow and Kaktovik as well as the Bering Sea communities of Gambell and Savoonga on Saint Lawrence Island (Appendix VB-1). Two whales (08KK1 and 11KK2) contained milk in the stomach, one fecal sample was lost (11S1), and one whale was sampled from Wainwright (10WW3) on the coast of the northeastern Chukchi Sea. These four animals were not included in the following analyses. Feeding status was classified for 149 bowhead whales that included: Barrow-spring (n = 50), Barrow-fall (n = 60), Kaktovik-fall (n = 13), Saint Lawrence Island-spring (n = 22), and Saint Lawrence Island-fall (n = 4) (Table VB-1). During the study period, diet samples included stomach samples from 96 whales (Barrow n = 82; Kaktovik n = 13; Saint Lawrence Island n = 1), field examination notes for 29 (Barrow n = 28; Saint Lawrence Island n = 1), and fecal samples from 24 bowheads (Saint Lawrence Island n = 24) (Appendix VB-1).

Table VB-1. *Numbers of subsistence harvested bowhead whales with feeding status determined and used in analyses from 2007-2012, by year (n=149).*

	2007	2008	2009	2010	2011	2012
Barrow - spring	11	9	2	12	4	12
Barrow - fall	7	11	15	8	9	10
Kaktovik - fall	3	2	3	3	1	1
St. Lawrence I. - spring	5	2	2	5	1	7
St. Lawrence I. - fall	0	0	0	2	0	2
Totals	26	24	22	30	15	32

Feeding status and comparisons between regions and seasons

Barrow: Of 50 bowheads sampled or examined at Barrow during the spring, five were considered to have been feeding (10%), 41 were categorized as not feeding, and the feeding status of four was uncertain. Of 60 bowheads sampled or examined at Barrow during the fall harvest, 2007-2012, 55 were considered to have been feeding (92%), the feeding status of five was uncertain, and no whales were considered not feeding. When comparing the seasonal feeding status at Barrow, a significantly larger proportion was feeding in the fall (92%) vs. the spring (10%) (Table VB-2, $p < 0.001$).

Kaktovik: Of 13 bowheads sampled or examined at Kaktovik during fall 2007-2012, seven were considered to have been feeding (54%), three were categorized as not feeding, and the feeding status of three was uncertain. When comparing the fall feeding status between Barrow and Kaktovik, a significantly smaller proportion of bowheads were feeding in the fall near Kaktovik (54%) in the eastern Beaufort Sea than near Barrow in the western Beaufort Sea (92%) (Table VB-2, $p < 0.001$).

Saint Lawrence Island: Of 22 bowheads sampled or examined at Saint Lawrence Island during the spring harvest, 16 were considered to have been feeding (73%) and six were considered not feeding. Of four bowheads sampled or examined at Saint Lawrence Island during the fall harvest, 2007-2012, three were considered to have been feeding (75%) and one whale was considered not feeding. When comparing the seasonal feeding status at Saint Lawrence Island, there was no difference in the proportion of bowhead whales that were feeding in the fall (75%) vs. the spring (73%) (Table VB-2, $p > 0.05$). When comparing the spring feeding status between Saint Lawrence Island and Barrow, there was a higher proportion of whales feeding near Saint Lawrence Island (73%) than near Barrow (10%) (Table VB-2, $p < 0.001$).

Table VB-2*. Percent feeding, by location and season for subsistence harvested bowhead whales examined during 2007-2012 (n=149).*

Location / Season	% Feeding
Barrow - spring (n=50)	10%
Barrow - fall (n=60)	92%
Kaktovik - fall (n=13)	54%
St. Lawrence I. - spring (n=22)	73%
St. Lawrence I. - fall (n=4)	75%

2007-2012 Diet

Barrow – spring: Stomach contents samples were available from five whales. Copepods, amphipods, and euphausiids each occurred in more than half (Table VB-3) of the samples. The most commonly eaten species of copepod was *Calanus glacialis*. The most commonly eaten euphausiid was *Thysanoessa raschii*. There were seasonal differences in the frequency of occurrence of prey types eaten by bowheads harvested near Barrow, with amphipods and mysids occurring significantly more often in whales harvested in the fall than the spring (Table VB-3, $p < 0.001$). Copepods, mysids and shrimp occurred with similar frequency in fall and spring ($p > 0.001$).

Percent prey by volume for three individual bowheads near Barrow during spring 2008, 2009, and 2012 is provided in Figure VB-3 (the other two stomach samples were extremely digested and did not meet the criteria for inclusion in analyses). The 2008 and 2009 samples taken during April-May were uniformly dominated by euphausiids (*Thysanoessa raschii*), whereas the April 2012 spring sample was dominated by copepods (*Calanus glacialis*).

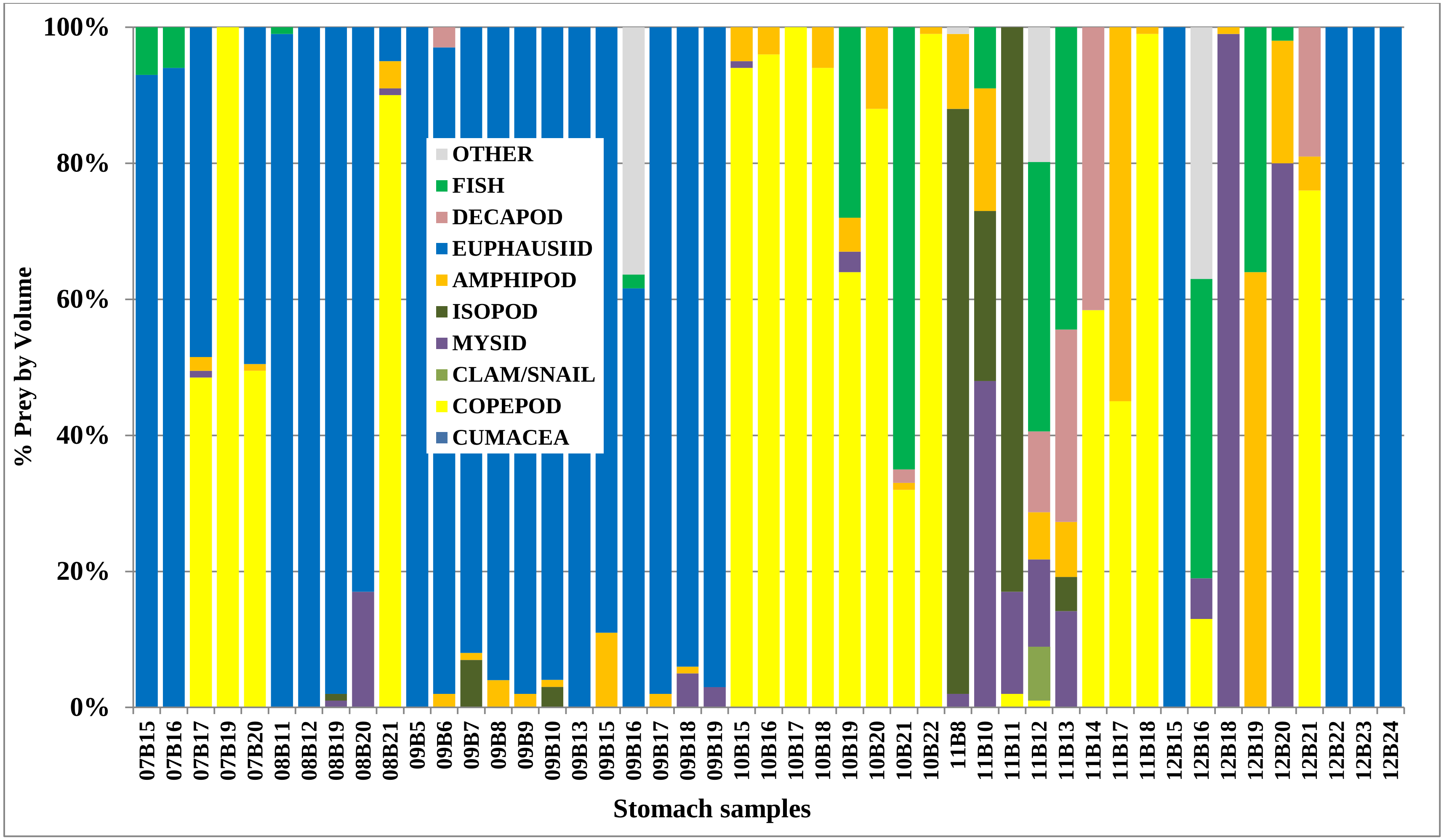

Figure VB-2. *Percent prey by volume for 47 individual bowhead whales harvested in the western Alaskan Beaufort Sea near Barrow during the fall (2007-2012).*

Barrow – fall: Stomach contents samples were available from 55 whales. Amphipods occurred in 50 samples, with copepods, mysids, euphausiids, and fish each occurring in more than half (Table VB-3). The most commonly eaten species of copepod were *Calanus hyperboreus* and *C. glacialis*. The most commonly eaten euphausiid was *Thysanoessa raschii*. *Neomysis rayii* and *Mysis oculata* were the most commonly eaten mysids. The most commonly eaten fish was the Arctic cod (*Boreogadus saida*), which occurred in 28 samples.

Percent prey by volume for 47 individual bowheads near Barrow during the fall from 2007-2012 is provided in Figure VB-2. Overall, the percent by volume samples during 2007-2009 were dominated by euphausiids (82%). During 2010, the dominant prey by volume was copepods (88%). A diversity of prey types dominated the 2011-2012 samples, including isopods, mysids, copepods, amphipods, and fish. Of particular interest, two of the volumetric samples dominated by fish during 2011 (11B12, 11B13) were from whales harvested during the last week of October. Of these, 11B12 included the remains of over 45 fish such as Arctic cod, stout eelblenny (*Anisarchus medius*), Arctic alligator fish (*Ulcina olrikii*), and unidentified sculpins (*Icelus* sp.; Cottidae). The stomach sample from 11B13 contained the remains of several hundred fish that included Arctic cod, Saffron cod (*Eleginus gracialis*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*) as well as unidentified sculpin (*Myoxocephalus* sp.) and cod (Gadidae, juveniles). To our knowledge, the number of fish involved with this sample has not been observed in any previous postmortem examination. Seven of the nine volumetric samples from 2012 were dominated by mysids and euphausiids with only one sample dominated by copepods. The one 2012 volumetric sample dominated by fish (12B16) contained identifiable remains of Arctic cod.

Kaktovik – fall: Stomach contents samples were available from seven whales (Table VB-3). Copepods and amphipods occurred in every sample. The most commonly eaten species of copepods overall were *Calanus hyperboreas* and *Pareuchaeta glacialis*. When comparing the frequency of occurrence of prey types eaten by bowhead whales harvested near Kaktovik and Barrow during the fall, amphipods, fish, and euphausiids occurred significantly more often in whales harvested near Barrow ($p < 0.001$). Copepods occurred with similar frequency in the fall ($p > 0.001$).

Percent prey by volume for seven individual bowheads near Kaktovik during the fall from 2007-2012 is provided in Figure VB-4. Copepods identified from the 2007 samples included *Calanus hyperboreus* and *Pareuchaeta glacialis*. Similarly, *Calanus hyperboreus* was identified in the 2008 volumetric sample. Copepods identified in the one copepod-dominant 2009 sample (09KK1) included *Calanus* sp. and *Metridea longa*. Copepods from the 2011 sample included *Calanus hyperboreus*, *Pareuchaeta glacialis*, and *Metridea longa*. For one stomach sample, (09KK2), the dominant prey was euphausiids (*Thysanoessa raschii*). This whale was harvested during the latter part of September and also included isopods as well as over 15 fish, which included: Arctic cod (*Boreogadus saida*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*), and Shorthorn sculpin (*Myoxocephalus scorpius*). Euphausiids, fish, and isopods were not identified in any other 2009 stomach samples from Kaktovik. Copepods identified in the 09KK2 sample included *Calanus hyperboreus, Pareuchaeta glacialis, and Metridea longa*.

Saint Lawrence Island – spring: Fecal samples were available from 15 whales and a stomach sample was available from one whale. Copepods occurred in 81% of the samples with mysids, shrimp, and clams occurring in 19% (Table VB-3). The most commonly eaten copepod was *Calanus glacialis*. Both mysid species *Mysis litoralis* and *Mysis oculata* were identified. In the frequency of prey types eaten by bowhead whales harvested during spring and fall, euphausiids were the only prey taxa with a seasonal difference with euphausiids occurring more in fall harvested whales (Table VB-3, $p < 0.001$). Volumetric data are not available for the Saint Lawrence Island diet samples.

Saint Lawrence Island – fall: Fecal samples were available from three whales. Copepods occurred in each sample and *Calanus glacialis* was identified (Table VB-3). Volumetric data are not available for the Saint Lawrence Island diet samples.

Table VB-3. *Frequency of occurrence for prey items identified from diet samples collected from bowhead whales subsistence-harvested near Barrow, Kaktovik, and Saint Lawrence Island during 2007-2012.*

	Barrow (spring) n=5	Barrow (fall) n=55	Kaktovik (fall) n=7	St. Lawrence I. (spring) n=16	St. Lawrence I. (fall) n=3
Copepod	60%	60%	100%	81%	100%
Amphipod	60%	91%	100%	6%	33%
Mysid	-	60%	43%	19%	-
Euphausiid	60%	58%	14%	-	67%
Fish	-	56%	14%	13%	-
Cumacea	-	27%	14%	-	-
Shrimp	-	24%	14%	19%	67%
Isopod	-	15%	14%	-	-
Crab	-	15%	-	-	-
Annelid worm	-	4%	14%	-	-
Echinoderm	-	4%	-	-	-
Barnacle	-	2%	-	-	-
Ostrocod	-	2%	-	-	-
Unid. Decapod	-	2%	-	6%	-
Snail	-	2%	8%	6%	-
Clam	-	2%	8%	19%	-
Jellyfish	-	2%	-	-	-

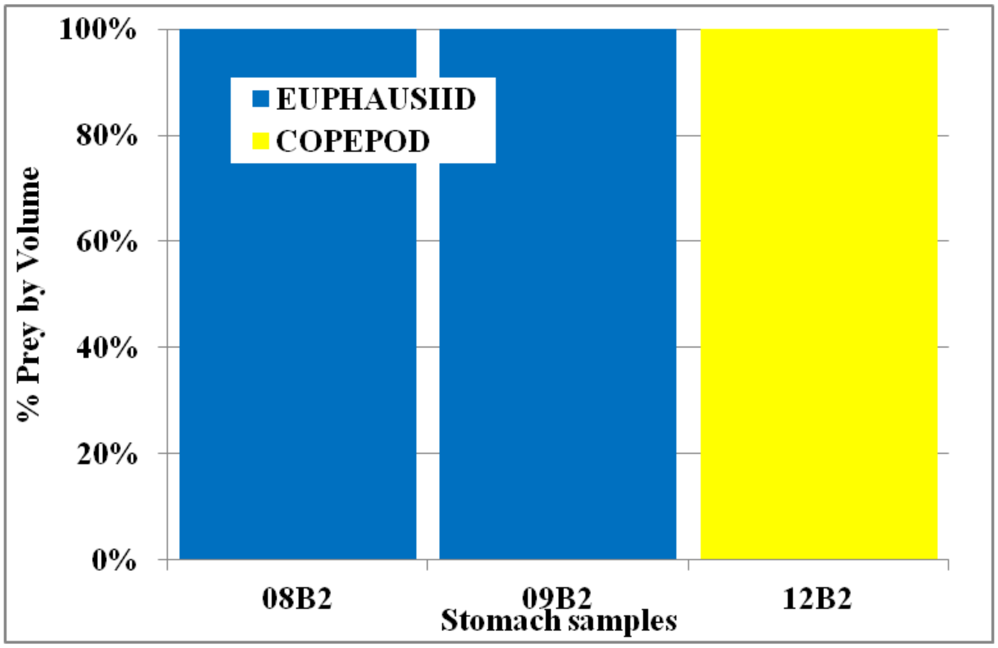

Figure VB-3. *Percent prey by volume for three individual bowhead whales harvested in the western Alaskan Beaufort Sea near Barrow during the spring (2008-2012).*

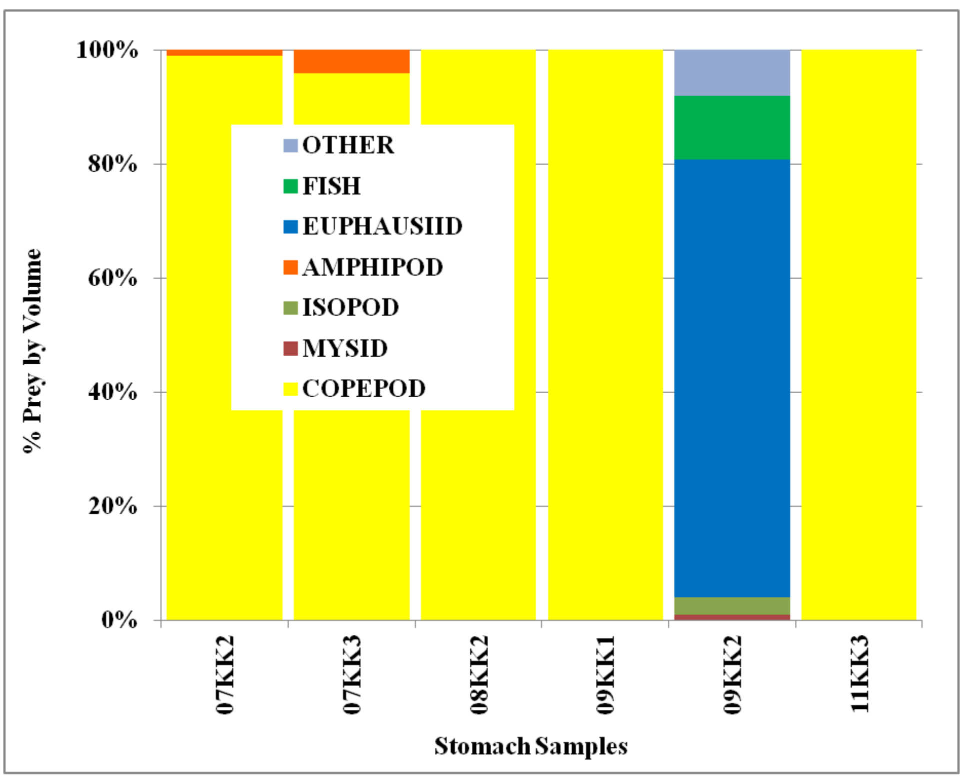

Figure VB-4. *Percent prey by volume for seven individual bowhead whales harvested in the eastern Alaskan Beaufort Sea near Kaktovik during the spring (2007-2011).*

Appendix VB-2 provides a list of over 60 prey taxa identified from all diet samples, regardless of status, by region and season. Photographs of stomach and fecal samples are provided in Appendix VB-3. A list of additional samples collected from bowhead whales harvested for subsistence at Kaktovik and Saint Lawrence Island during 2007-2012 for the North Slope Borough Bowhead Health Assessment project is provided in Appendix VB-4.

Discussion

Caution should be used in the interpretation of these results. Samples sizes for some regions (eastern Beaufort Sea, Bering Sea) and seasons (Bering Sea-fall) were quite small. Additionally, it is difficult to use stomach contents and feces to interpret the diet of bowhead whales for several reasons that include: no accounting for the various states of digestion, the wide range of sample volumes available in the field, as well as the lack of data on total volume in the animal, etc. However, the examination of diet samples can provide information such as whether or not whales had fed and what prey types were eaten relatively recently.

Our results from the Beaufort Sea validated previous bowhead whale feeding ecology studies that determined the nearshore waters of the Alaskan Beaufort Sea are an integral part of the bowhead whale summer/fall feeding range. During this study, the proportion of feeding whales near Barrow in the western Beaufort Sea during the fall was more than expected based on previous study results of 75% (Lowry et al. 2004). The proportion of feeding whales (54%) near Kaktovik in the eastern Beaufort Sea during fall was less than the 75% reported in Lowry et al. (2004). Similarly, the proportion of feeding whales in the western Beaufort Sea during spring was less than the 31% previously reported.

During this project, amphipods, copepods, and mysids occurred most frequently in whales harvested near Barrow in the fall while amphipods, copepods, and euphausiids occurred most frequently in whales harvested near Barrow in the spring. As in previous studies, prey that occurred least often included benthic and/or epibenthic prey (i.e., isopods, annelid worms, clams, snail, etc.). Copepods and amphipods were the most frequently occurring prey taxa from harvested whales near Kaktovik in the eastern Beaufort Sea as has been reported (Lowry et al. 2004). Of note, euphausiids were present in numbers large enough to dominate, by volume, at least one stomach sample during 2009 from Kaktovik.

The percent by volume results near Barrow during the fall indicate a switch from a relatively consistent annual dominance by either euphausiids or copepods during 2007-2010 to an eclectic mix of dominant prey types during 2011 and 2012 that included euphausiids and copepods but also mysids, isopods, amphipods, and fish indicating these prey taxa were not incidentally ingested. The occurrence of fish as prey has been reported near Barrow - generally as minor components of samples that otherwise contained euphausiids or copepods. However, during 2011-2012 this was not the case.

Whether these changes reflect effects of decreasing sea ice near Barrow (Moore and Laidre 2006), various states of digestion, changes in prey availability, and/or competition due to recent range extensions of other species of large baleen whales into the eastern Chukchi and western Beaufort seas near Barrow (Moore 2008, Hashgagen et al. 2009, George et al. Section VA: this volume) is unknown. Additionally, water depth near Barrow has been thought to correspond with diet. That is, shelf waters near Barrow are potentially dominated by euphausiids with a more diverse prey selection in deeper offshore waters (Moore et al. 2010). Bowhead whale harvest locations remain proprietary Alaska Eskimo Whaling Commission data and were not available for the harvested whales used in this study.

The importance of the Saint Lawrence Island bowhead whale diet samples should not be underestimated. Though fecal samples provide an estimate of the proportion of animals feeding that may not be directly comparable to estimates based on stomach contents, they provided new information on the diet and feeding ecology of bowhead whales in the northern Bering Sea including the potential dietary diversity of whales using that region. Bowhead feeding has been studied in only some areas of their range, typically Alaska, and to some extent western Canada. Additional areas of potential importance for feeding include Russian waters of the Bering Strait region, the northern Chukotka Peninsula, and east of Wrangell Island (Quakenbush et al. 2010). Saint Lawrence Island is located in the western Bering Sea within 40 miles of the Chukotka Peninsula and is an area where bowhead whales exhibit feeding behavior and are known to overwinter (Moore and Reeves 1993, Noongwook et al. 2007, Citta et al. 2012). This project helps expand our current understanding of the bowhead's ecology and biology when it is not occupying the seasonal northern and eastern limits of its range.

The diet results from the northern Bering Sea confirm feeding behavior described by Saint Lawrence Island community members (Noongwook et al. 2007). Bowhead whales had been feeding during early spring (April-May) before the northward migration and they had been feeding after returning to the northern Bering Sea from their southbound migration in late fall (November – December). Though caution should be taken when interpreting small seasonal sample sizes, results from Saint Lawrence Island suggest a relatively large proportion of whales feed in the northern Bering Sea/Bering Strait region. Whales were shown to feed significantly more often near Saint Lawrence Island in the spring before their northward migration than when they were passing near Barrow travelling to their eastern Beaufort Sea summering range. Regional differences in prey that occurred within the Beaufort Sea and potentially between the Beaufort and Bering seas are most likely a reflection of regional prey availability. Lastly, results from the northern Bering Sea from this study provide some support to previous isotope studies that indicate bowhead whales acquire a significant portion of their annual food budget from the Bering-Chukchi seas (Schell and Saupe 1993, Lee et al. 2005)

Though the examination of stomach contents and feces provides direct evidence of feeding status and what prey were eaten, the significance of regions as relatively important feeding areas is unknown. However, this study not only agrees with previous feeding ecology assessments that determined the nearshore waters of the Alaskan Beaufort Sea are an integral part of the bowhead whale summer/fall feeding range but also indicates that bowhead whales commonly feed near Saint Lawrence Island more than previously thought. The high proportion of feeding whales that frequent Barrow and Kaktovik during the fall, and the potential importance of the waters near Saint Lawrence Island in the feeding ecology and diet of the bowhead whale, should be considered when assessing the potential chronic and/or acute effects of decreasing sea ice, increasing large vessel traffic, and potential resource exploration and extraction activities within the Chukchi and Beaufort seas.

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Appendix VB-1. *Location, identification number, harvest date, total length (meters), sex, and status for 153 subsistence harvested bowhead whales examined and/or sampled for evidence of feeding during 2007-2012. Samples that contained milk and/or were lost are indicated by *.*

Location	ID #	Date	Length (m)	Sex	Status	Data	Examined
Savoonga	07S1	Apr-07	10.0	M	Not feeding	Lab	Stomach/feces
Savoonga	07S2	Apr-07	8.3	F	Feeding	Lab	Feces
Savoonga	07S3	Apr-07	10.7	M	Not feeding	Lab	Feces
Gambell	07G3	May-07	15.3	F	Feeding	Lab	Feces
Gambell	07G4	May-07	15.2	F	Feeding	Lab	Feces
Kaktovik	07KK1	Sep-07	8.3	M	Feeding	Lab	Stomach
Kaktovik	07KK2	Sep-07	8.1	F	Feeding	Lab	Stomach
Kaktovik	07KK3	Sep-07	9.0	F	Feeding	Lab	Stomach
Barrow	07B1	Apr-07	9.8	M	Not feeding	NSB notes	Stomach
Barrow	07B2	Apr-07	8.6	M	Not feeding	Lab	Stomach
Barrow	07B3	Apr-07	12.0	F	Not feeding	NSB notes	Stomach
Barrow	07B4	May-07	10.5	M	Not feeding	NSB notes	Stomach
Barrow	07B5	May-07	8.5	F	Not feeding	NSB notes	Stomach
Barrow	07B6	May-07	11.0	M	Not feeding	NSB notes	Stomach
Barrow	07B7	May-07	11.1	M	Not feeding	NSB notes	Stomach
Barrow	07B8	May-07	14.9	M	Not feeding	NSB notes	Stomach
Barrow	07B9	May-07	14.3	F	Not feeding	NSB notes	Stomach
Barrow	07B10	May-07	16.1	F	Not feeding	NSB notes	Stomach
Barrow	07B11	May-07	15	M	Not feeding	NSB notes	Stomach
Barrow	07B14	Oct-07	8.1	F	Uncertain	Lab	Stomach
Barrow	07B15	Oct-07	10.1	F	Feeding	Lab	Stomach
Barrow	07B16	Oct-07	14.4	F	Feeding	Lab	Stomach
Barrow	07B17	Oct-07	11.1	M	Feeding	Lab	Stomach
Barrow	07B18	Oct-07	6.1	F	Uncertain	Lab	Stomach
Barrow	07B19	Oct-07	8.6	M	Feeding	Lab	Stomach
Barrow	07B20	Oct-07	8.9	M	Feeding	Lab	Stomach
Savoonga	08S1	Apr-08	7.6	F	Feeding	Lab	Feces
Savoonga	08S2	Apr-08	13.7	M	Feeding	Lab	Feces
Kaktovik	08KK1*	Sep-08	7.2	M	Milk	Lab	Stomach/feces
Kaktovik	08KK2	Sep-08	12.7	M	Feeding	Lab	Stomach
Kaktovik	08KK3	Sep-08	9.8	M	Not feeding	Lab	Stomach
Barrow	08B1	Apr-08	8.7	F	Uncertain	NSB notes	Stomach
Barrow	08B2	Apr-08	8.8	M	Feeding	Lab	Stomach
Barrow	08B3	May-08	9.2	M	Not feeding	Lab	Stomach
Barrow	08B4	May-08	8.7	F	Not feeding	Lab	Stomach

Appendix VB-1. (Continued)

Location	ID #	Date	Length (m)	Sex	Status	Data	Examined
Barrow	08B5	May-08	9.2	F	Not feeding	Lab	Stomach
Barrow	08B6	May-08	8.6	M	Not feeding	NSB notes	Stomach
Barrow	08B7	May-08	9.2	M	Not feeding	Lab	Stomach
Barrow	08B8	May-08	8.4	F	Not feeding	Lab	Stomach
Barrow	08B9	May-08	8.4	M	Uncertain	Lab	Stomach
Barrow	08B10	Oct-08	12.4	M	Feeding	Lab	Stomach
Barrow	08B11	Oct-08	8.9	F	Feeding	Lab	Stomach
Barrow	08B12	Oct-08	9.3	M	Feeding	Lab	Stomach
Barrow	08B13	Oct-08	10.6	M	Feeding	Lab	Stomach
Barrow	08B14	Oct-08	13.6	F	Feeding	Lab	Stomach
Barrow	08B16	Oct-08	8.1	F	Uncertain	Lab	Stomach
Barrow	08B17	Oct-08	9.7	M	Feeding	Lab	Stomach
Barrow	08B18	Oct-08	8.3	F	Feeding	Lab	Stomach
Barrow	08B19	Oct-08	8.2	F	Feeding	Lab	Stomach
Barrow	08B20	Oct-08	8.7	F	Feeding	Lab	Stomach
Barrow	08B21	Oct-08	8.3	M	Feeding	Lab	Stomach
Savoonga	09S1	Apr-09	13.5	F	Feeding	Lab	Feces
Savoonga	09S3	Apr-09	13.3	M	Feeding	Lab	Feces
Kaktovik	09KK1	Sep-09	15.3	F	Feeding	Lab	Stomach
Kaktovik	09KK2	Sep-09	13.2	M	Feeding	Lab	Stomach
Kaktovik	09KK3	Sep-09	6.6	F	Empty	Lab	Stomach/feces
Barrow	09B1	May-09	8.4	F	Feeding	Lab	Stomach
Barrow	09B2	May-09	14.8	M	Feeding	Lab	Stomach
Barrow	09B5	Sep-09	9.8	M	Feeding	Lab	Stomach
Barrow	09B6	Sep-09	9.9	M	Feeding	Lab	Stomach
Barrow	09B7	Sep-09	11.3	F	Feeding	Lab	Stomach
Barrow	09B8	Sep-09	10.3	F	Feeding	Lab	Stomach
Barrow	09B9	Sep-09	8.7	M	Feeding	Lab	Stomach
Barrow	09B10	Sep-09	8.9	F	Feeding	Lab	Stomach
Barrow	09B11	Sep-09	7.2	F	Feeding	Lab	Stomach
Barrow	09B12	Sep-09	8.7	F	Uncertain	NSB notes	Stomach
Barrow	09B13	Sep-09	8.1	M	Feeding	Lab	Stomach
Barrow	09B14	Sep-09	10.2	F	Feeding	Lab	Stomach
Barrow	09B15	Oct-09	8.7	M	Feeding	Lab	Stomach
Barrow	09B16	Oct-09	7.8	F	Feeding	Lab	Stomach
Barrow	09B17	Oct-09	9.9	F	Feeding	Lab	Stomach
Barrow	09B18	Oct-09	8.4	M	Feeding	Lab	Stomach

Appendix VB-1. (Continued)

Location	ID #	Date	Length (m)	Sex	Status	Data	Examined
Barrow	09B19	Oct-09	10.6	F	Feeding	Lab	Stomach
Gambell	10G2	Apr-10	11.8	M	Feeding	Lab	Feces
Gambell	10G3	May-10	14.0	M	Feeding	Lab	Feces
Gambell	10G4	May-10	7.8	M	Feeding	Lab	Stomach/Feces
Gambell	10G5	May-10	14.0	M	Feeding	Lab	Stomach
Savoonga	10S1	Apr-10	15.0	F	Not feeding	Field notes	Stomach/Feces
Savoonga	10S3	Dec-10	17.1	F	Not feeding	Lab	Feces
Savoonga	10S4	Dec-10	13.3	F	Feeding	Lab	Feces
Barrow	10B1	May-10	10.9	F	Not feeding	Lab	Stomach
Barrow	10B2	May-10	8.3	F	Not feeding	Lab	Stomach
Barrow	10B4	May-10	8.7	M	Not feeding	NSB notes	Stomach
Barrow	10B5	May-10	8.7	M	Not feeding	NSB notes	Stomach
Barrow	10B6	May-10	8.4	F	Not feeding	Lab	Stomach
Barrow	10B7	May-10	8.4	M	Not feeding	Lab	Stomach
Barrow	10B8	May-10	7.3	M	Uncertain	Lab	Stomach
Barrow	10B9	May-10	8.7	U	Not feeding	NSB notes	Stomach
Barrow	10B10	May-10	10.7	F	Uncertain	Lab	Stomach
Barrow	10B11	May-10	7.5	M	Not feeding	NSB notes	Stomach
Barrow	10B13	May-10	13.1	F	Not feeding	Lab	Stomach
Barrow	10B14	May-10	8.3	F	Not feeding	Lab	Stomach
Barrow	10B15	Oct-10	12.5	F	Feeding	Lab	Stomach
Barrow	10B16	Oct-10	7.9	M	Feeding	Lab	Stomach
Barrow	10B17	Oct-10	11	M	Feeding	Lab	Stomach
Barrow	10B18	Oct-10	9.1	F	Feeding	Lab	Stomach
Barrow	10B19	Oct-10	11.1	F	Feeding	Lab	Stomach
Barrow	10B20	Oct-10	7.8	M	Feeding	Lab	Stomach
Barrow	10B21	Oct-10	11.5	M	Feeding	Lab	Stomach
Barrow	10B22	Oct-10	7.3	F	Feeding	Lab	Stomach
Wainwright	10WW3	Oct-10	7.5	F	Feeding	Lab	Stomach
Kaktovik	10KK1	Sep-10	8.3	M	Uncertain	Lab	Stomach
Kaktovik	10KK2	Sep-10	8.8	F	Uncertain	Lab	Stomach
Kaktovik	10KK3	Sep-10	10.9	M	Uncertain	Lab	Stomach
Savoonga	11S1*	Apr-11	16.5	M	---	---	Feces (lost)
Savoonga	11S2	Apr-11	14.5	M	Feeding	Lab	Feces
Barrow	11B1	Apr-11	8.8	M	Not feeding	NSB notes	Stomach
Barrow	11B2	Apr-11	8.6	M	Not feeding	NSB notes	Stomach
Barrow	11B4	May-11	7.8	F	Not feeding	NSB notes	Stomach

Appendix VB-1. (Continued)

Location	ID #	Date	Length (m)	Sex	Status	Data	Examined
Barrow	11B6	May-11	16.9	F	Not feeding	NSB notes	Stomach
Barrow	11B8	Oct-11	8.4	F	Feeding	Lab	Stomach
Barrow	11B9	Oct-11	12.5	F	Feeding	Lab	Stomach
Barrow	11B10	Oct-11	8.6	M	Feeding	Lab	Stomach
Barrow	11B11	Oct-11	8.5	M	Feeding	Lab	Stomach
Barrow	11B12	Oct-11	10.2	M	Feeding	Lab	Stomach
Barrow	11B13	Oct-11	8.2	M	Feeding	Lab	Stomach
Barrow	11B14	Oct-11	11.7	M	Feeding	Lab	Stomach
Barrow	11B17	Oct-11	14.5	F	Feeding	Lab	Stomach
Barrow	11B18	Oct-11	10.2	F	Feeding	Lab	Stomach
Kaktovik	11KK2*	Sep-11	6.6	F	Milk	Lab	Stomach
Kaktovik	11KK3	Sep-11	8.9	F	Feeding	Lab	Stomach
Savoonga	12S1	Apr-12	12.1	F	Not feeding	Lab	Feces
Savoonga	12S2	Apr-12	13.6	F	Feeding	Lab	Feces
Savoonga	12S3	Apr-12	8.1	M	Not feeding	Field notes	Feces
Savoonga	12S4	Apr-12	8.2	F	Not feeding	Lab	Feces
Savoonga	12S5	Apr-12	8.2	M	Feeding	Lab	Feces
Savoonga	12S6	Apr-12	13.7	M	Feeding	Lab	Feces
Savoonga	12S7	Nov-12	17.5	F	Feeding	Lab	Feces
Savoonga	12S8	Nov-12	15.5	F	Feeding	Lab	Feces
Gambell	12G2	Apr-12	8.4	F	Feeding	Lab	Feces
Barrow	12B1	Apr-12	10.1	F	Not feeding	NSB notes	Stomach
Barrow	12B2	Apr-12	10.1	F	Feeding	Lab	Stomach
Barrow	12B3	Apr-12	9.9	M	Feeding	Lab	Stomach
Barrow	12B4	Apr-12	8.8	F	Not feeding	Lab	Stomach
Barrow	12B5	Apr-12	7.9	F	Not feeding	NSB notes	Stomach
Barrow	12B6	Apr-12	8.2	M	Not feeding	NSB notes	Stomach
Barrow	12B7	Apr-12	9.0	F	Not feeding	Lab	Stomach
Barrow	12B8	Apr-12	8.3	M	Not feeding	NSB notes	Stomach
Barrow	12B11	May-12	9.7	M	Not feeding	Lab	Stomach
Barrow	12B12	May-12	8.4	M	Not feeding	NSB notes	Stomach
Barrow	12B13	May-12	9.3	M	Not feeding	NSB notes	Stomach
Barrow	12B14	May-12	7.7	M	Not feeding	NSB notes	Stomach
Barrow	12B15	Oct-12	8.4	M	Feeding	Lab	Stomach
Barrow	12B16	Oct-12	10.3	M	Feeding	Lab	Stomach
Barrow	12B17	Oct-12	10.8	F	Uncertain	Lab	Stomach
Barrow	12B18	Oct-12	9.4	F	Feeding	Lab	Stomach

Appendix VB-1. (Continued)

Location	ID #	Date	Length (m)	Sex	Status	Data	Examined
Barrow	12B19	Oct-12	9.4	M	Feeding	Lab	Stomach
Barrow	12B20	Oct-12	8.9	M	Feeding	Lab	Stomach
Barrow	12B21	Oct-12	13.3	F	Feeding	Lab	Stomach
Barrow	12B22	Oct-12	9.2	F	Feeding	Lab	Stomach
Barrow	12B23	Oct-12	8.5	F	Feeding	Lab	Stomach
Barrow	12B24	Oct-12	10.1	M	Feeding	Lab	Stomach
Kaktovik	12KK1	Sep-12	13.4	M	Not feeding	Lab	Stomach/feces

Appendix VB-2. *Prey and other items consumed by all bowhead whales harvested in the Alaskan Beaufort and Bering seas during 2007–2012 and examined for evidence of feeding. Locations and seasons where whales were harvested are indicated after each taxon (BS=Barrow/Spring, BF=Barrow/Fall, KF=Kaktovik, SLIS=St. Lawrence I./Spring, SLIF=St. Lawrence I/Fall).*

CNIDARIA
Hydroida [BF]

ANNELIDA
Polychaeta [BF, BS]
Capitellidae [KF]
Maldanidae [KF]
Pectinariidae [KF]

MOLLUSCA
Gastropoda [BF, SLIS]
Trochidae [KF]
Bivalvia [BF, SLIS]
Astarte sp. [KF]
Ennucula tenuis [BF, SLIS]
Nuculana sp. [SLIS]

PRIAPULA
Priapulidae [KF]

CRUSTACEA
Ostracoda [BF]
Copepoda [BF, KF, SLIS]
Aetididae [BF]
Calanus sp. [BF, KF, SLIF]
Calanus glacialis [BF, BS, KF,]
Calanus hyperboreus [BF, BS,]
Chiridius polaris [BF]
Limnocalanus grimaldii [BF]
Metridea longa [BS, BF, KF]
Pareuchaeta sp. [BF, KF]

Copepoda (cont.)
Pareuchaeta glacialis [BF, KF]
Mysidacea [BF, BS, KF]
Mysis sp. [BF, KF]
Mysis litoralis [BS, SLIS]
Mysis occulata [BF, KF, SLIS]
Neomysis rayii [BF, BS]
Cumacea [BF]
Diastylis sp. [BF, BS, KF]
Diastylis bidentata [BF]
Diastylis sulcata [BF]
Eudorellopsis sp. [BF]
Isopoda
Saduria entomon [BF, BS, KF]
Amphipoda [BF, KF, SLIF]
Acanthostepheia sp. [KF]
Acanthostepheia
Anonyx sp. [BF, BS]
Ampeliscidae [BF]
Ampelisca sp. [BF]
Apherusa sp. [BF]
Atylus sp. [BS]
Eusirus sp. [BF, BS]
Gammarid [SLIS]
Gammarus sp. [BS]
Hyperiidae [BF, BS, KF]
Hyperia medusarum [BF, KF]
Hyperoche medusarum [BF]
Isaeidae [BF]
Lysianassidae [BF, KF]
Melita sp. [BF, SLIS]

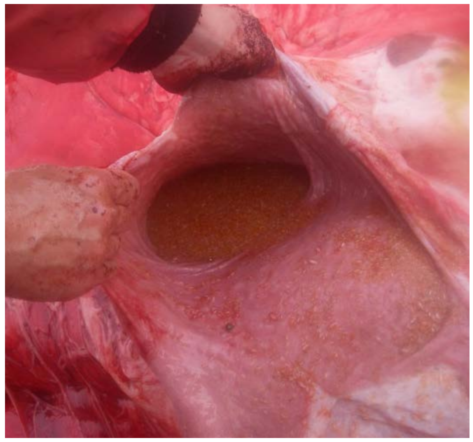
Amphipoda (cont.)
Monoculodes sp. [BF]
Oedicerotidae [BF]
Onisimus sp. [BF, BS, KF, SLIS]
Parathemisto sp. [BF]
Parathemisto libellula [BF,]
Paroediceros sp. [BF]
Pleustes sp. [BF]
Podoceridae [BF].
Pontoporeia sp. [BF]
Pontoporeia femorata [BF]
Stenothoidae [BF]
Weyprechtia sp. [BF, BS]
Decapoda [BF, SLIS]
Argis sp. [BF]
Argis lar [BF]
Crangonidae [BF, KF, SLIS]
Eualus sp. [BF]
Eualus fabricii [BF]
Eualus gaimardi [BF]
Hermit crab [BF]
Hippolytidae [BF, SLIS]
Paguridae [BF]
Pandalus sp. [BF]
Pandalidae [BF]
Sabinea septemcarinata [BF,]
"Shrimp" parts [BF, KF, SLIS]
Euphausiacea [BF, BS]
Thysanoessa sp. [BF, BS]
Thysanoessa inermis [BF, BS]
Thysanoessa raschii [BF, BS,]

Cirripedia
Barnacle [BF]

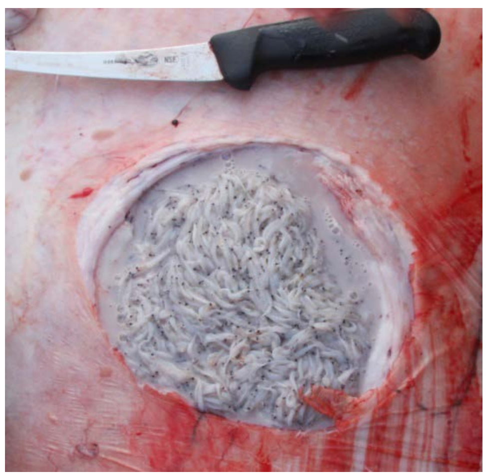
ECHINODERMATA
Ophiura sp. [BF, KF]

VERTEBRATA
Osteichthyes [BF, BS, SLIS]
Ammodytes hexapterus [BF]
Anisarchus medius [BF]
Boreogadus saida [BF, BS,]
Cottidae [BF]
Eleginus gracilis [BF, BS]
Gadidae [BF, KF]
Gymnacanthus tricuspis
Icelus sp. [BF]
Myoxocephalus sp. [BF]
Myoxocephalus scorpius
Ulcina olrikii [BF]

Appendix VB-3. *Photographs of fecal and stomach contents during field examinations of harvested bowhead whales.*



Copepods in the stomach of a subsistence harvested bowhead landed at Kaktovik (07KK2).



Freshly consumed euphausiids from a subsistence harvested bowhead landed at Barrow (09B8).

Feces from a subsistence harvested bowhead landed on St. Lawrence Island (10G2).

Appendix VB-4. *Identification numbers and additional tissues collected from 63 subsistence harvested bowhead whales sampled at Kaktovik (KK), Savoonga (S), and Gambell (G) during 2007-2012 that were provided to the North Slope Borough (NSB) Dept. of Wildlife Management for the Bowhead Health Assessment project for study and archive.*

ID#	Skin	Blubber	Muscle	Eye	Liver	Kidney	Urine	Tongue	Spleen	Baleen	Serum	Ovaries	Other
07KK1	X	X	X	X	X	X	X	X	X	X	X	-	Lung, testis, pancreas, intestine
07KK2	X	X	X	X	X	X	X	-	X	X	X	X	Lung
07KK3	X	X	X	X	X	X	X	X	X	X	X	X	Lung, intestine
07S1	X	X	X	X	-	-	-	-	-	-	-	-	-
07S2	X	X	X	X	X	X	-	-	X	-	-	X	Intestine
07S3	X	X	X	X	X	X	-	-	X	-	-	-	Intestine
07S4	X	-	X	X	-	-	-	-	-	-	-	-	-
07G2	X	-	X	-	-	-	-	-	-	-	-	-	-
07G3	X	X	X	X	-	-	-	-	-	-	-	-	-
07G4	X	X	X	X	-	-	-	-	-	-	-	-	-
08KK1	X	X	X	X	X	X	-	X	X	X	X	-	Lung, body fat, heart, intestine
08KK2	X	X	X	X	X	X	-	X	X	X	X	-	Lung, testes, body fat, bladder, heart, intestine
08KK3	X	X	X	X	X	X	-	X	X	X	X	-	Lung, testes, heart, intestine
08S1	X	X	X	X	-	-	-	-	-	X	-	-	-
08S2	X	X	X	X	-	X	-	-	-	X	-	-	Testis
08S3	X	X	-	-	-	-	-	-	-		-	-	-
08S4	X	X	X	-	-	-	-	-	-	X	-	-	-
08G1	X	X	X	-	-	-	-	-	-	X	-	-	-
08G2	X	X	X	-	-	-	-	-	-		-	-	-
09KK1	X	X	X	X	-	-		X	X	X	X	X	Lung, intestine, body fat, fetus
09KK2	X	X	X	X	X	X		X	X	X	X		Lung, intestine, body fat, heart, testes
09KK3	X	X	X	X	X	-	X	X	X	X	X	X	Lung, intestine, body fat
09S1	X	X	X	X	X	X	-	-	-	X	X	X	-
09S2	X	-	X	-	-		-	-	-	-	-	-	-
09S3	X	X	X	X	-	X	-	-	-	X	-	-	-
09G1	X	-	X	X	-		-	-	-	X	-	-	-
10KK1	X	X	X	X	X	X	X	X	X	X	X	-	Lung, body fat, heart, lymph node, bladder, cyamids
10KK2	X	X	X	X	X	X	X	X	X	X	X	X	Lung, heart, lymph node, cyamids
10KK3	X	X	X	X	X	-	-	X	-	X	X	-	Lung, body fat, heart, testes
10G1	X	X	-	X	-	-	-	-	-	X	-	-	-
10G2	X	X	X	X	-	X	-	X	-	X	-	-	Epididymis, lung
10S1	X	X	X	X	X	X	-	-	-	X	-	X	Intestine
10S1F	X	X	X	X	X	X	-	-	-	X	-	-	Intestine, testis

Appendix VB-4. (Continued)

ID#	Skin	Blubber	Muscle	Eye	Liver	Kidney	Urine	Tongue	Spleen	Baleen	Serum	Ovaries	Other
10G3	X	X	X	X	-	-	-	-	-	X	-	-	Intestine, epididymis, testis
10G4	X	X	X	X	-	X	-	X	-	X	-	-	Epididymis, testis, , cyamids
10G5	X	X	X	X	X	X	-	-	X	X	-	-	-
10S2	X	-	-	X	-	-	-	-	-	X	-	-	-
10G6	X	-	-	-	-	-	-	-	-	-	-	-	-
10S3	X	X	X	X	-	-	-	-	-	X	-	-	-
10S4	X	-	X	-	-	-	-	-	-	X	-	X	-
11KK1	X	X	X	X	-	-	-	X	-	X	-	X	Cyamids
11KK2	X	X	X	X	X	X	-	X	X	X	-	X	Lung, heart, lymph node
11KK3	X	X	X	X	X	-	-	X	X	X	X	X	Lung, heart
11S1	X	-	X	X	-	-	-	-	-	-	-	-	"False" nipple
11S2	X	X	X	X	-	-	-	-	-	-	-	-	"False" nipple
11G1	X	-	-	-	-	-	-	-	-	-	-	-	-
11G2	X	-	-	-	-	-	-	-	-	-	-	-	-
11G3	X	X	X	X	-	-	-	-	-	-	-	-	-
12KK1	X	X	X	X	X	X	X	X	X	X	X	-	Lung, heart, lymph node, testis
12KK2	X	-	-	-	-	-	-	-	-	-	-	-	-
12S1	X	X	X	X	X	-	X	-	X	X	-	X	-
12S2	X	-	X	X	-	X	-	-	-	X	-	X	-
12S2F	X	X	X	X	X	-	-	X	-	X	-	-	Intestine
12S3	X	X	X	X	X	-	-	-	-	X	-	-	Intestine
12S4	X	X	X	X	X	X	-	-	X	X	-	X	Lung
12S5	X	X	X	X	X	X	-	X	X	-	-	-	"False" nipples
12S6	X	-	-	-	X	-	-	-	-	-	-	-	-
12S7	X	X	X	X	-	-	-	-	-	X	-	X	-
12S7F	X	-	X	-	X	X	-	-	-	X	-	X	Lung, intestine
12S8	X	X	X	X	X	-	-	-	-	X	-	X	-
12S8F	X	X	X	-	X	X	-	-	-	-	-	-	Penis, testis, intestine
12G1	X	X	X	X	-	-	-	-	-	-	-	X	-
12G2	X	X	X	X	-	-	X	-	-	-	-	X	-
ID#	**Skin**	**Blubber**	**Muscle**	**Eye**	**Liver**	**Kidney**	**Urine**	**Tongue**	**Spleen**	**Baleen**	**Serum**	**Ovaries**	**Other**
	63	49	55	49	29	26	9	19	20	41	15	20	

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Section V - North Slope Borough Research
C - Bowhead Whale Digestive Efficiency

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Abstract

Bowhead whales (*Balaena mysticetus*) are a subsistence resource of cultural significance to Arctic Native communities. Prey density is of paramount importance to filter feeding cetaceans to maintain energy balance, yet little is known about bowhead metabolic demands and digestive efficiency of their common zooplankton prey. Samples of fresh zooplankton and digestive contents were taken along the alimentary tract of subsistence-harvested bowheads (2009-2012) from the forestomach, fundic and pyloric chambers, duodenal ampulla, small intestine, and large intestine. We used proximate composition analyses (% lipid, % protein) and bomb calorimetry to assess changes in energy density and composition of digesta. Assimilation efficiency was calculated based on "start" composition of forestomach contents to "end" composition of colon contents and was between 40-50% for gross energy density. Protein digestion occurred in the forestomach, consistent with chitinolytic, microbial fermentation leading to lipid release from prey. Lipids were not taken up until the duodenum (consistent with typical mammalian digestion) with an efficiency of approximately 50-60%. Due to the high caloric density of lipids, this trend was repeated in gross energy content. Digestive efficiency was calculated using published or estimated data on daily food intake and defecation volumes of bowhead whales and was on average 77%. Proportions of individual fatty acids change along the alimentary tract; the proportions of saturated fatty acids (SAFA) increase in the colon compared with ingested food. Specifically, long chain SAFAs (e.g., 20:0 and 22:0) appear in the colon, but are not present in the diet pointing to bacterial synthesis in the gut. In contrast, polyunsaturated fatty acids (PUFA) are taken up, in particular essential fatty acids, such as 20:4 ω6, 20:4 ω3, and 22:6 ω3, and do not occur in the colon. Using respiratory frequency of migrating whales and lung volume estimates, we determined metabolic rate (MR) of an average-sized (9m) whale as ~4.3kW (1.1x Kleiber) when migrating and 7.9kW (2x Kleiber) when feeding. Estimates of daily energy intake indicate that whales may expend as much energy when feeding/migrating as is gained (~8kW for a 9m whale) with a digestive efficiency of 77%. This emphasizes the importance of finding high density prey patches and minimizing the search, but also indicates that migrating whales can acquire sufficient energy near Barrow to offset their migratory costs and avoid expending energy gained on the summer foraging grounds. Fat reserves stored in bowhead blubber far exceed thermoregulatory requirements; we estimate that a 9m bowhead could fast over 1 year (migratory MR, assuming no MR adjustments), suggesting a built-in fail-safe for years with unfavorable prey densities.

Introduction

The Arctic ecosystem is undergoing rapid change, including a significant loss of sea ice coverage and thickness, with record ice minima reported since 2007 and a new record low in 2012 (Perovich et al. 2010, NSIDC 2012). While sea ice in the Arctic has been recognized as an important parameter in the seasonality of sympagic, pelagic, and benthic processes (Renaud et al. 2007, Iken et al. 2010), its role in sustaining these ecosystems and food webs remains largely unknown. However, management plans and risk assessments of top Arctic predators already recognize the potential of a disrupted benthic food chain and altered foraging strategies due to sea ice loss (Cameron et al. 2010).

Bowhead whales (*Balaena mysticetus*) are endangered baleen whales adapted to life in the Arctic Ocean. They rely on a thick (up to 50cm) blubber layer for insulation, although it has been argued that this fat deposit exceeds their thermoregulatory needs (Ford et al. 2013). Bowheads are exceptionally long-lived (George et al. 1999, 2011, Rosa et al. 2012) and have a slow metabolic rate (George 2009). The Bering-Chukchi-Beaufort seas stock migrates annually between the Beaufort Sea where they spend the summer feeding and the Bering Sea where they spend the winter at the southern limit of the ice pack (Moore and Reeves 1993). Bowheads have been hunted for centuries and they are a cultural and nutritional staple to the Inupiat peoples of Alaska and several circumpolar countries. Like right whales (*Eubalaena* spp.), bowhead whales faced near extinction during commercial whaling in the 19th and 20th centuries, but are now recovering at a robust rate of 3.4% per year, while sustaining a quota-regulated subsistence harvest (George et al. 2004, Koski et al. 2010). However, the changing Arctic Ocean does not come without challenges for this mysticete. Increased human and industrial activities, including ship traffic, fisheries and gear interactions, and noise pollution are new threats to this population (Reeves et al. 2012) with yet unknown energetic consequences for bowhead whales.

Foraging studies and an improved understanding of energy flow in the Arctic are crucial aspects in the management and conservation of free-ranging cetaceans. As mysticetes, bowheads rely on small zooplankton prey, such as copepods and euphausiids (Lowry et al. 2004). However, engulfing krill patches while swimming with mouths agape provides hydrodynamic and energetic challenges. Increasing foraging efficiency is therefore critically important, and rorquals as well as right whales rely on very high prey densities (and a well-developed sense of olfaction to detect these aggregations) to balance energy expense and gain (Baumgartner and Mate 2003, Laidre et al. 2007, Simon et al. 2009, Goldbogen et al. 2011, Thewissen et al. 2011). As an additional energy-saving measure, bowheads sometimes aggregate into a hydrodynamic echelon formation while skim feeding (Fish et al. 2012). This formation also makes efficient use of the entire zooplankton patch by utilizing vortices that channel escaped prey into the mouth of the trailing whale (Fish et al. 2012). In the Arctic, and particularly around Barrow, Alaska, density and abundance of krill patches is largely dependent on weather patterns and ocean conditions known as 'the krill trap' (Ashjian et al. 2010, Okkonen et al. 2011, Okkonen Section III: this volume). Nevertheless, prey quality is equally important, and diminishing energy/nutrient density of prey can affect overall fitness, including body condition and reproductive success (Pörtner and Farrell 2008, Spitz et al. 2012). Dietary shifts and alteration in the spatial and temporal distribution of food resources as well as changes to food quality can thus be an early indicator of stress on a population. Changes in sea ice abundance are well known to affect primary productivity in the Arctic and then propagate to biomass and nutritional quality of secondary consumers (Leu et al. 2010, Brown and Arrigo 2012). Understanding energy flow in the Arctic ecosystem and physiological response of important subsistence species, such as the bowhead whale, to prey abundance and prey quality changes remains, therefore, critical.

The aim of this study was to 1) estimate digestive efficiency of bowhead whales by analyzing the contents of the alimentary tract from forestomach to colon for gross energy density, lipid, and protein content; 2) apply bulk stable carbon and nitrogen isotope analysis to bowhead whale gut contents to evaluate if ingested prey can shed light on feeding events; 3) identify uptake efficiency of individual fatty acids to determine if bowhead whales exhibit a preference for specific dietary lipids; 4) analyze blood chemistry profiles of feeding and fasting bowhead whales to compare and provide reference values of nutritional condition; and 5) use this information to estimate metabolic demand and fasting capability of bowhead whales. We hypothesized that the overall digestive efficiency and metabolic demand of bowhead whales is comparable to that of other mysticetes.

Methods

Field Sampling

Bowhead whales were sampled during Native subsistence harvests in the communities of Barrow, Kaktovik, Gambell, Savoonga, and Wainwright either during spring or fall migration of this species. Depending on season, whales were towed by the hunters onto ice (spring) or shore (fall). Free-flowing blood was collected from the palatal rete / corpus cavernosum maxillaris (Ford et al. 2013) as soon as possible after death, generally not longer than 10 hours postmortem, and stored cool and dark until centrifugation in the laboratory. Morphometric measurements, including standard length from the tip of rostrum to the fluke notch, were recorded and the animals sexed based on appearance of the genital slit. Sex was later confirmed by internal examination of gonads.

Samples of digestive tract contents were taken along the alimentary tract of bowhead whales and included (in order of food passage from oral opening) forestomach, fundic chamber, pyloric chamber, duodenal ampulla, duodenum, jejunum, ileum, upper colon, and colon (Fig. VC-1). Samples were only collected if the respective compartment contained digesta and not all whales were sampled intensively. It was generally only possible to obtain contents of the entire digestive tract when whales were landed in Barrow in the fall due to logistical difficulties and ease of access. Additional samples from the small intestine (including duodenal ampulla, jejunum, ileum, and upper colon) were only collected in 2011 and 2012. Samples collected from individual whales are identified in Table VC-1. Feeding status was determined by direct examination of the stomach. If prey was present, the whale was classified as ‘feeding’, if the stomach was empty or only contained watery fluid without prey, the whale was categorized as ‘not feeding’. All samples were collected in either whirlpack® bags or in pre-weighed 50mL Falcon™ tubes and immediately frozen at -20°C until analysis at the Marine Mammal Laboratory at the University of Alaska Fairbanks (UAF). In addition, fresh euphausiid prey (*Thysanoessa* spp.) was collected in Barrow in September 2009 and 2012 after wash-up events (Okkonen et al. 2011). Fresh copepod prey (identified as *Calanus glacialis*) were sampled by C. Ashjian during a research cruise to the Beaufort Sea in September 2012.

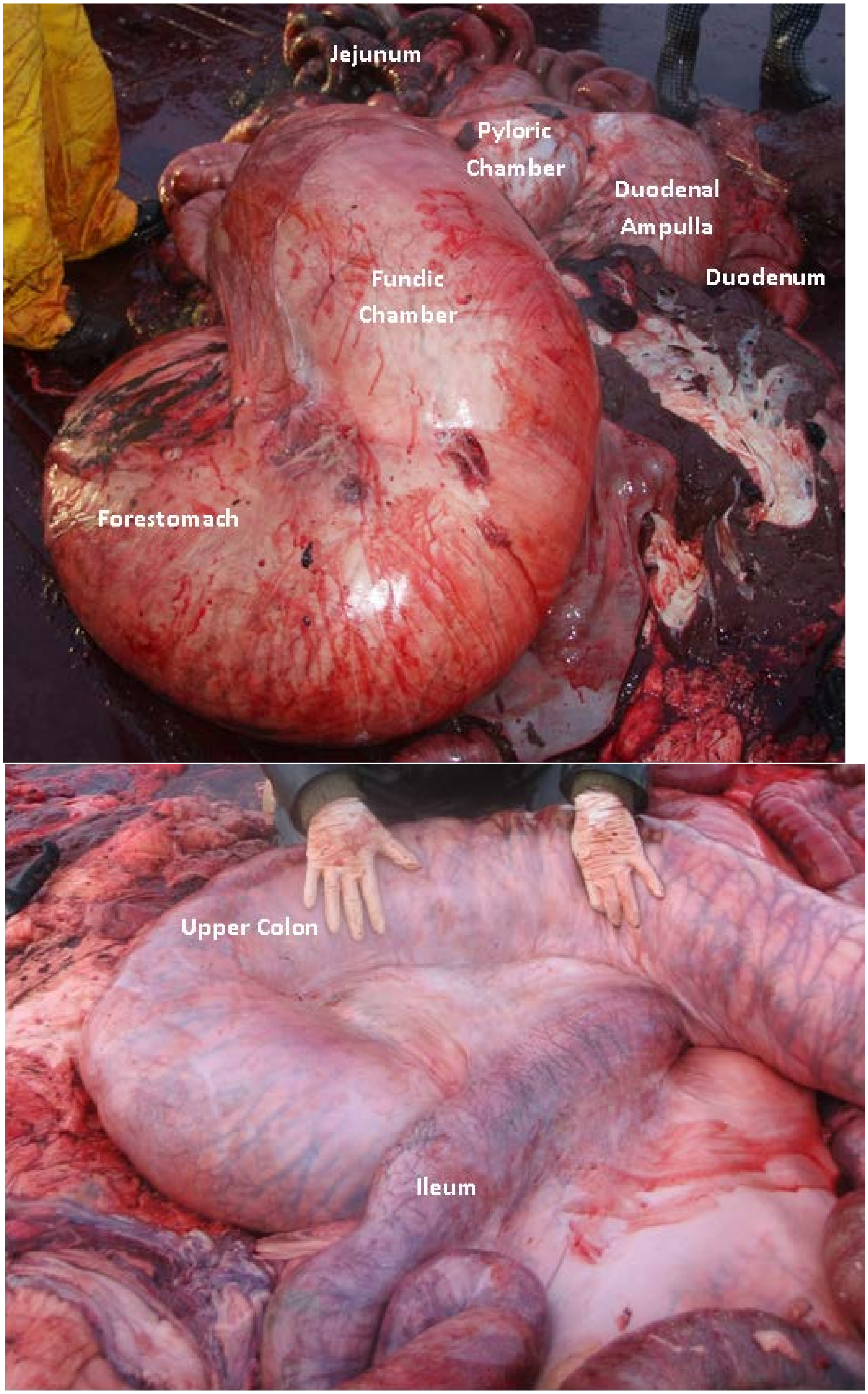

Figure VC-1. *Overview of a bowhead whale stomach (A) with intestinal tract compartments identified where digesta was sampled in this study. Ileum and colon are shown in a separate image (B).*

Table VC-1. *Bowhead whale individual identifiers, harvest locations, sampling season, morphometrics (sex and standard length), feeding status, and samples collected as part of this study (2009-2012). Abbreviations: S=Serum, F=Forestomach, N=Fundic Chamber, P=Pyloric Chamber, A=Duodenal Ampulla, D=Duodenum, J=Jejunum, I=Ileum, U=Upper Colon, C=Colon.*

Whale ID	Location	Season	Length [m]	Sex	Feeding Status	Samples
09B5	Barrow	Fall 2009	9.8	M	Feeding	S, F, D, C
09B6	Barrow	Fall 2009	9.9	M	Feeding	S, F, N, P, D, C
09B7	Barrow	Fall 2009	11.3	F	Feeding	S, F, N, P, D, C
09B8	Barrow	Fall 2009	10.3	F	Feeding	S, F, N, P, D, C
09B9	Barrow	Fall 2009	8.7	M	Feeding	S, F, N, P, D, C
09B10	Barrow	Fall 2009	8.9	F	Feeding	S, F, N, P, D, C
09B12	Barrow	Fall 2009	8.7	F	Feeding	S, P, D, C
09B13	Barrow	Fall 2009	8.0	M	Feeding	S
09KK3	Kaktovik	Fall 2009	6.6	F	Feeding	S
10B1	Barrow	Spring 2010	10.9	F	Not Feeding	S, C
10B2	Barrow	Spring 2010	8.3	F	Not Feeding	C
10B3	Barrow	Spring 2010	8.0	F	Not Feeding	S, C
10B4	Barrow	Spring 2010	8.7	M	Not Feeding	S, C
10B5	Barrow	Spring 2010	8.7	M	Not Feeding	S, C
10B6	Barrow	Spring 2010	8.4	F	Not Feeding	S, C
10B7	Barrow	Spring 2010	8.4	M	Not Feeding	S, C
10B8	Barrow	Spring 2010	7.3	M	Not Feeding	C
10B9	Barrow	Spring 2010	8.7	F	Not Feeding	S, C
10B10	Barrow	Spring 2010	10.7	F	Not Feeding	S, C
10B11	Barrow	Spring 2010	7.5	M	Not Feeding	S, C
10B12	Barrow	Spring 2010	9.8	F	Not Feeding	S, C
10B13	Barrow	Spring 2010	13.1	F	Not Feeding	C
10B14	Barrow	Spring 2010	8.3	F	Not Feeding	C
10G2	Gambell	Spring 2010	11.8	M	Feeding	C
10G4	Gambell	Spring 2010	7.8	M	Feeding	C
10G5	Gambell	Spring 2010	14.0	M	Feeding	C
10B15	Barrow	Fall 2010	12.5	F	Feeding	S, F, D, C
10B16	Barrow	Fall 2010	7.9	M	Feeding	S, F, C
10B17	Barrow	Fall 2010	11.0	M	Feeding	C
10B18	Barrow	Fall 2010	9.1	F	Feeding	S, F, D, C
10B19	Barrow	Fall 2010	7.9	M	Feeding	S
10B20	Barrow	Fall 2010	7.8	M	Feeding	S, D
10B21	Barrow	Fall 2010	11.5	M	Feeding	S
10B22	Barrow	Fall 2010	7.3	F	Feeding	S, F, D, C
10WW3	Wainwright	Fall 2010	7.5	F	Feeding	F
10KK2	Kaktovik	Fall 2010	8.8	F	--	C
10KK3	Kaktovik	Fall 2010	10.9	M	--	C
10S3	Savoonga	Fall 2010	17.1	F	Not Feeding	D
10S4	Savoonga	Fall 2010	13.3	F	Feeding	C

Table 1: continued

Whale ID	Location	Season	Length [m]	Sex	Feeding Status	Samples
11S1	Savoonga	Spring 2011	16.5	M	--	
11S2	Savoonga	Spring 2011	14.5	M	Feeding	
11B8	Barrow	Fall 2011	8.4	F	Feeding	S, F, P, A, D, J, I, U, C
11B9	Barrow	Fall 2011	12.5	F	Feeding	S, F, N, P, A, D, J, I, U, C
11B10	Barrow	Fall 2011	8.6	M	Feeding	S, F, D, C
11B11	Barrow	Fall 2011	8.5	M	Feeding	S, F, D, C
11B12	Barrow	Fall 2011	10.2	M	Feeding	S, D, C
11B13	Barrow	Fall 2011	8.2	M	Feeding	S, F, C
11B14	Barrow	Fall 2011	11.7	M	Feeding	S, F, D, C
11B16	Barrow	Fall 2011	13.9	M	--	S, C
11B17	Barrow	Fall 2011	14.5	F	Feeding	S, C
11B18	Barrow	Fall 2011	10.2	F	Feeding	S, C
11KK1	Kaktovik	Fall 2011	13.9	F	--	D
11KK2	Kaktovik	Fall 2011	6.6	F	Milk	F, C
11KK3	Kaktovik	Fall 2011	8.9	F	Feeding	F, C
12B1	Barrow	Spring 2012	10.1	F	Not Feeding	S, C
12B2	Barrow	Spring 2012	10.1	F	Feeding	S, C
12B3	Barrow	Spring 2012	9.9	M	Feeding	S, C
12B4	Barrow	Spring 2012	8.8	F	Not Feeding	S, C
12B5	Barrow	Spring 2012	7.9	F	Not Feeding	S, C
12B6	Barrow	Spring 2012	8.2	M	Not Feeding	C
12B7	Barrow	Spring 2012	9.0	F	Not Feeding	S
12B8	Barrow	Spring 2012	8.3	M	Not Feeding	S, C
12B14	Barrow	Spring 2012	7.7	M	Not Feeding	S
12S1	Savoonga	Spring 2012	12.1	F	Not Feeding	D
12S2	Savoonga	Spring 2012	13.6	F	Feeding	D
12S4	Savoonga	Spring 2012	8.2	F	Not Feeding	F, C
12S5	Savoonga	Spring 2012	8.2	M	--	F, C
12S6	Savoonga	Spring 2012	13.7	M	--	C
12G2	Gambell	Spring 2012	8.4	F	--	D
12B15	Barrow	Fall 2012	8.4	M	Feeding	S, F, N, A, D, J, I, U, C
12B16	Barrow	Fall 2012	10.3	M	Feeding	S, F, P, D, J, I, U, C
12B17	Barrow	Fall 2012	10.8	F	--	S, I, U, C
12B18	Barrow	Fall 2012	9.4	F	Feeding	S, F, N, P, A, D, J, I, U, C
12B19	Barrow	Fall 2012	9.4	M	Feeding	S, F, N, P, A, D, J, I, U, C
12B20	Barrow	Fall 2012	8.9	M	Feeding	S, F, D, I, U, C
12B21	Barrow	Fall 2012	13.3	F	Feeding	S, F, D, J, C
12B22	Barrow	Fall 2012	9.2	F	Feeding	S, C
12B23	Barrow	Fall 2012	8.5	F	Feeding	S, F, C
12B24	Barrow	Fall 2012	10.1	M	Feeding	S, F, C
12KK1	Kaktovik	Fall 2012	13.4	M	Not Feeding	C

Proximate Composition

In the laboratory, digestive tract content were partially thawed and filled into pre-weighed Falcon™ tubes. This step was omitted if samples were already collected into pre-weighed tubes in the field. Samples were weighed and freeze-dried for a minimum of 48 hours and percent water of prey and alimentary tract contents was determined as loss of mass during lyophilization. Content of different compartments were then lipid-extracted using chloroform:methanol in a modified Soxhlet procedure after Logan and Lutcavage (2008). Tissue nitrogen content was measured using a CNS 2000, Leco Combustion analyzer and ash content was determined via combustion of samples in a muffle furnace at 550°C for 8 hours. The subtractions of inorganics (i.e., ash content) from dry matter allows for the calculation of organic matter in the sample and further subtraction of lipid content provides lean dry mass. Crude protein content can then be calculated from lean dry mass assuming all nitrogen is bound to protein. In addition, all samples were analyzed for gross energy density using bomb calorimetry (Parr Model 1281). All proximate composition data are based on dry weight unless otherwise noted.

Blood Chemistry

Blood was centrifuged for approximately 10 minutes at the Barrow Arctic Research Center and serum was collected in cryovials and immediately frozen at -20°C until analysis in Fairbanks. Blood chemistry profiles were measured using an Abaxis VetScan Classic. Parameters analyzed included albumin (ALB), alkaline phosphatase (ALP), alanine aminotransferase (ALT), amylase (AMY), aspartate aminotransferase (AST), blood urea nitrogen (BUN), calcium (Ca^{2+}), creatine kinase (CK), creatinine (CRE), gamma-glutamyl transferase (GGT), globulin (GLOB), glucose (GLU), potassium (K^+), magnesium (Mg), sodium (Na^+), phosphate (PHOS), total bilirubin (TBIL), and total protein (TP). Values were compared between feeding and non-feeding whales. Similar blood constituents and their variability between sexes in Alaskan bowhead whales were determined by Heidel et al. (1996) and serve here as a point of reference.

Stable Isotope Analysis

Prey and digestive content samples of 8 intensively sampled whales (n = 2 from 2011, n = 6 from 2012) were analyzed for $\delta^{15}N$ and $\delta^{13}C$ at the Alaska Stable Isotope Facility at UAF. Samples were freeze-dried as described above and a subsample of powder, 0.2-0.4 mg, was weighed into tin capsules using a micro-balance (Sartorius Model M2P). Samples were not lipid-extracted prior to analysis. While lipids are depleted in ^{13}C and their presence can influence the carbon isotope signature of tissues (DeNiro and Epstein 1977), the extraction procedure can also alter the stable nitrogen isotope signature (Pinnegar and Polunin 1999, Sweeting et al. 2006). Thus, $\delta^{13}C$ data are presented together with relative changes in %lipid in the intestinal tract to provide context for $\delta^{13}C$ values. Stable isotope analysis was performed using a Finnigan MAT DeltaPlusXP Isotope Ratio Mass Spectrometer (IRMS) directly coupled to a Costech Elemental Analyzer (ECS 4010, Italy). Stable isotope ratios are expressed in conventional delta (δ) notation:

$$\delta X\ (‰) = [(R_{sample} / R_{standard}) - 1] \times 1000$$

where X is ^{15}N or ^{13}C and represents the relative difference between isotope ratios in the sample (R_{sample}, $^{15}N/^{14}N$ or $^{13}C/^{12}C$) and in standards, i.e., atmospheric N_2 and Vienna Pee Dee Belemnite, respectively. Peptone (No. P-7750) was used as a laboratory-working standard and was run every 10 samples; tin capsule blanks were run every 20 samples. The precision of analysis, expressed as one standard deviation from multiple analyses of peptone (n = 12) conducted during the sample runs was 0.1‰ for both $\delta^{15}N$ and $\delta^{13}C$.

Fatty Acid Analysis

Lipids were extracted from freeze-dried euphausiid and copepod prey and alimentary tract content (forestomach, jejunum, and colon) of 3 bowhead whales harvested during fall 2011 using chloroform and methanol. Lipids were then transesterified to fatty acid (FA) methyl esters (FAME) with Hilditch reagent (Folch et al. 1957, Budge et al. 2006). FA analyses have been conducted at the Kodiak Seafood and Marine Science Center. Fatty acid methyl esters were analyzed using a gas chromatography (GC) system (GC/FID model 6850, Agilent Technologies, Wilmington, Delaware) coupled to a flame ionization detector (Bechtel and Oliveira 2006). A GC 6890N coupled to a mass spectrometer MS5973 (Agilent Technologies) was used to assert FA identity of compounds not present in the commercial FA standard mixtures such as Supelco 189-19, Bacterial Acid Methyl Esters Mix, Marine Oil #1, and Marine Oil #3 (Reppond et al. 2009). GC conditions have been adapted from Budge et al. (2006). Up to 65 FAs were identified in samples including those reported in bowhead whale blubber by Budge et al. (2008).

Energetics Model

Theoretical and/or measured allometric and physiological data for an average-sized 9m bowhead whale are provided in Table VC-2. We used stomach volume estimates by Tarpley et al. (1987) for an average bowhead whale to gain energy intake. Forestomach evacuation rates have been estimated for fin whales (*Balaenoptera physalus*) between 3-6hrs (Vikingsson 1997). For this study, we assumed a mean passage time from forestomach to fundic chamber of 6hrs or 4 daily feeding events (see stable isotope data below). Defecation volume and energy loss was estimated by applying the allometric equation implemented by Swaim et al. (2009) (Table VC-2). Digestibility or assimilation efficiency was calculated based on “start” proximate composition of forestomach material to “end” composition of colon content. Fresh prey was not used as beginning composition as gross energy content of fresh prey was generally lower than forestomach energy density and lipid content of Arctic zooplankton is highly seasonal (Falk-Petersen et al. 2000). In addition, dietary data (see Sheffield and George Section VB: this volume) showed a mix of different prey taxa rather than a single species. Digestive efficiency/digestible energy were calculated using daily energy intake (daily forestomach volume and energy density/proximate composition of prey in the forestomach, wet weight) and daily fecal energy loss (daily fecal volume and colon energy density/proximate composition, wet weight).

Bowhead whale metabolic demands (for an average 9m whale) were calculated using the equations provided in Table VC-2, but were also estimated based on lung volume and blow frequency data (Table VC-2). Whales were assumed to oxidize fats and generate 19.7kJ/LO_2 heat (Schmidt-Nielsen 1997). Air exchange in the lungs is between 60-90% per breath (Olsen et al. 1969). Stale air in the lungs (residual volume and dead space contains about 10% O_2 (Olsen et al. 1969) to be mixed with 21% atmospheric oxygen, resulting in 20% O_2 in the lungs. Expulsed air contains approximately 10% O_2, resulting in a 50% extraction efficiency (Olsen et al. 1969). Similarly, extraction efficiency of O_2 at the lungs was assumed to be 45% of the tidal volume by Blix and Folkow (1995), resulting in almost identical O_2 consumption estimates. Fasting capability of bowheads was approximated using blubber mass to body mass ratios and average lipid content of bowhead blubber (Table VC-2). Available blubber lipid was then used to calculate maximum fasting times assuming "business-as-usual" metabolic demands. Our calculations are therefore likely an underestimate as fasting marine mammals undergo metabolic depression (e.g., Rea and Costa 1992). On the other hand, our calculations also assume complete depletion of blubber lipid stores without thermoregulatory adjustment of metabolic rate (e.g., Worthy 1991), which would lead to an overestimate of the fasting capability. Overall, this estimate provides a general ballpark and should not be taken too literally.

Table VC-2. *Allometric and physiological variables for an average-sized bowhead whale, approximately 9m standard body length (rostrum to fluke notch).*

Body Mass (BM) [kg]	**Blubber Mass [kg]**	**Blubber Lipid [kg]**	**Forestomach Volume [L]**	**Fundic + Pyloric Chambers + Duodenal Ampulla [L]**	**Forestomach Evacuation Rate**	**Daily Defecation Mass [g]**
12,000	5,280	4,224	57.2	59.4	3-6 hrs	24,507 (17,008 lean)
--	44% of BM	80%	--	--	--	$FE = 0.85\ W^{0.63}$
George et al. 2007	George et al. 2007	Mau 2004	Tarpley et al. 1987	Tarpley et al. 1987	Vikingsson 1997	Swaim et al. 2009

Food Passage Time	**Small Intestine : Body Length Ratio**	**Colon : Body Length Ratio**	**Small Intestine Inside Diameter [cm]**	**Colon Inside Diameter [cm]**	**Small Intestine Volume [L]**	**Colon Intestine Volume [L]**
15-18 hrs	4	0.4	3.5	15	35	59
--	36 m	3.6 m	--	--	$\Pi*1.75^2*3{,}600$	$\Pi*7.5^2*360$
Vikingsson 1997	Olsen et al. 1994	Olsen et al. 1994	Tarpley et al. 1987	This study	$\Pi*r^2*h$	$\Pi*r^2*h$

Total Lung Capacity (TLC) [L]	**Tidal Volume [L]**	**Residual Volume [L]**	**Respiratory Frequency – Migrating [blow/min]**	**Kleiber Basal Metabolic Rate [W/day]**	**Active Metabolic Rate [W/day]**
600 (336 lean)	540 (302 lean)	42 (24 lean)	0.4	3,887	14,102
5% of BM	90% of TLC	7% of TLC	--	$BMR=3.39*M^{0.75}$	$AMR=12.3*M^{0.75}$
Schmidt-Nielsen 1997	Olsen et al. 1969	Fahlman et al. 2011	Krutzikowsky and Mate 2000	Lavigne et al. 1990	Goldbogen et al. 2011

Results and Discussion

Proximate composition (%water, %lipid, %crude protein) and gross energy density of bowhead whale intestinal tract contents by season and location is provided in Table VC-3. Change in gross energy content in forestomach, duodenum, and colon by year is shown in Figure VC-2. The pattern of energy density in the digestive tract compartments stays similar among years (regardless of changes in prey composition, see Sheffield and George Section VB: this volume) with the majority of energy not taken up until the particles pass the duodenum. While assimilation efficiency is variable and ranges from 40-50% (Table VC- 3), it does not differ significantly among years ($p = 0.45$). Due to the high caloric density of lipids, this pattern is repeated for fat digestion with the majority of lipids taken up as they pass through the duodenum (Fig. VC-3). This is consistent with typical mammalian digestion under the action of pancreatic lipase in the duodenum (Carey et al. 1983). Lipid assimilation efficiency ranges from 48% in 2011 to 63% in 2012. This agrees with values reported by Nordøy (1995) for minke whales (*Balaenoptera acutorostrata*).

Table VC-3. *Proximate composition (mean ± standard deviation) of bowhead whale intestinal tract contents, 2009-2012.* H_0*: no difference in assimilation efficiency among years (Barrow only): p = 0.45*

Location	Season	Compartment	Sample size	%Water	%Lipid	%Nitrogen	%Ash	Crude Protein	Caloric Content [kJ/g]	Assimilation Efficiency
Barrow	Fall 2009	Forestomach	6	82.7±3.5	48.2±11.0	9.0±0.7	12.9±2.1	4.4±1.3	23.3±0.8	53.6±5.7
		Fundic Chamber	5	86.2±2.9	52.1±12.0	8.8±1.0	12.3±2.2	3.3±1.4	23.0±2.3	
		Pyloric Chamber	6	88.9±4.9	49.3±10.8	7.2±2.6	11.8±2.2	2.8±1.4	22.8±1.4	
		Duodenum	7	85.1±3.3	54.6±6.8	8.4±1.5	12.6±3.8	3.2±1.3	23.1±2.1	
		Colon	7	78.0±3.5	25.3±8.2	4.1±0.4	45.5±11.4	2.3±0.4	10.6±1.1	
Barrow	Spring 2010	Colon	14	86.1±4.4	44.4±15.1	6.5±2.7	20.1±17.7	2.6±1.4	19.4±5.3	-
St. Lawrence Island	Spring 2010	Duodenum	2	87.7±0.3	50.1±17.7	10.±2.8	6.7±0.6	3.9±2.4	23.3±3.0	-
		Colon	4	79.0±7.2	43.2±11.5	5.8±1.3	15.4±10.8	3.5±1.1	22.5±3.0	
Wainwright	Spring 2010	Forestomach	1	93.2	65.2	6.4	8.7	0.9	23.0	-
Barrow	Fall 2010	Forestomach	4	90.3±2.7	50.4±18.1	6.3±2.0	5.1±2.1	1.9±1.1	25.4±2.9	45.3±12.9
		Duodenum	4	88.3±6.1	56.5±10.8	7.6±1.9	6.7±1.5	2.6±2.2	21.7±3.1	
		Colon	5	81.0±4.1	27.0±8.1	5.8±0.8	29.2±10.4	3.5±0.7	15.7±4.4	
Kaktovik	Fall 2010	Colon	2	82.6±1.6	29.7±8.3	6.7±0.6	23.0±2.6	3.9±0.3	18.4±1.0	-
St. Lawrence Island	Spring 2011	Colon	2	73.0±0.8	10.6±6.1	4.5±0.5	39.9±2.7	4.0±0.3	11.9±0.3	-
Barrow	Fall 2011	Forestomach	6	81.2±4.9	46.0±21.3	7.0±3.0	5.1±2.6	5.0±4.2	27.8±3.9	43.4±12.2
		Fundic Chamber	1	89.0	66.3	5.7	5.2	1.3	26.3	
		Pyloric Chamber	2	85.8±9.2	66.3±25.1	5.5±3.5	5.1±4.1	1.2±0.9	20.9±2.5	
		Duodenum	6	87.6±1.9	43.8±16.6	6.7±0.9	6.3±0.8	2.8±1.0	22.7±5.2	
		Colon	10	85.3±2.3	27.8±9.0	6.2±1.6	23.0±10.3	3.2±0.9	19.3±4.3	
Kaktovik	Fall 2011	Forestomach	2	77.3±4.3	75.5±17.9	2.2±1.4	1.8±0.7	0.8±0.9	32.7	49.5
		Duodenum	1	89	33.4	8.8	8.3	3.7	18.9	
		Colon	2	84.2±3.0	41.7±23.5	5.1±2.9	24.0±1.6	2.7±2.7	22.8±8.9	
Barrow	Spring 2012	Colon	7	83.0±3.9	35.9±7.2	8.0±1.3	14.1±8.9	4.5±0.7	24.1±3.8	-
St. Lawrence Island	Spring 2012	Forestomach	2	92.8±7.5	7.7±10.9	8.1±8.2	44.8±44.7	4.7±6.6	22.1	-
		Duodenum	4	88.2±1.7	42.5±15.5	7.9±0.8	18.8±9.6	2.7±0.7	20.2±2.9	
		Colon	2	80.8±8.1	30.8±10.6	6.5±0.1	28.4±8.3	3.8±1.3	18.4±4	

Location	Season	Compartment	Sample size	%Water	%Lipid	%Nitrogen	%Ash	Crude Protein	Caloric Content [kJ/g]	Assimilation Efficiency
Barrow	Fall 2012	Forestomach	8	84.7±9.2	33.1±22.0	10.4±2.6	14.3±9.8	6.7±6.3	24.0±6.5	41.5±18.8
		Fundic Chamber	2	88.5±5.1	22.1±31.3	11.1±1.0	11.3±3.5	6.3±5.4	23.4±0.8	
		Pyloric Chamber	3	91.7±1.7	20.5±22.2	10.4±0.3	13.7±6.4	2.6±2.6	23.0±0.6	
		Duodenum	6	89.0±3.4	40.8±26.8	9.5±2.7	9.3±2.8	4.4±3.7	25.7±2.8	
		Colon	10	82.5±6.1	13.2±10.3	6.5±2.4	35.4±13.4	3.8±2.1	16.0±4.4	
Kaktovik	Fall 2012	Colon	1	85.1	30.9	6.2	29.1	3.0	15.8	-

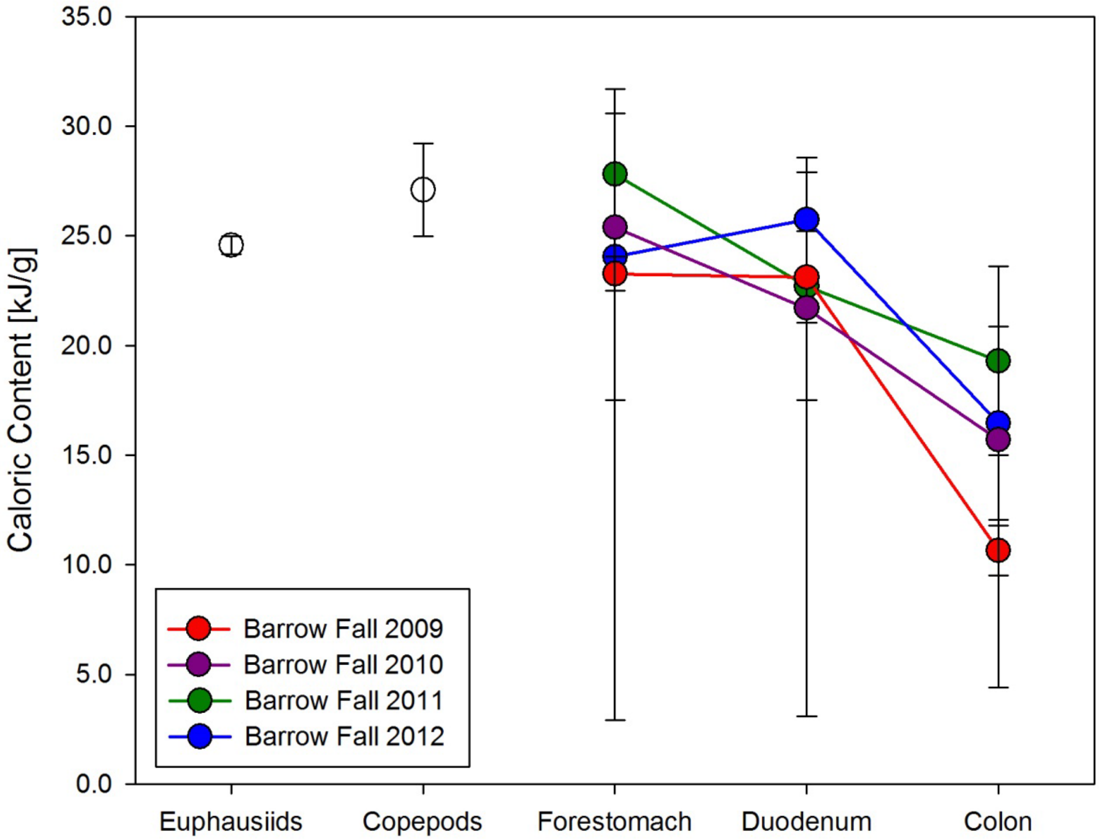

Figure VC-2. *Energy density of prey (mean ± SD in kJ/g dry wt) and intestinal tract contents of bowhead whales subsistence-harvested during the fall migration in Barrow 2009-2012. Caloric content and digestive efficiency did not differ among sampling years.*

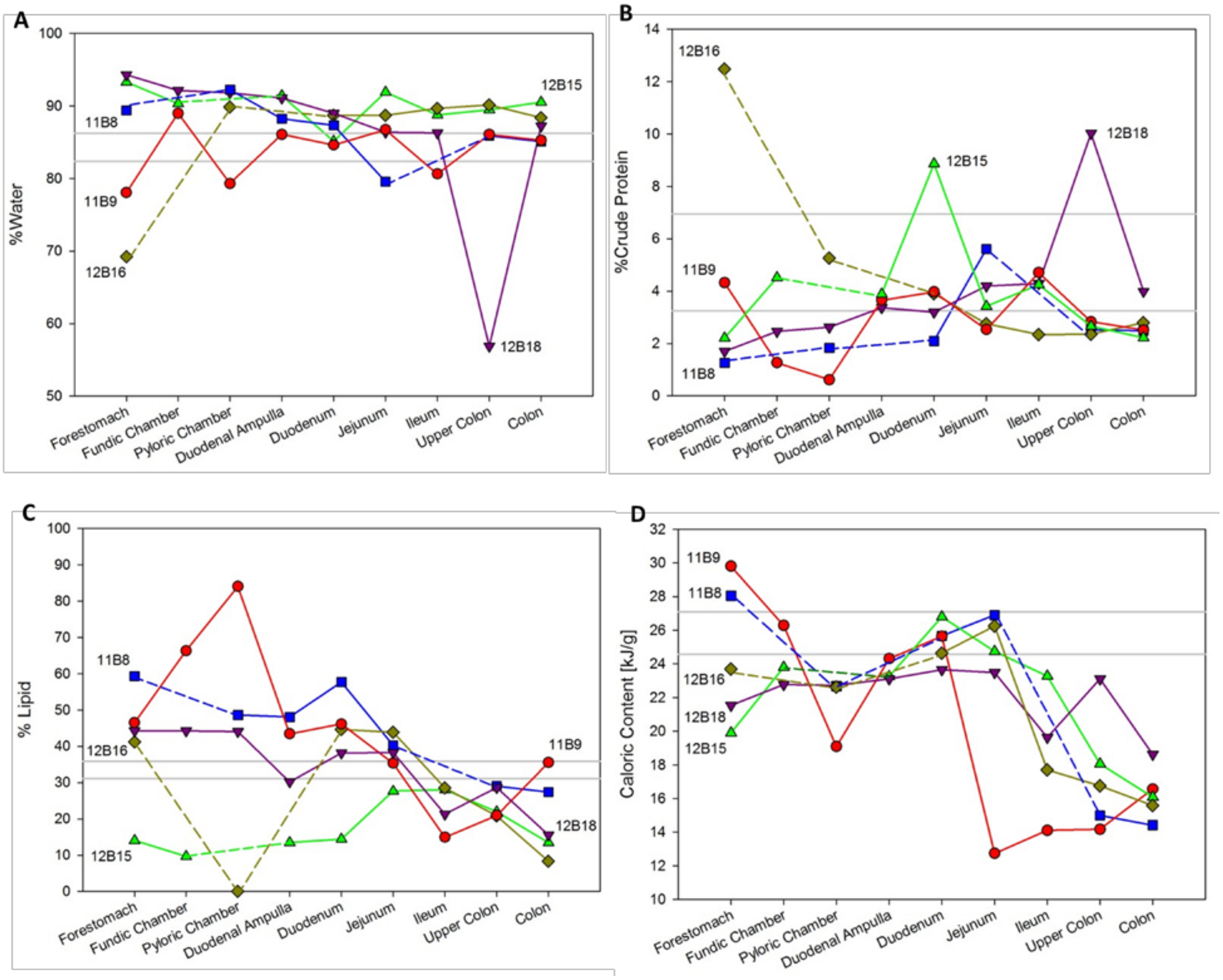

Figure VC-3. *Changes in (A) water, (B) protein (dry wt), (C) lipid (dry wt), and (D) caloric content (dry wt) along the digestive tract for five bowhead whales sampled in fall 2011 and 2012. Gray lines reference proximate composition range of euphausiids and copepods. Broken lines are extrapolated and no sample exists for this gastric compartment.*

Crude protein is highly variable in digesta of different compartments. Generally, there was a drop in crude protein from the forestomach to the pyloric chamber (Fig. VC-3), but not consistently so, and in some years (e.g., 2010) protein contents were higher in the large intestine compared with stomach contents. Measurement of protein contents in the gut could be biased by sloughing of the digestive tract lining which consequently influences analyses of modified gut contents and not prey. Thus, protein assimilation efficiency was not calculated. Herwig et al. (1984) described volatile fatty acid release in bowhead whale forestomachs and Olsen et al. (2000) identified chitinolytic bacteria in the forestomach of minke whales to help with the breakdown of the chitin exoskeleton of their zooplankton prey. Bacterial fermentation of cellulose (structurally very similar to chitin) in the rumen and production of short chain fatty acids is well described for artiodactyls, close relatives of cetaceans (Lin et al. 1985, Thewissen et al. 2001). It is therefore likely that volatile fatty acids are the byproduct of chitin fermentation by forestomach fauna of whales to release lipids and wax esters from crustacean prey. Chitinolytic bacteria resemble therefore a form of 'can-opener' for bowheads to prepare lipids for uptake by the duodenum. Fermentation by chitinolytic bacteria also explains the drop in crude protein observed from the forestomach to the pyloric chamber as chitin, compared with cellulose, contains nitrogen that might be used by the stomach fauna.

Assessment of the digestive efficiency of bowhead whales required a variety of additional variables to ultimately calculate net energy gain from ingested prey. To estimate forestomach evacuation rates and thus calculate daily energy input, we applied stable carbon and nitrogen isotope ratios to the digestive content of different alimentary tract compartments. Generally, stable isotopes are commonly used in ecological research to investigate trophic position, habitat use, and migratory patterns (e.g., Hobson and Schell 1998, Hoekstra et al. 2002, Horstmann-Dehn et al. 2012). Stable nitrogen isotopes are integrated into consumer tissues with enrichment occurring at each trophic step due to the preferential incorporation of the heavier isotope (^{15}N) into tissues (Newsome et al. 2010). Changes in δ^{15}N in a predator can therefore point to changes in prey composition (Carroll et al. 2013). Stable carbon isotope ratios, on the other hand, have been used to determine carbon source and illustrate habitat use (Hobson and Schell 1998, Horstmann-Dehn et al. 2012). Benthic organisms are typically enriched in ^{13}C compared with the pelagic food chain and predators relying on either ecosystem can be readily distinguished (e.g., Dehn et al. 2007, Horstmann-Dehn et al. 2012). As mentioned, changes in prey composition can alter stable isotope ratios. In this study, stable isotope ratios varied along the digestive tract within individual whales (Figs. VC-4 and VC-5). Stable carbon and nitrogen isotope ratios of fresh euphausiids and copepod prey were relatively similar (-22.8 ± 0.1‰, 11.1 ± 0.1‰ for euphausiid δ^{13}C and δ^{15}N, respectively, and -24.0 ± 1.0‰, 11.6 ± 0.4‰ for copepod δ^{13}C and δ^{15}N, respectively). Figure VC-4 illustrates stable isotope ranges in a whale with isopods in the stomach (A) and a whale with mixed copepod/amphipod diet (B), while Figure VC-5 shows a whale feeding on euphausiids (A), and copepods (B). In all these examples, stable nitrogen isotope ratios span the range of one trophic level (10.2 to 13.5‰ (Fig.VC-4A), 11.1 to 13.8‰ (Fig. VC-4B), 13.6 to 15.9‰ (Fig. VC-5A), and 13.4 to 16.3 (Fig. VC-5B), illustrating daily variability in prey composition. Stable carbon isotope ranges are also variable, and trophic shifts are typically accompanied by changes in δ^{13}C. However, δ^{13}C is also associated with changes in lipid content (DeNiro and Epstein 1977), i.e., increase in lipid and a decrease in δ^{13}C and vice versa (Figs. VC-4 and VC-5). Within individual whales, we identified typically four distinct stable isotope signature spikes that occur in the forestomach, pyloric chamber/duodenal ampulla, along the small intestine, and along the large intestine (Figs. VC-4 and VC-5). Volume estimates from TableVC-2 for forestomach (57L), combined fundic, pyloric chambers, and duodenal ampulla (59.4L), small intestine (35L), and colon (59L) also suggests that evacuation of the forestomach would fill the remaining chambers, then the small intestine, and then the colon. This agrees with the stable isotope spikes identified in these alimentary tract compartments. Taken together with forestomach evacuation rates every 3-6hrs reported in fin whales (Vikingsson 1997), it is reasonable to conclude that bowheads empty their forestomachs every 6 hrs or have 4 daily feeding events. Daily gross energy intake for an average 9m bowhead whale feeding near Barrow is thus roughly 900 MJ (wet weight average from 2009-2012) or 5.7 GJ dry. This is almost 20 times lower than energy deposition estimates of minke whales on their feeding grounds (Christiansen et al. 2013) not even taking digestibility and fecal energy losses into account. Considering the massive blubber layer of bowheads during their fall migration, it stands to argue that they ‘snack’ while traveling, but that this feeding pattern does not necessarily represent their effort or quality of bowhead whale prey on the feeding grounds.

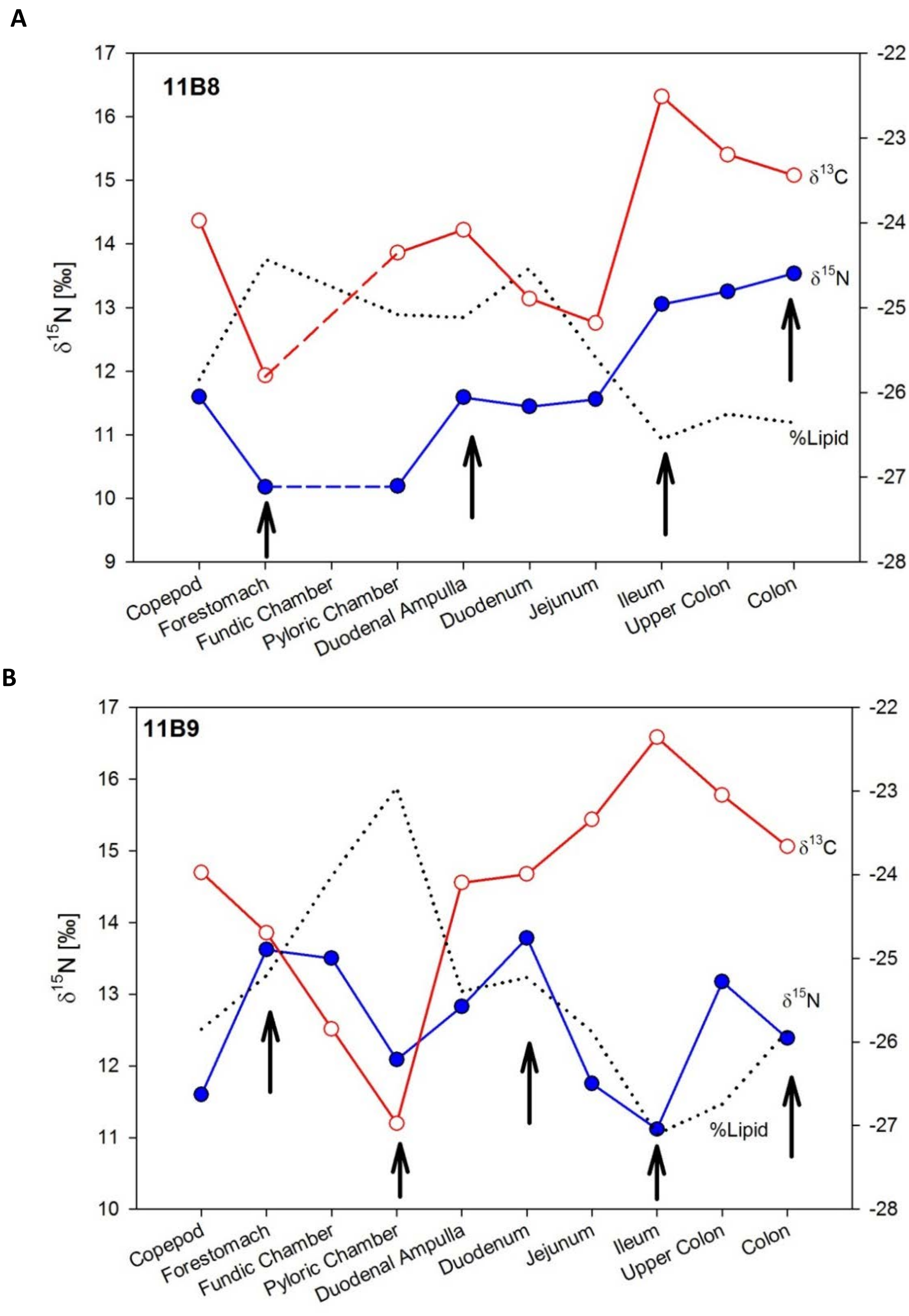

Figure VC-4. *Stable carbon (red open symbols) and nitrogen (blue solid symbols) isotopes in the intestinal tract contents (sequentially from forestomach to colon) of two female bowhead whales (11B8 and 11B9) harvested in fall 2011 in Barrow (8.4m and 12.6m standard length, respectively). The dotted black line indicates relative changes in %lipid in the intestinal tract to provide context for $\delta^{13}C$ values. Broken blue and red lines are extrapolated and no sample exists for this gastric compartment. The stomach of 11B8 contained isopods (86% by volume) and 11B9 contained copepods and amphipods (no volume data available). Stable isotope data are also given for fresh copepods (Calanus glacialis). Arrows indicate changes in stable isotope signatures that could be indicative of feeding events.*

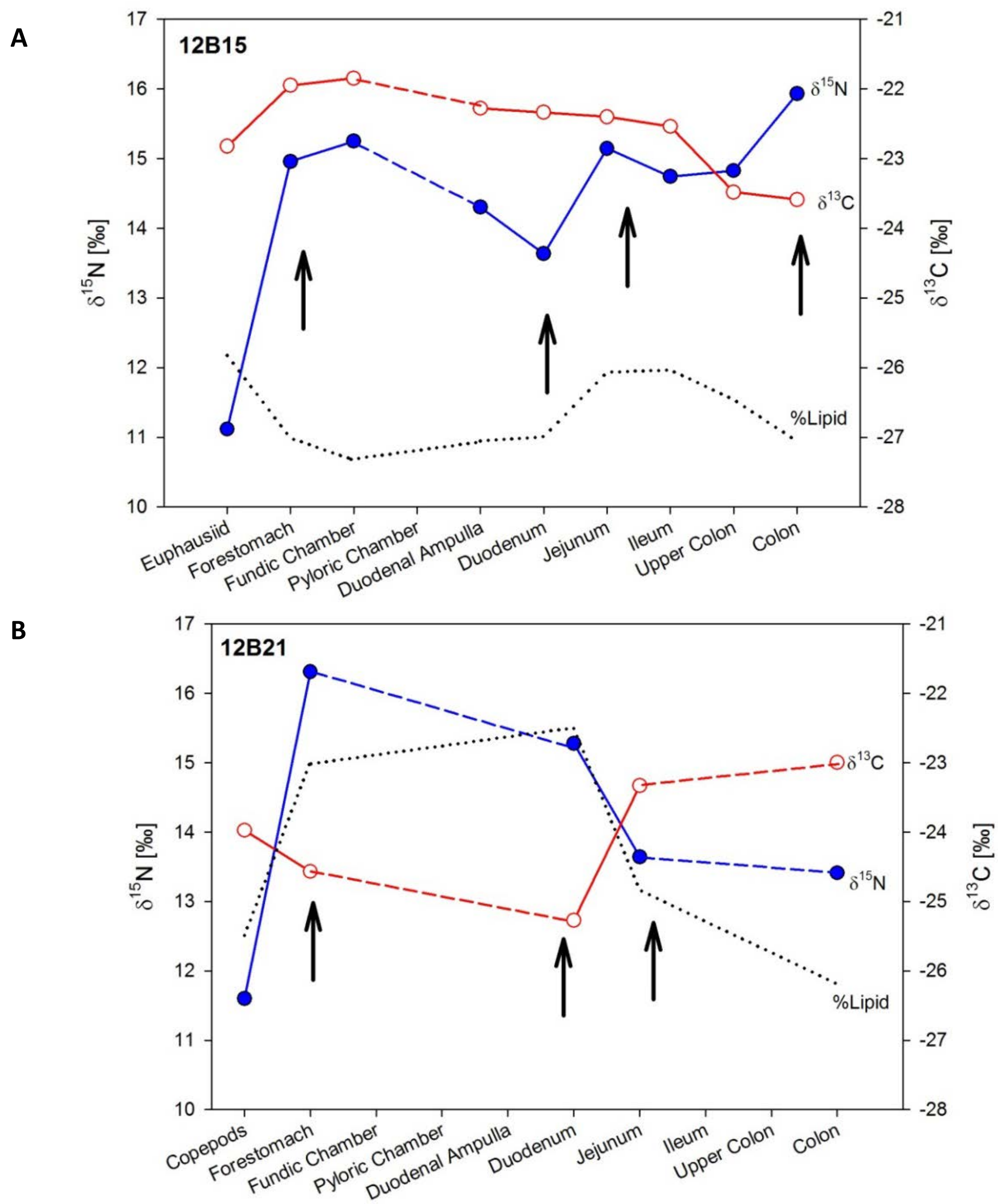

Figure VC-5. *Stable carbon (red open symbols) and nitrogen (blue solid symbols) isotopes in the intestinal tract contents (sequentially from forestomach to colon) of a male and female bowhead whale (12B15 and 12B21, respectively) harvested in fall 2012 in Barrow (8.4m and 13.3m standard length, respectively). The dotted black line indicates relative changes in %lipid in the intestinal tract to provide context for $\delta^{13}C$ values. Broken blue and red lines are extrapolated and no sample exists for this gastric compartment. The stomach of 12B15 contained euphausiids (100% by volume) and 12B21 contained copepods (76% by volume). Stable isotope data are also given for (A) euphausiids (Thysanoessa spp.) and (B) fresh copepods (Calanus glacialis). Arrows indicate changes in stable isotope signatures that could be indicative of feeding events.*

Digestive efficiency of bowhead whales was assessed by estimating total energy input based on forestomach caloric values (Table VC-3) and forestomach volumes (57.2L) reported by Tarpley et al. (1987) for an average 9m bowhead whale. Energy loss was determined using allometric relationships of body mass to daily fecal volumes. The thick blubber layer of bowhead whales (44% of body mass, George et al. 2007) can skew allometric relationships based on total body mass and for example, lung volume estimates of bowhead whales only scale with body mass if the blubber mass is subtracted (total lung capacity of 280L for a 9m whale, George personal communication, vs. 336L using 5% of lean body mass, Table VC-2). As described above, 4 daily feeding events were assumed. Bowhead whale digestive efficiency was on average 77% when using wet mass and 82% on a dry mass basis. Digestive efficiency (wet mass basis) was lowest in 2010 (64%) and highest in 2011 (84%). This is on the lower end for digestive efficiencies reported for North Atlantic right whales (*Eubalaena glacialis*; 94%) and minke whales (93% when consuming euphausiids (*Thysanoessa* spp.) (Martensson et al. 1994); 95% when consuming capelin (*Mallotus villosus*) (Mathiesen et al. 1995)). Digestive efficiencies are generally higher when fish prey is consumed, e.g., 85% for killer whales (*Orcinus orca*) (Williams et al. 2004), 88% for ringed seals (*Pusa hispida*) consuming Arctic cod (*Boreogadus saida*) (Lawson et al. 1997), and 92-95% for harp seals (*Pagophilus groenlandicus*) eating herring (*Clupea harengus*) (Keiver et al. 1984). For phocid seals, digestive efficiency dropped when consuming krill (e.g., 84% in crabeater seals (*Lobodon carcinophaga*, Martensson et al. 1994) and 72% for harp seals feeding on shrimp (Keiver et al. 1984), presumably due to the overall difficulty in digesting wax esters that occur in large proportions in zooplankton and other crustaceans (Nordøy 1995). Using in vitro digestibility experiments, Nordøy et al. (1993) confirmed digestive efficiency estimates of approximately 90% in minke whales, eating either krill or fish.

Bowhead metabolic demands were estimated using available lung volume and O_2 extraction efficiencies for an average 9m whale. Bowhead whale blow frequency during migration is reported as 0.4 blow/min (Krutzikowsky and Mate 2000) and 0.7 blow/min when feeding (Carroll et al. 1987). Our estimated power output for migrating and feeding whales (based on an average 9m whale) is 4.3kW and 7.9kW, respectively. This range agrees well with metabolic rates estimates for minke whales of 80kJ/kg*day (Blix and Folkow 1995) or 6.5kW when applied to an average 9m bowhead whale (Table VC-2), but is much higher than resting metabolic rate estimates based on a heat-loss model by George (2009) of ~1.8kW. Active metabolic rate, when calculated using equations by Goldbogen et al. (2011) for blue whales (*Balaenoptera musculus*), yield 14.1kW and appear much too high for bowheads. This likely points to differences in energy expenditure between lunge-feeding rorquals and balaenids. Energy gained from prey using 77% digestive efficiency (see above) is on average (2009-2012) 7.9kW for a 9m bowhead whale, and is similar to the estimated expenditure during feeding. This illustrates the need for high prey densities as described for other mysticete species (e.g., Baumgartner and Mate 2003, Goldbogen et al. 2011) to balance energy gain and expenditure. However, on the feeding grounds (or whales harvested during their fall migration when returning from their feeding grounds) bowhead whales gain blubber lipid as well as girth (Mau 2004, George 2009) suggesting substantial energy gain. Christiansen et al. (2013) reported that minke whales deposit as much as 15.5GJ, and this is likely much more for bowhead whales given their larger size and thicker blubber. It follows that bowheads on the feeding grounds feed either more energy efficiently, digest with higher efficiency, or forage on more energy rich prey. It is, however, also interesting that bowheads feeding near Barrow appear to gain energy that could then be used during migration without 'breaking in' to stores gained on the feeding grounds as described above. Fat reserves stored in bowhead blubber far exceed thermoregulatory requirements or likely energy needs on the winter breeding grounds while fasting. We estimate that a 9m bowhead, relying solely on its lipid blubber stores (Table VC-2), could fast over 1 year (447 days) at migratory metabolic rate. As described above, this assumes no metabolic rate adjustments during fasting (e.g., Rea and Costa 1992). Adults could likely endure much longer periods (George, 2009), but some bowheads that are near the end of their growth hiatus ~ age 4 (Lubetkin et al. 2008, George 2009) may not be able to endure a season with poor prey. Zooplankton abundance and biomass in the Arctic is highly variable and is dependent on meteorological, oceanographic, and sea ice patterns (Ashjian et al. 2010, Okkonen et al. 2011, Questel et al. 2012). Sufficient prey density is of vital importance to filter-feeding whales, thus an over-accumulation of lipid stores may serve as built-in fail-safe for unfavorable prey years.

Reference ranges for serum chemistry parameters can provide important insights into seasonal and physiological variability of marine mammals. Serum chemistry means and ranges for free-ranging bowheads by year and feeding status are given in Table VC-4. These values are well within the range reported by Heidel et al. (1996) for bowheads harvested during fall season 1992 near Barrow as well as minke whales (Tryland and Brun 2001). However, total body length (and therefore age) of the whales that are part of the study by Heidel et al. (1996) was higher. Variables, such as ALP, have been associated with age and other physiological parameters including pregnancy (Cornell et al. 1988, Schweigert 1993, Heidel et al. 1996). In this study, serum chemistry can differentiate between feeding and non-feeding whales in a principal components analysis and was co-correlated with harvest season (i.e., non-feeding during spring and feeding in the fall, Fig. VC-6). Length/age was similar between the feeding and non-feeding whales (Table VC-4). Variables driving the separation between the two groups are ALP, AMY, CRE, and GLU that are higher in fasting whales, while ALB, ALT, AST, GGT, Mg, and BUN are higher in feeding whales (Fig. VC-6). Although somewhat counter-intuitive, this indicates that fasting bowhead whales tend to have higher levels of glucose and enzymes associated with production of bile and bone reconstruction (ALP) and pancreatic juices (AMY). Fasting hyperglycemia was also observed in Northern elephant seals (*Mirounga angustirostris*) and glucose recycling via the Cori cycle has been suggested (Champagne et al. 2005). Gluconeogenesis using lactate produced by glucose-consuming tissues, such as red blood cells and the brain, is fueled by ATP generated during fat oxidation in the liver. Glucose is then cycled back through the blood stream to tissues that need it (Champagne et al. 2005). This scenario is reasonable in fasting whales relying on fat oxidation of their blubber stores. Creatinine is a waste product of muscle breakdown and higher levels could be indicative of muscle catabolism. However, fasting adapted marine mammals, such as bowhead whales, will avoid muscle catabolism (Castellini and Rea 1992) and other associated indicators of muscle breakdown (e.g., BUN, CK, and AST) do not support extensive muscle wasting in fasting whales. Dehydration could increase CRE levels (reviewed in Trumble et al. 2006), but this was not assessed in this study. Trumble et al. (2006) also note that a proportional increase in muscle mass will yield elevated CRE, thus a loss of blubber mass and a relative increase in muscle mass on the wintering grounds could account for increases in CRE. For feeding whales, ALB, ALT, AST, GGT might be higher due to overall longer haul times in the fall (meaning that season is the influencing variable, not feeding) and leakage of enzymes from damaged tissues (Heidel et al. 1996, Tryland and Brun 2001), but these variables were also elevated in captive harbor seals (*Phoca vitullina*) in an experimental feeding trial when fed a pollock (*Theragra chalcogramma*) compared to a herring or mixed fish diet (Trumble et al. 2006). Similarly, Tryland and Brun (2001) found elevated values of AST and ALT in lipemic (i.e., recent meal) minke whale serum. These variables may therefore be associated with digestion, but specifically a high protein diet (Trumble et al. 2006). Similarly, blood (or serum) urea nitrogen has been associated with both an increased intake of dietary nitrogen/protein, but also with stage III fasting (Castellini and Rea 1992). As BUN in bowhead whales in this study has a stronger weight in feeding whales, it is likely that this variable also is an indicator of food intake, specifically high protein food. Euphausiids have overall higher crude protein content than copepods (6.9 ± 0.6% and 3.3 ± 0.3% dry weight, respectively), thus, these variables might indicate prey source to some degree.

Table VC-4. *Serum chemistry of bowhead whales harvested in Barrow, Alaska, during spring and fall migration, 2009-2012 (SD = standard deviation, n = sample size, * = 1 unknown).*

Season	No. feeding	Stats	Length [cm]	ALB [g/dL]	ALP [U/L]	ALT [U/L]	AMY [U/L]	AST [U/L]	BUN [mg/dL]	Ca^{2+} [mg/dL]	CK [U/L]	CRE [mg/dL]	GGT [U/L]	GLOB [g/dL]	GLU [mg/dL]	K^{+} [mmol/L]	PHOS [mg/dL]	Mg [mg/dL]	Na^{+} [mmol/L]	TBIL [mg/dL]	TP [g/dL]
Fall 2009	7 of 8	Mean	945	5.1	211	346	31	254	75	12.1	2,922	1.8	12	2.2	94	7.6	10.9	4.9	161	0.3	7.3
		±SD	±107	±0.5	±48	±543	±5	±235	±13	±1.2	±3,228	±0.4	±5.7	±1.0	±35	±1.2	±1.7	±1.0	±5	±0.1	±1.0
		Range	800-1,130	4.1-6.0	146-289	7.0-1,517	25-39	0-652	59-94	10.8-14.7	0-7,461	1.1-2.4	2.5-18	1.3-4.4	49-161	5.3-8.9	7.6-12.7	3.2-6.6	153-166	0.3-0.4	6.2-8.9
		n	8	8	8	7	8	8	8	8	8	8	8	8	8	7	8	8	7	8	8
Spring 2010	0 of 10	Mean	898	4.5	266	20	36	87	58	10.3	1,063	5.6	4.1	1.3	160	7.5	9.1	3.0	145	0.2	6.5
		±SD	±112	±1.7	±90	±38	±12	±131	±12	±2.8	±1,373	±2.0	±3.1	±0.8	±91	±1.7	±2.3	±0.8	±18	±0.1	±1.5
		Range	750-1,090	0.0-5.9	136-376	2.5-124	12-53	21-452	34-71	5.9-15.6	0-3,961	2.5-9.4	0.0-11.0	0.0-2.4	77-397	6.0-10.6	5.4-13.3	1.8-4.1	128-163	0.0-0.4	4.3-8.1
		n	10	10	10	10	10	10	10	10	10	10	10	10	10	7	10	9	4	10	10
Fall 2010	7 of 7	Mean	914	4.5	172	18	23	169	50	10.4	2,659	3.2	4.6	1.0	118	6.4	9.2	4.3	143	0.3	5.5
		±SD	±205	±1.1	±42	±30	±20	±155	±13	±2.3	±3,280	±1.5	±3.1	±0.3	±46	±1.6	±2.5	±1.7	±24	±0.1	±1.1
		Range	730-1,250	2.8-5.4	118-241	2.5-84	9-64	38-418	34-70	6.7-13.2	0-9,204	1.9-6.0	2.5-10.0	0.6-1.4	72-180	4.3-8.4	6.0-13.0	2.5-7.2	110-164	0.2-0.4	3.9-6.5
		n	7	7	7	7	7	7	7	7	7	7	7	7	7	5	7	6	4	7	7
Fall 2011	9 of 10*	Mean	1,067	4.7	262	50	28	223	66	12.2	1,892	3.9	8.3	2.1	114	7.1	10.7	4.5	146	0.3	7.4
		±SD	±238	±0.5	±107	±50	±8	±188	±11	±2.0	±2,486	±1.4	±7.6	±0.6	±30	±1.1	±2.2	±1.4	±9	±0.1	±0.7
		Range	820-1,450	4.0-5.5	82-495	11-155	22-47	40-664	51-83	9.3-15.6	143-8,353	1.4-6.3	2.0-28.0	1.4-2.8	71-167	5.2-8.3	7.6-14.9	2.7-7.4	134-153	0.2-0.4	6.3-8.6
		n	10	10	10	10	10	10	10	10	10	10	10	10	10	6	10	9	4	10	10
Spring 2012	2 of 8	Mean	898	5.0	399	35	31	151	64	11.8	2,817	5.1	3.6	4.0	126	7.3	11.0	3.9	150	0.4	7.8
		±SD	±96	±0.6	±145	±54	±12	±177	±10	±0.7	±2,226	±1.0	±2.6	±0.9	±32	±1.8	±2.9	±1.0	±6	±0.1	±0.5
		Range	775-1,011	4.1-6.2	196-575	2.5-156	16-51	30-532	53-77	11.0-13.4	0-5,058	3.5-6.1	2.0-10.0	2.4-5.3	85-183	5.2-10.2	8.6-17.5	2.8-5.8	139-156	0.3-0.4	7.0-8.5
		n	8	8	8	8	8	8	8	8	8	7	8	8	8	5	8	8	6	5	8
Fall 2012	9 of 10	Mean	984	5.2	300	318	30	490	71	12.1	1,509	3.4	6.6	3.7	147	6.7	10.9	4.7	149	0.4	7.5
		±SD	±146	±0.6	±90	±458	±8	±653	±9	±1.3	±1,724	±1.6	±2.9	±0.7	±48	±1.7	±2.1	±0.8	±2	±0.1	±1.1
		Range	838-1,334	4.5-6.1	163-450	2.5-1,337	17-40	38-1,842	56-84	10.9-14.2	0-5,761	1.6-7.4	2.5-13.0	2.9-4.7	86-233	3.1-8.2	8.8-15.3	3.7-6.0	146-150	0.3-0.4	6.0-9.7
		n	10	10	10	10	10	10	10	10	10	10	10	10	10	7	10	10	5	10	10

Season	No. feeding	Stats	Length [cm]	ALB [g/dL]	ALP [U/L]	ALT [U/L]	AMY [U/L]	AST [U/L]	BUN [mg/dL]	Ca^{2+} [mg/dL]	CK [U/L]	CRE [mg/dL]	GGT [U/L]	GLOB [g/dL]	GLU [mg/dL]	K^{+} [mmol/L]	PHOS [mg/dL]	Mg [mg/dL]	Na^{+} [mmol/L]	TBIL [mg/dL]	TP [g/dL]
All Feeding		Mean	974	4.9	257	134	29	297	66	11.8	2,243	3.2	7.9±	2.5	122	7.0	10.7	4.6	152	0.3	7.1
		±SD	±170	±0.7	±96	±302	±11	±394	±14	±1.8	±2,694	±1.6	5.9	±1.3	±44	±1.5	±2.5	±1.1	±13	±0.1	±1.3
		Range	730-1,450	2.8-6.1	118-515	2.5-1,517	9-64	0-1,842	34-94	6.7-15.6	0-9,204	1.1-7.4	2.0-28.0	0.6-4.7	49-233	3.1-8.9	6.0-17.5	2.5 -7.4	110-166	0.2-0.4	3.9-9.7
		n	34	34	34	33	34	34	34	34	34	34	34	34	34	23	34	32	19	33	34
All Non-Feeding		Mean	895	4.7	309	125	34	118	62	11.0	1,708	5.1	4.3	2.3	143	7.4	9.6	3.6	148	0.3	6.9
		±SD	±107	±1.4	±130	±327	±11.8	±174	±11	±2.2	±1,798	±1.9	±2.8	±1.5	±72	±1.6	±2.0	±1.2	±12	±0.1	±1.3
		Range	750-1,090	0.0-6.2	136-575	2.5-1,337	12-53	21-652	34-77	5.9-15.6	0-5,058	2.4-9.4	0.0-11.0	0.0-5.3	77-397	5.2-10.6	5.4-13.3	1.8-6.6	128-163	0.0-0.4	4.3-8.5
		n	18	18	18	18	18	18	18	18	18	17	18	18	18	13	18	17	10	15	18

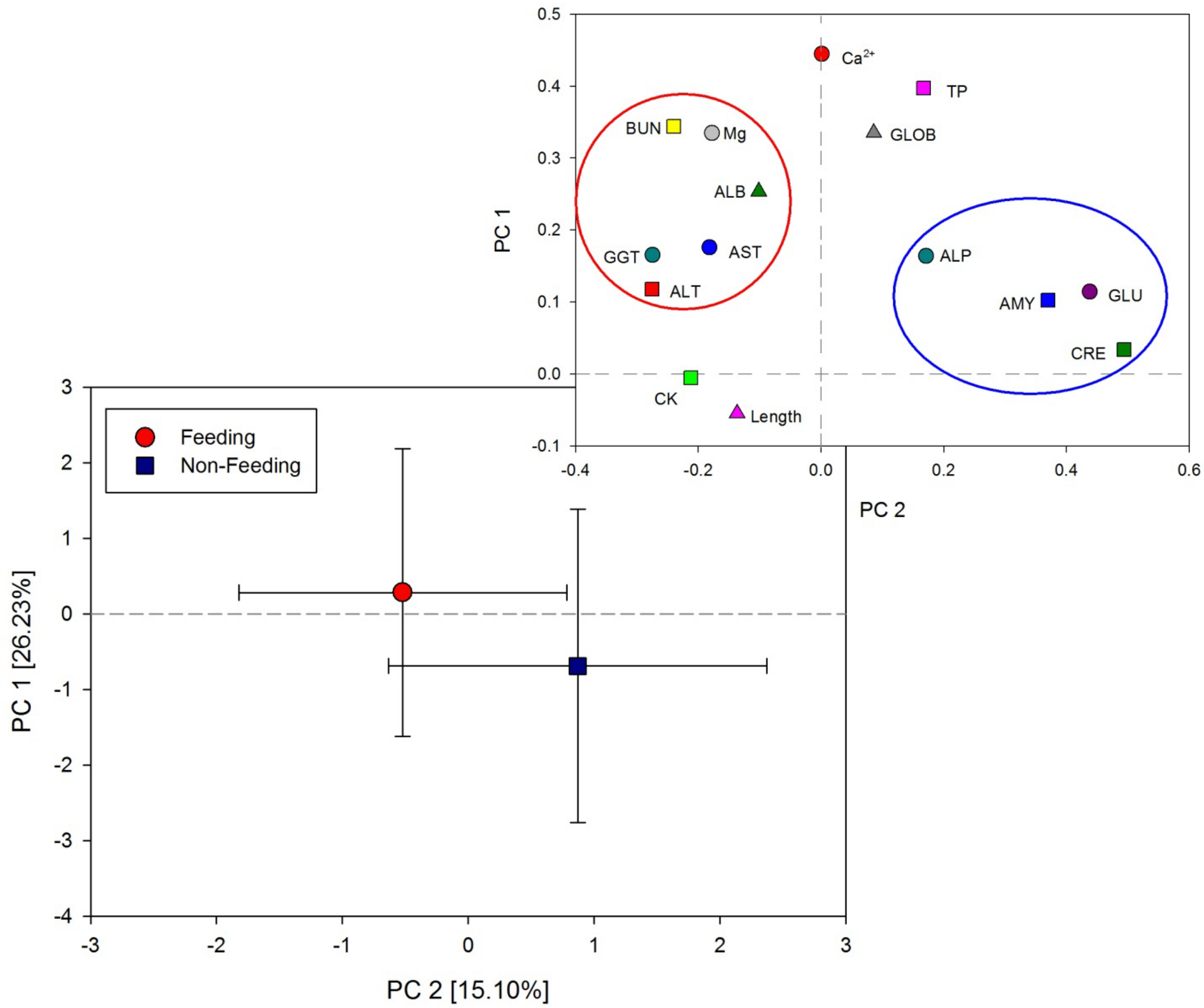

Figure VC-6. *Principle component analysis for blood chemistry parameters measured in bowhead whale serum. Bowheads were separated by feeding status (i.e., feeding vs. non-feeding). The first two principal components (PC1 and PC2) explained 41.33% of the variability between feeding and fasting bowhead whales. A loading plot of the variables is shown in the upper right. Variables driving the separation by a positive loading in PC2 (blue circle) are alkaline phosphatase (ALP), amylase (AMY), creatinine (CRE), and glucose (GLU), while albumin (ALB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyl transpeptidase (GGT), magnesium (Mg), and blood urea nitrogen (BUN) are driving the separation by a negative loading of PC2 (red circle).*

Diet determination and direct observation of marine mammal feeding can be challenging, particularly in the Arctic, due to their remote distribution and seasonally restricted access to their habitat. Many studies have, therefore, utilized indirect methods to describe cetacean diets, including quantification of fatty acids (Budge et al. 2008, Petursdottir et al. 2013). Fatty acid signature analysis is a powerful tool for diet assessments (although not without its own set of limitations), because certain prey FAs are passed from prey to predator and are deposited predictably in the predators' adipose tissue (Iverson et al. 2004). While this method has been used in a variety of pinnipeds (e.g., Cooper et al. 2005, Thiemann et al. 2007, Tucker et al. 2009), only relatively few studies have described FA signature profiles in cetaceans (e.g., Herman et al. 2005, Budge et al. 2008, Waugh et al. 2012, Petursdottir et al. 2013). Considering a lipid assimilation efficiency of ~60% in bowhead whales, as determined herein, it begs the question if all prey FAs are assimilated with equal efficiency or if there is preference for certain FAs or FA classes. We therefore determined the proportional contribution of FAs to forestomach, small, and large intestinal contents of three bowheads as well as fresh euphausiid and copepod prey. Fatty acid proportions of prey generally agreed with those found in the forestomach containing large quantities of that prey (Tables VC-5 and VC-7) with the exception of 11B8 whose stomach contained isopods (Table VC-6), a prey not analyzed here for its FA signature. During the digestive process, relative proportions of FAs changed significantly along the alimentary tract with FAs generally becoming more saturated (repeated measures ANOVA, $p < 0.05$) and elongated, and polyunsaturated FAs (PUFA) contributing less (Tables VC-5-7 and Fig. VC-6). Essential PUFAs, such as 20:4ω6, 20:4 ω3, and 22:6 ω3 appear to be completely taken up by the time the colon is reached compared with forestomach content, however, large variability among whales confounded this result in a repeated measures ANOVA, ($p > 0.05$). Statistical differences between FA composition of North Atlantic right whale feces compared with fresh prey were also reported by Swaim et al. (2009), and these authors argued that the FAs in feces are not of dietary origin, but reflect a bacterial source. However, lengthening and hydrolyzation of FAs is already evident in relative proportions of FAs in the small intestine (Tables VC-5-7 and Fig. VC-6) suggesting a source in the stomach. As described above, chitinolytic bacteria have been described in mysticete forestomachs (Olsen et al. 2000), and this rumen fauna (or other not yet described bacteria) are likely involved in FA alterations. Hydrogenation and isomerization of monounsaturated FAs (MUFA) and PUFAs are well known to occur in the rumen of farm animals (Doreau and Ferlay 1994, Doreau and Chilliard 1997) leading to higher proportions of SAFAs. Prey fatty acids are therefore likely transformed before their uptake in the small intestine, thus the amount and composition of FAs leaving the stomach of mysticete whales differs from absorbed FAs. This makes the use of fatty acid signature analysis and description of fatty acids in the blubber useless for these whales. A discrepancy between FA proportions in blubber and diet of minke whales was described by Petursdottir et al. (2013), but was attributed to variability in the whale diet. Future studies should include blood and blubber fatty acid analysis in addition to digestive content to better understand preferential uptake, FA transformations, and inconsistencies to ingested prey. Fatty acid preferences may also change with sex, age, and physiological status (e.g., pregnancy) and these factors should be determined in subsequent research.

Table VC-5. *Relative proportions of selected fatty acids in the intestinal tract contents of a female bowhead whale (12B21) harvested in fall 2012 in Barrow (13.3 m standard length). The stomach contained copepods (76% by volume). Relative proportions of fatty acids are also given for fresh copepods (Calanus glacialis) and euphausiids (Thysanoessa spp.).*

	Fatty acids	**Euphausiids**	**Copepods**	**Forestomach**	**Jejunum**	**Colon**
Saturates	12:0	0.20	0.24	0.30	0.11	0.94
	i 13:0	0.26	0.64	0.45	0.87	2.33
	13:0	0.01	0.11	0.12	0.06	0.09
	i 14:0	0.16	0.07	0.07	0.05	0.23
	14:0	6.29	5.83	6.68	4.95	5.27
	i 15:0	0.10	0.41	0.37	0.04	0.56
	ai 15:0	0.03	0.13	0.12	0.09	0.84
	15:0	1.15	0.53	0.45	0.78	1.54
	i 16:0	0.07	0.10	0.06	0.19	0.39
	ai 16:0	0.00	0.11	0.10	0.00	0.00
	16:0	22.26	5.34	4.85	10.24	23.93
	i 17:0	0.05	0.10	0.06	0.21	0.79
	ai 17:0	0.10	0.12	0.11	0.12	0.25
	17:0	0.11	0.13	0.07	0.29	1.31
	i 18:0	0.27	0.43	0.71	0.42	0.25
	18:0	1.69	0.18	0.18	2.90	9.77
	20:0	0.00	0.00	0.00	0.19	8.37
	22:0	0.00	0.00	0.00	0.00	3.98
	Subtotal	**32.76**	**14.45**	**14.70**	**21.51**	**60.81**
Monounsaturates	14:1w9	0.00	0.37	0.43	0.76	0.00
	14:1w5	0.09	0.22	0.27	0.11	0.00
	16:1w11	2.07	0.31	0.36	0.46	0.24
	16:1w9	0.09	0.14	0.16	0.16	0.23
	16:1w7	16.42	10.40	9.53	6.83	1.98
	16:1w5	0.27	1.55	1.10	0.93	0.41
	17:1w9	0.02	0.06	0.18	0.00	0.00
	18:1w9 trans	0.00	0.00	0.00	0.20	0.00
	18:1w9 cis	9.08	3.31	3.26	4.42	1.05
	18:1w7	7.09	0.65	0.69	2.13	0.17
	18:1w5	0.15	0.80	0.44	1.02	0.54
	20:1w13	0.00	0.00	0.00	0.00	0.40
	20:1w11	0.00	0.28	0.29	0.59	1.14
	20:1w9	0.19	5.42	5.30	19.63	3.32
	20:1w7	0.00	0.00	0.00	0.00	2.90
	20:1w5	0.43	0.17	0.15	0.41	0.89
	22:1w11	0.13	2.97	3.20	14.57	2.66
	22:1w9	0.21	0.46	0.45	1.65	0.83
	22:1w7	0.00	0.00	0.00	0.00	3.15
	22:1w5	0.11	0.00	0.00	0.24	0.84
	24:1w9	0.00	0.47	0.36	0.96	4.24
	Subtotal	**36.37**	**27.58**	**26.18**	**55.06**	**24.97**

	Fatty acids	Euphausiids	Copepods	Forestomach	Jejunum	Colon
Polyunsaturates	16.2w6	0.00	0.06	0.09	0.12	0.47
	16:2w4	1.37	0.50	0.74	0.44	0.08
	16:3w4	0.25	0.32	0.74	0.20	0.00
	16:4w1	0.31	0.87	1.15	0.27	0.09
	18:2w6 trans	0.00	0.06	0.00	0.11	0.00
	18:2w6 cis	0.38	0.54	0.50	0.58	0.00
	18:2w4	0.00	0.16	0.12	0.00	0.22
	18:3w6	0.15	0.15	0.19	0.18	0.13
	18:3w4	0.00	0.17	0.18	0.00	0.19
	18:3w3	0.22	0.43	1.43	0.49	0.30
	18:3w1	0.00	0.80	0.87	0.19	0.00
	18:4w3	0.39	3.94	3.51	0.92	0.65
	18:4w1	0.00	0.10	0.15	0.00	0.00
	20:2w6	0.13	0.00	0.00	0.00	0.21
	20:4w6	0.31	0.19	0.31	0.45	0.00
	20:3w3	0.00	0.00	0.00	5.16	5.79
	20:3w4	0.00	15.95	19.81	0.00	0.00
	20:4w3	0.21	0.58	0.61	0.35	0.00
	20:5w3	20.76	10.83	7.27	2.39	0.39
	21:5w3	0.18	0.23	0.21	0.00	0.00
	22:4w6	0.00	10.61	13.34	5.28	2.43
	22:5w6	0.00	1.67	1.88	0.78	0.00
	22:5w3	0.00	0.60	1.74	0.77	1.07
	22:6w3	6.10	8.85	3.96	4.58	0.00
	Subtotal	**30.75**	**57.62**	**58.81**	**23.24**	**12.03**
Other	c7Me:16:0	0.00	0.00	0.00	0.00	0.93
	7Me:16:1w9	0.00	0.09	0.08	0.09	1.26
	Subtotal	**0.00**	**0.09**	**0.08**	**0.09**	**2.19**
	Total	**99.87**	**99.74**	**99.77**	**99.90**	**100.00**

Table VC-6. *Relative proportions of selected fatty acids in the intestinal tract contents of a female bowhead whale (11B8) harvested in fall 2011 in Barrow (8.4 m standard length). The stomach contained isopods (86% by volume). Relative proportions of fatty acids are also given for fresh copepods (Calanus glacialis) and euphausiids (Thysanoessa spp.).*

	Fatty acids	Euphausiids	Copepods	Forestomach	Jejunum	Colon
Saturates	12:0	0.20	0.24	0.12	0.09	0.26
	i 13:0	0.26	0.64	0.82	0.58	1.83
	13:0	0.01	0.11	0.15	0.07	0.17
	i 14:0	0.16	0.07	0.00	0.02	0.22
	14:0	6.29	5.83	1.66	7.07	5.26
	i 15:0	0.10	0.41	0.12	0.14	0.45
	ai 15:0	0.03	0.13	0.08	0.08	0.91
	15:0	1.15	0.53	20.82	7.27	1.80
	i 16:0	0.07	0.10	0.00	0.00	0.40
	ai 16:0	0.00	0.11	0.32	0.23	0.00
	16:0	22.26	5.34	6.51	15.07	27.69
	i 17:0	0.05	0.10	0.05	0.09	0.50
	ai 17:0	0.10	0.12	0.12	0.13	0.25
	17:0	0.11	0.13	0.00	0.21	1.28
	i 18:0	0.27	0.43	0.29	0.26	0.25
	18:0	1.69	0.18	0.98	4.83	18.49
	20:0	0.00	0.00	0.10	0.30	5.91
	22:0	0.00	0.00	0.00	0.00	4.86
	24:0	0.00	0.00	0.00	0.00	1.34
	Subtotal	**32.75**	**14.47**	**32.14**	**36.44**	**70.53**
Monounsaturates	14:1w9	0.00	0.37	1.30	0.76	0.00
	14:1w7	0.03	0.05	0.10	0.06	0.00
	14:1w5	0.09	0.22	0.12	0.07	0.00
	16:1w11	2.07	0.31	0.30	0.38	0.29
	16:1w9	0.09	0.14	0.49	0.29	0.11
	16:1w7	16.42	10.40	31.11	19.68	1.35
	16:1w5	0.27	1.55	0.26	0.34	0.11
	17:1w9	0.02	0.06	0.50	0.03	0.00
	18:1w13	0.00	0.07	0.54	0.07	0.00
	18:1w9 trans	0.00	0.00	0.23	0.19	0.00
	18:1w9 cis	9.08	3.31	14.78	10.35	0.34
	18:1w7	7.09	0.65	2.76	4.44	1.55
	18:1w5	0.15	0.80	0.71	0.81	0.47
	20:1w11	0.00	0.28	0.40	0.31	0.72
	20:1w9	0.19	5.42	1.56	0.98	2.11
	20:1w7	0.00	0.00	0.00	0.00	2.82
	20:1w5	0.43	0.17	0.24	0.28	1.59
	22:1w11	0.13	2.97	1.32	0.90	3.76
	22:1w9	0.21	0.46	0.26	0.25	1.19
	22:1w7	0.00	0.00	0.00	0.00	3.65
	22:1w5	0.11	0.00	0.00	0.00	0.80
	24:1w9	0.00	0.47	0.29	0.24	2.21
	Subtotal	**36.38**	**27.70**	**57.27**	**40.43**	**23.07**

	Fatty acids	Euphausiids	Copepods	Forestomach	Jejunum	Colon
Polyunsaturates	16.2w6	0.00	0.06	0.00	0.00	0.13
	16:2w4	1.37	0.50	0.75	0.77	0.00
	16:3w4	0.25	0.32	0.45	0.51	0.00
	16:4w1	0.31	0.87	0.38	0.66	0.00
	18:2w6 trans	0.00	0.06	0.23	0.00	0.00
	18:2w6 cis	0.38	0.54	0.45	0.54	0.00
	18:2w4	0.00	0.16	0.00	0.00	0.00
	18:3w6	0.15	0.15	0.00	0.24	0.24
	18:3w4	0.00	0.17	0.53	0.18	0.45
	18:3w3	0.22	0.43	0.28	0.31	0.00
	18:3w1	0.00	0.80	4.08	1.49	0.00
	18:4w3	0.39	3.94	0.35	0.79	0.00
	18:4w1	0.00	0.10	0.00	0.26	0.00
	20:2w6	0.13	0.00	0.00	0.00	0.96
	20:4w6	0.31	0.19	0.00	0.47	0.00
	20:3w3	0.00	0.00	0.41	0.00	0.85
	20:3w4	0.00	15.95	0.00	0.00	0.00
	20:4w3	0.21	0.58	0.00	0.41	0.00
	20:5w3	20.76	10.83	2.51	13.81	0.00
	21:5w3	0.18	0.23	0.00	0.00	0.00
	22:4w6	0.00	10.61	0.00	0.00	1.24
	22:5w6	0.00	1.67	0.00	0.00	0.00
	22:5w3	0.00	0.60	0.00	0.00	0.00
	22:6w3	6.10	8.85	0.00	2.08	0.00
	Subtotal	**30.76**	**57.61**	**10.42**	**22.52**	**3.87**
Other	c7Me:16:0	0.00	0.00	0.00	0.00	1.08
	7Me:16:1w9	0.00	0.09	0.00	0.00	0.13
	Subtotal	**0.00**	**0.09**	**0.00**	**0.00**	**1.21**
	Total	**99.89**	**99.87**	**99.83**	**99.39**	**98.68**

Table VC-7. *Relative proportions of selected fatty acids in the intestinal tract contents of a female bowhead whale (11B9) harvested in fall 2011 in Barrow (12.6 m standard length). The stomach contained copepods and amphipods (no volume data available). Relative proportions of fatty acids are also given for fresh copepods (Calanus glacialis) and euphausiids (Thysanoessa spp.).*

	Fatty acids	**Euphausiids**	**Copepods**	**Forestomach**	**Jejunum**	**Colon**
Saturates	12:0	0.20	0.24	0.28	0.13	0.61
	i 13:0	0.26	0.64	0.50	3.78	3.01
	13:0	0.01	0.11	0.03	0.00	0.06
	i 14:0	0.16	0.07	0.03	0.00	0.38
	14:0	6.29	5.83	3.43	4.04	3.03
	i 15:0	0.10	0.41	0.12	0.19	0.50
	ai 15:0	0.03	0.13	0.03	0.00	1.39
	15:0	1.15	0.53	2.47	0.75	2.04
	i 16:0	0.07	0.10	0.00	0.62	0.65
	ai 16:0	0.00	0.11	0.00	0.00	0.00
	16:0	22.26	5.34	4.57	31.33	23.35
	i 17:0	0.05	0.10	0.03	0.40	0.55
	ai 17:0	0.10	0.12	0.10	0.20	0.23
	17:0	0.11	0.13	0.05	1.09	1.16
	i 18:0	0.27	0.43	0.23	0.00	0.44
	18:0	1.69	0.18	0.85	14.10	16.87
	20:0	0.00	0.00	0.07	0.58	6.93
	22:0	0.00	0.00	0.00	0.00	6.35
	Subtotal	**32.75**	**14.47**	**12.79**	**57.21**	**67.55**
Monounsaturates	14:1w9	0.00	0.37	0.11	0.21	0.16
	14:1w7	0.03	0.05	0.03	0.00	0.18
	14:1w5	0.09	0.22	0.15	0.00	0.00
	16:1w11	2.07	0.31	0.29	0.95	0.20
	16:1w9	0.09	0.14	0.08	0.41	0.11
	16:1w7	16.42	10.40	16.17	9.00	2.50
	16:1w5	0.27	1.55	0.42	0.62	0.14
	17:1w9	0.02	0.06	0.03	0.65	0.00
	18:1w9 trans	0.00	0.00	0.19	1.28	0.38
	18:1w9 cis	9.08	3.31	2.98	7.90	0.21
	18:1w7	7.09	0.65	1.60	6.83	1.63
	18:1w5	0.15	0.80	0.43	1.01	0.39
	20:1w11	0.00	0.28	0.75	0.85	0.70
	20:1w9	0.19	5.42	6.87	3.75	2.15
	20:1w7	0.00	0.00	0.00	0.00	3.73
	20:1w5	0.43	0.17	1.35	1.07	1.77
	22:1w11	0.13	2.97	6.64	4.07	2.97
	22:1w9	0.21	0.46	1.84	1.31	1.28
	22:1w7	0.00	0.00	0.00	0.00	3.49
	22:1w5	0.11	0.00	0.36	0.00	0.81
	24:1w9	0.00	0.47	0.25	1.51	1.17
	Subtotal	**36.38**	**27.63**	**40.54**	**41.42**	**23.97**

	Fatty acids	Euphausiids	Copepods	Forestomach	Jejunum	Colon
Polyunsaturates	16.2w6	0.00	0.06	0.00	0.00	0.14
	16:2w4	1.37	0.50	0.96	0.00	0.00
	16:3w4	0.25	0.32	0.52	0.00	0.00
	16:4w1	0.31	0.87	0.82	0.00	0.15
	18:2w6 cis	0.38	0.54	0.35	0.00	0.00
	18:2w4	0.00	0.16	0.00	0.00	0.00
	18:3w6	0.15	0.15	0.19	0.00	0.21
	18:3w4	0.00	0.17	0.20	0.00	0.59
	18:3w3	0.22	0.43	0.34	0.00	0.36
	18:3w1	0.00	0.80	0.59	0.00	0.33
	18:4w3	0.39	3.94	0.56	0.00	0.00
	18:4w1	0.00	0.10	0.17	0.00	0.00
	20:2w6	0.13	0.00	0.90	0.00	0.42
	20:4w6	0.31	0.19	0.32	0.00	0.00
	20:3w3	0.00	0.00	0.00	0.00	2.22
	20:3w4	0.00	15.95	13.42	0.00	0.00
	20:4w3	0.21	0.58	0.59	0.00	0.00
	20:5w3	20.76	10.83	8.39	0.00	0.48
	21:5w3	0.18	0.23	0.00	0.00	0.00
	22:4w6	0.00	10.61	0.00	0.00	2.76
	22:5w6	0.00	1.67	15.65	0.00	0.00
	22:5w3	0.00	0.60	1.03	0.00	0.67
	22:6w3	6.10	8.85	1.61	1.38	0.00
	Subtotal	**30.76**	**57.55**	**46.61**	**1.38**	**8.33**
Other	7Me:16:1w9	0.00	0.09	0.00	0.00	0.14
	Subtotal	**0.00**	**0.09**	**0.00**	**0.00**	**0.14**
	Total	**99.89**	**99.74**	**99.94**	**100.01**	**99.99**

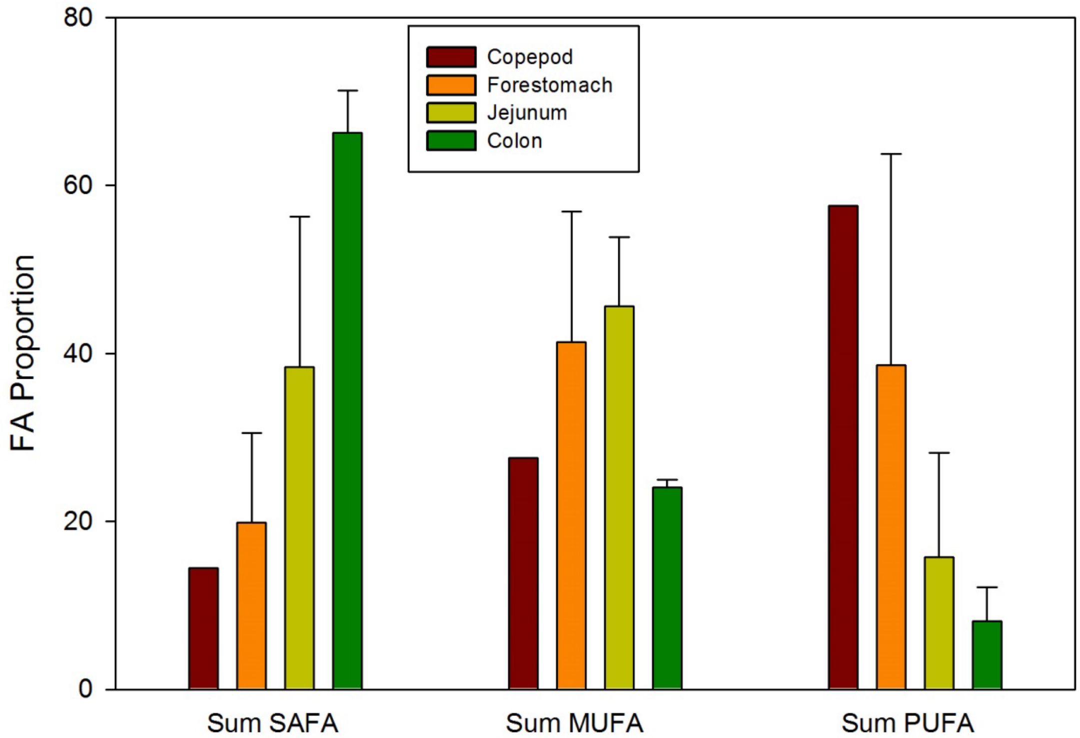

Figure VC-7. *Changes in proportional contribution of broad fatty acid groups, i.e., saturated fatty acids (SAFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA) to the intestinal tract contents of three bowhead whales (11B8, 11B9, and 12B21). Copepod fatty acid groups are provided for comparison. Overall, SAFAs increase from forestomach to colon, while PUFAs decrease.*

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SECTION VI – PROJECT INTEGRATION AND CONCLUSIONS

Beginning in 2006, with the initiation of "Bowhead Whale Feeding Variability in the Western Beaufort Sea: Feeding Observations and Oceanographic Measurements and Analyses," a list of objectives was set out for what became known as BOWFEST (the Bowhead Whale Feeding Ecology Study). These objectives were:

1. Document patterns and variability in the timing and locations of bowhead whales feeding in the western Beaufort Sea.
2. Estimate temporal and spatial patterns of habitat use by bowhead whales in the study area.
3. Document bowhead whale prey distributions and abundance in the immediate vicinity of feeding bowhead whales as well as in neighboring areas without whales.
4. Document "fine scale" oceanographic and other relevant environmental conditions both near feeding bowhead whales and in neighboring areas without whales.
5. Characterize oceanographic features on a "coarse scale" relative to the study area.

These objectives were addressed using multiple research platforms in the BOWFEST study area, northeast of Point Barrow (Fig. VI-1). Data were collected over the short-term (late August to mid-September each year) during aerial surveys, tagging studies, zooplankton and oceanographic sampling, and passive acoustic monitoring; and long-term from year-round passive acoustic and oceanographic moorings, summer small boat surveys, and stomach contents and digestive efficiency from bowhead whales harvested during the spring and fall migrations.

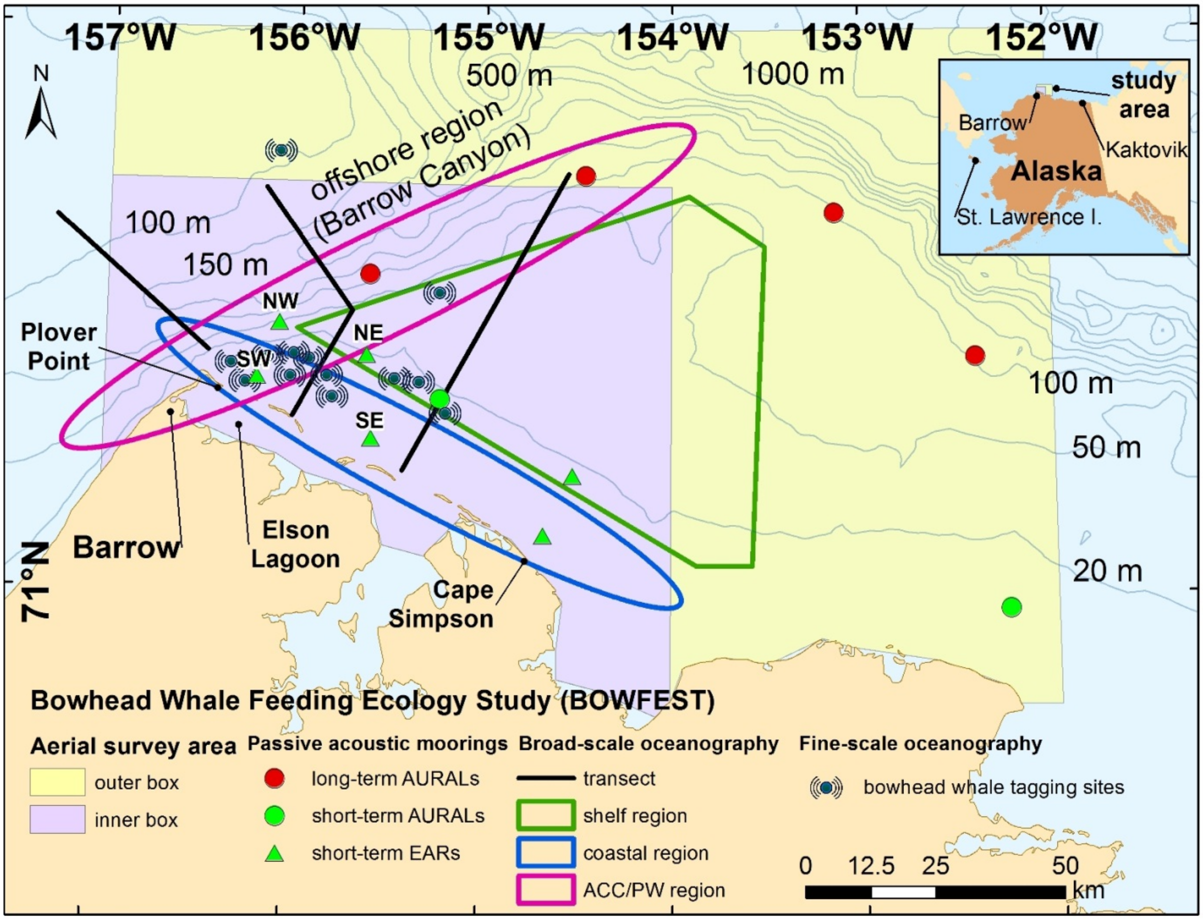

Figure VI-1.— *The Bowhead Whale Feeding Ecology Study (BOWFEST) area (2007-2012). Sampling included aerial surveys (2007-2011), small boat surveys (2008-2012, within the inner and outer aerial survey boxes), passive acoustic monitoring and oceanographic moorings (2007-2012 general sites shown, with regions for mobile arrays noted: northwest (NW), northeast (NE), southwest (SW), and southeast (SE)), broad-scale oceanography (2007-2011 primary transects shown, though sampling also occurred within each region (shelf, coastal, ACC/PW (Alaska Coastal Current/Pacific Water), and offshore)), fine-scale oceanography and whale tagging (2009-2011), and collection of stomach samples and digestive tracts at Barrow, Kaktovik, and Saint Lawrence Island (2007-2012).*

Objective 1: Document patterns and variability in the timing and locations of bowhead whales feeding in the western Beaufort Sea.

Documenting presence and distribution of bowhead whales within the study area was fairly straightforward (Objective 2), however, determining where and when whales were feeding was another matter altogether. The area northeast of Barrow, particularly the shallow shelf east of Barrow Canyon, has been an occasional feeding area of high use for bowhead whales in summer. During the late August to mid-September study period, aerial observations (Rugh et al. Section I: this volume) included obvious feeding bouts: observers noted feeding behavior during 7% to 50% of sightings among the five years of the study; and 16% to 51% of photographed whales exhibited feeding behavior in any given year (Table VI-1). Bowhead feeding behavior was characterized by an open mouth (skim feeding), multiple swim directions, coordinated group feeding (echelon feeding), a fecal plume, mud plumes and/or mud on the dorsal surface (epibenthic feeding) of the whale. Mapping locations of photographed feeding bowhead whales revealed that 91% were located in shelf waters, predominantly along the 20 m isobath. More feeding behavior was observed and photographed during years when most sightings occurred on the shelf (2007, 2009, and 2010).

Starting in 2008, boat-based surveys were conducted from late June/mid-July to mid-late September (George et al. Section VA: this volume). Similar to the aerial survey results, observers reported feeding bowhead whales more often in 2009 and 2010 (~55% - 67% of sightings), than in other years (~30%) (Table VI-1). During those two years, whales were found in waters averaging ~25 m in depth versus the 40+ m depths in other years. Although whales were present periodically throughout the summer months, most sightings occurred in September.

From 2009 to 2011, bowhead whale diving behavior was monitored using short-term (1-3 hour) tags deployed from small boats during the September study period (Baumgartner Section IV: this volume). With the exception of the whale tagged in 2011, all whales were tagged in shelf waters. Tagged whales traveled extensively while they were monitored; some remained at the surface during these traveling periods, while others made repeated and regular dives close to the sea floor. The regular diving behavior was very suggestive of prospecting or searching behavior related to feeding (two of the four events in 2009, and one of eight events in 2010; see Table VI-2).

It is likely much more feeding was occurring than was evident from the aircraft, aerial photographs, or boat-based surveys. Based on stomach examinations, 92% of bowhead whales harvested near Barrow during the fall migration had food in their stomachs (Sheffield and George Section VB: this volume (Table VI-3). This is in stark contrast to the spring harvest when only 10% of the whales had food in their stomachs.

Objective 2: Estimate temporal and spatial patterns of habitat use by bowhead whales in the study area.

Temporally, bowhead whales were seen or heard in the study area during all seasons but winter. Results from the aerial surveys suggest individual bowhead whales may not stay in the study area for long: 45% of all the aerial sightings of bowheads were recorded as “traveling” with only 3 intra-year resightings of identifiable whales. Direction of travel was highly variable among years, only in 2008 was swim direction significantly clustered around a mean (295°T, n =

21 sightings), and clearly westward. In fact, none of the three whales resighted in September (one in 2009, two in 2011) had moved west of the original sighting; all subsequent sightings (2 days later in 2009 and 4 days later in 2011) were to the east. Individuals identified in the study area in late August to mid-September also changed from year to year. Of the 762 identifiable whales photographed over the five year study, only 3 inter-year resightings were found (Rugh et al. Section I: this volume). This low resighting rate suggests the Barrow area is not necessary preferred by a small, select group of individuals during late summer but instead is visited periodically by the large open population of western Arctic bowhead whales.

Passive acoustic monitoring (Berchok et al. Section II: this volume) detected calling bowhead whales in the study area throughout the summer, and not solely during the spring and fall migrations. This was seen clearly in 2009 and 2011, where peak or near-peak presence continued between the migrations. The end of the main pulse of calling for the fall migration varied between early- to mid-November, with the long-term recorder array detecting clear east to west movements in 2008, 2010, and 2011 (Table VI-4). The spring migration was detected every year recorders were present (from 2009 through 2012). In all four years, a sudden and near-simultaneous onset of bowhead whale calling was observed at the long-term sites around the beginning of April. The spring migration saw an extensive pulse of calling that was maintained at peak presence levels well into summer in all years (at one or more mooring sites), except for 2010 and 2012 when levels substantially dropped in July and June, respectively.

During the summer months, the temporal and spatial distribution of bowhead whales within the study area varied from year to year. Physical characteristics of the BOWFEST study area include lagoons, barrier islands, a broad shelf, steep slope, and Barrow Canyon. With the exception of the lagoons, bowhead whales were at times found in close proximity to the islands and in waters ranging from the shelf to the canyon.

In 2007, the aerial team found whales in shelf waters (on the 20 m isobath) on two days in late August, by September none were found by the aerial, oceanography, or tagging crews (Tables VI-1 and VI-2). Bowhead whale calling also decreased in early September on the long-term acoustic recorders. Peak calling occurred in early October, with more calling on the western recorders suggesting the fall migrants arrived in the BOWFEST area from the north rather than the east (Table VI-4).

In 2008, small boat surveys found bowhead whales in deeper shelf waters (45 m mean depth). Aerial observations included a few whales scattered in Barrow Canyon, large groups along the canyon shelf break north of Barrow, some groups along the 20 m isobath on the shelf, and small numbers in deeper waters to the east (see Highlights Table 1). The short-term acoustic recorders detected more calling inshore than offshore at Cape Simpson (Fig. VI-1), however, near Barrow Canyon there was more calling offshore than inshore (Table VI-4).

In 2009, most bowhead whale sightings during aerial and small boat surveys occurred along the 20 m isobath. Mean sighting depth during the small boat surveys was 26 m. Aerial observers also saw a few whales in Barrow Canyon and along the shelf break near Barrow (Table VI-1). All long-term recorders detected calling whales throughout the summer (Table VI-4), however, comparisons between long- and short-term acoustic recorders showed the greatest percent of calling occurred inshore. As mentioned under Objective 1, 2009 and 2010 were years in which more feeding behavior was documented during the aerial and small boat surveys; and prospecting/search behavior was noted during half of the tagging events in 2009. Feeding whales remained in the study area well into October (George et al. Section VA: this volume).

In 2010, there was no inshore-offshore bias to bowhead whale distribution (Rugh et al. Section I, Berchok et al. Section II, and George et al. Section VA: this volume). The aerial team found large numbers of whales near the barrier islands, closer to shore than during any other study year, and spread across the shelf to the slope. Small boat surveys reported more whales in shallow water (25 m mean water depth) than in any other year. For the period of time (mid-September) with overlapping inshore and offshore effort on the passive acoustic recorders, there was initially a greater calling presence inshore, but this evened out rapidly (Table VI-4).

In 2011, aerial surveys found whales in Barrow Canyon and deeper waters to the east, not on the shelf. Most sightings occurred in waters >100 m deep. Mean sighting depth during small boat surveys was 56 m, the deepest of all study years (Table VI-1). At the beginning of September, on recorders with overlapping inshore/offshore effort, calling was higher offshore than inshore. Higher calling levels were inshore during the second half of September. Long-term recorders in the western portion of the study area (closer to Barrow Canyon) had a higher percentage of time with calls than the recorders in the east. Overall, the spatial and temporal differences observed year to year may, in part, be reflected in prey distributions which are discussed under Objective 3.

When examining bowhead whale habitat preferences based on all years of the aerial survey data, we considered four parameters in the model: bathymetry, bathymetric slope, distance from shore, and distance from the shelf break (Rugh et al. Section I: this volume). Both distance from shore and distance from the shelf break were significant in predicting the presence of bowhead whales ($p < 0.01$). Bowhead whales preferred to be close to shore and to the shelf break; therefore, their preferred habitat were areas where the shelf break came closest to shore. However, the model was only able to correctly discriminate between the presence (bowhead sighting) and absence (random points) 67% of the time. As mentioned earlier, feeding bowheads were predominantly found in shelf waters.

Habitat partitioning within the study area among cetacean species was also evident during the aerial and small boat surveys. Gray whales (*Eschrichtius robustus*) were seen each summer near Barrow (Rugh et al. Section I and George et al. Section VA: this volume) and their feeding areas were consistent from year to year. Bowhead and gray whales showed fairly strong spatial segregation, with most bowhead whales in shelf waters <50 m deep to the east of Point Barrow and gray whales near the 50 m isobath along the eastern edge of Barrow Canyon, with some overlap just north of Point Barrow (Rugh et al. Section I and George et al. Section VA: this volume). Mean water depth of gray whales sightings during small boat surveys was on average 37 m deeper than bowhead whale sightings (Table VI-1). Bathymetry, as well as bathymetric slope, distance from shore, and distance from the shelf break were significant in predicting gray whale presence ($p < 0.01$) (Rugh et al. Section I: this volume). Gray whales preferred to be in waters along the shelf break. The model was able to correctly classify gray whale presence and absence 96% of the time (Rugh et al. Section I: this volume).

Beluga whales (*Delphinapterus leucas*), when seen, were generally over Barrow Canyon (Rugh et al. Section I: this volume), though large numbers were observed at times near the barrier islands (Rugh et al. Section I and George et al. Section VA: this volume). Of the four parameters included in the model, only bathymetry was significant in predicting beluga whale presence ($p < 0.01$). These animals preferred to be in deeper water than would be predicted at random and the model correctly discriminated sightings from non-sightings 82% of the time (Rugh et al. Section I: this volume).

While there was a large portion of overlap for these species, there is clear spatial separation in their preferred habitats. Bowhead whale preferred habitat, regardless of behavior observed, included shelf, shelf break, and canyon waters primarily north and east of Barrow, beluga whale habitat primarily included the canyon, while gray whale preferred habitat located at the interface of bowhead shelf and beluga canyon habitat – following the shelf break (Rugh et al. Section I: this volume).

Objective 3: Document bowhead whale prey distributions and abundance in the immediate vicinity of feeding bowhead whales as well as in neighboring areas without whales.

Although bowhead whales exhibited foraging behavior during tagging operations that were conducted during the same time period as the aerial surveys, they did not appear to target available euphausiid or copepod swarms (Baumgartner Section IV: this volume). It is possible that recently tagged whales were still responding to the tagging operations and not interested in eating. However, evidence suggests that the sample area lacked prey patches that were sufficiently concentrated to warrant feeding. Zooplankton abundance, particularly that of the whales' primary prey (euphausiids and large copepods), was low in proximity to the tagged whales. With the exception of 2009, the abundance of euphausiids and large copepods was generally low both in the presence and absence of bowhead whales (Table VI-2). For all zooplankton taxa except euphausiids, abundance in the presence of whales was highest in 2010. The abundances of large copepods, naked pteropods, and chaetognaths were comparatively very low in 2009 and 2011. In contrast, the abundance of gelatinous zooplankton was quite high, particularly in 2010. During the tagging study, zooplankton sampling both in the presence and absence of bowhead whales indicated no relationship between the occurrence of the whales and zooplankton abundance.

Broad-scale oceanography was also conducted from late August to mid-September (Ashjian et al. Section IIIB: this volume). Of the five years of the study, 2009 provided the most favorable feeding conditions for bowhead whales, with large, high-biomass euphausiids being delivered across the shelf. Euphausiid "wash-ups" occurred on 7 August and 19 September on the beach in Elson Lagoon in 2009 (George et al. Section VA: this volume). Other years, although providing concentrations of euphausiids, might be considered less favorable simply because the euphausiids were dominated by smaller life stages that provided lower biomass (Table VI-2). The abundance and relative proportions of larger adult and juvenile vs. smaller furcilia euphausiids also varied interannually, with euphausiid abundances in 2009 being dominated by large juvenile/adults, 2010 and 2011 being dominated by small furcilia, and 2007 and 2008 having more equivalent proportions of the two size categories. These differences likely were related to larger scale patterns in euphausiid population structure, abundance, and transport from the Bering Sea (Ashjian et al. Section IIIB: this volume).

The large copepod *Calanus glacialis*, one of the important prey items of bowhead whales, was seen consistently only in the offshore region. *C. glacialis* is widespread on the Chukchi Shelf and is found also along the shelf break and along the slope of the Arctic Basin but is not considered to be a coastal species. Its presence in the offshore regions of Barrow Canyon (in particular in 2010), where the water may have originated either in the Canada Basin or in the Bering Sea water flowing through the Chukchi Sea, is consistent with this known distribution. The Alaska Coastal Current (ACC), with water of more coastal origin, should not be expected to be a source of *C. glacialis*. Other zooplankton distributions of note included the dominance of the small copepod, *Pseudocalanus* spp., on the shelf in 2007; and the importance of benthic and echinoderm larvae in all regions in 2011 (Table VI-2)

During all years of the aerial study, muddy whales were photographed, however only in 2010 and 2011 were photographs obtained showing open mouth (skim) feeding (Table VI-1). Muddy whales and mud plumes were also observed during small boat surveys with surface (skim) feeding noted, in particular in 2009. Fast swimming euphausiids may account for the preponderance of surface feeding observed in 2009 and 2010. In 2010, groups of bowhead whales were observed swimming in echelon formation during the aerial survey, and in an unusual position, on their sides instead of upright. The following excerpt from Fish et al. (2013) provides insights into this behavior:

> "Boat-based sampling of hydrography and plankton was conducted in the same region near Barrow, also a part of the BOWFEST program. Data showed that upwelling-favorable winds followed by weak winds, particularly from the south-southwest, can result in large quantities of euphausiids being upwelled and then "trapped" on the Beaufort Sea shelf (Okkonen et al. 2011). An observation of diel vertical migration (DVM) in acoustic backscatter records in the area supported the evidence of occasional high abundance of euphausiids (Ashjian et al. 2010). At the time of the sighting, the average winds were from the west-southwest at 5.3 m/s (~10 kn), creating favorable conditions for trapping large quantities of euphasiids [sic] on the Beaufort Sea shelf. Also, the clearest DVM occurred between 7 and 13 September providing further evidence of high prey abundance in the Barrow area at the time of the sighting.
>
> Side-swimming whales while foraging represents an unusual behavior that has implications for the hydrodynamics of the whales. There are potential benefits to the echelon formation of side-swimming whales based on observations of the vortices produced and proximity and location of the whales. The vortices shed from the surface of a leading whale could help to concentrate prey to be consumed by a trailing whale. The location of adjacent whales would produce a flow field that would aid in pulling along each trailing whale by the Bernoulli effect. Side-feeding of bowhead whales in concert with echelon formation swimming can increase feeding efficiency and/or decrease the overall energy cost of locomotion when foraging."

Bowhead whales are known to feed on prey on the surface, in the water column, and on the sea floor (epibenthic). Depending on prey type, feeding efficiency and/or energy cost may change from year to year. Part of the BOWFEST study also included examining stomach contents of whales harvested during the migration period (Sheffield and George Section VB: this volume) and calculating their digestive efficiency (Horstmann-Dehn and George Section VC: this volume). Though sampling was not during the summer period, whales were feeding in the BOWFEST study area just after the conclusion of our observations and our expectation is that prey community composition would be similar to that observed in summer. The importance of the region near Barrow as a feeding area during the fall migration is also reflected in the proportion of harvested animals that had been feeding near Barrow (92%) versus at Kaktovik (54%).

Bowhead whales that were harvested in late fall near Barrow had more euphausiid prey (82% prey by volume) in 2007-2009, but in 2010 the dominant prey was copepods (88%). This pattern follows the broad scale oceanographic results discussed above, where euphausiid size classes included larger adults and juveniles advected onto the shelf during 2007-2009, but mostly smaller furcilia in 2010, which may have been targeted by side-swimming echelon groups. We can only speculate that bowhead harvested in 2010 fed on larger copepods found in offshore waters (as noted in the broad scale oceanographic study), as bowhead whale harvest locations remain proprietary Alaska Eskimo Whaling Commission data and were not available for the harvested whales used in this study.

Bowhead whale stomachs in 2011 (and 2012) had a diversity of prey types, including isopods, mysids, copepods, amphipods, and fish (Table VI-3). The occurrence of Arctic cod in bowhead whale stomachs was unusual, and may explain the increased presence of another predator, beluga whales, in the study area in 2011.

Examinations of bowhead whale digestive tracks sometimes revealed mud, which may occur incidental to consuming epibenthic prey, such as *Mysis oculata*. These mysids were the most commonly eaten prey identified from the stomachs of bowhead whales killed near Barrow, particularly in 2011 (Sheffield and George Section VB: this volume). The ACC/PW region (Ashjian et al. Section IIIB: this volume, see also Fig. VI-1) aligned with the observed gray whale distribution and overlapped with bowhead whale preferred habitat (Rugh et al. Section I and George et al. Section VA: this volume). Here benthic larvae were present in all years this region was sampled and enumerated (2007, 2010, and 2011), consistent with mud plumes and muddy whales observed in those years.

The efficiency of prey consumption was studied through sampling digestive tracts and using proximate composition analyses (%lipid, %protein) and bomb calorimetry to assess changes in energy density and composition of digesta (based on samples from 80 bowhead whales). The digestive efficiency was lowest (64%) in 2010 and highest (83%-84%) in 2009 and 2011, respectively (Table VI-3). This variability in efficiency emphasizes the importance of finding high density prey patches and minimizing the search, but also indicates that migrating whales may acquire sufficient energy near Barrow to offset their migratory costs and avoid expending energy gained on the summer foraging grounds. Whales continued to feed even after reaching their wintering grounds. During the spring, a larger proportion of bowhead whales near Saint Lawrence Island (73%) were feeding than at Barrow (10%). There was no seasonal difference in the proportion of harvested whales feeding near Saint Lawrence Island (spring 73% vs. fall 75%) (Sheffield and George Section VB: this volume).

Estimates of daily energy intake indicate that relatively young bowhead whales may expend as much energy when feeding near Barrow as is gained (~8 kW for a 9 m whale) with a digestive efficiency of 77% (Horstmann-Dehn and George Section VC: this volume). Recent studies have shown that sub-adults show marked seasonal changes (i.e., returning much thinner in the spring) and likely have high energy requirements. This does not appear to be true for older adult bowhead whales (George et al. In prep.). Generally, fat reserves stored in bowhead whale blubber far exceed thermoregulatory requirements; for example, the sample results from a 9 m bowhead indicate it could fast over 1 year (migratory metabolic rate (MR), assuming no MR adjustments), suggesting a built-in fail-safe for years with unfavorable prey densities. An adult can likely fast several years on an insufficient diet. Regardless of the prey consumed, bowhead whale digestive efficiency remained at ~80%, which was lower than efficiencies reported for minke (*Balaenoptera acutorostrata*) or North Atlantic right whales (*Eubalaena glacialis*) (Horstmann-Dehn and George Section VC: this volume).

Objective 4: Document "fine scale" oceanographic and other relevant environmental conditions both near feeding bowhead whales and in neighboring areas without whales.

Fine scale oceanographic data (temperature, salinity, and chlorophyll fluorescence) were collected near tagged whales, but not presented in Baumgartner (Section IV: this volume) as none of the tagged whales appeared to be feeding. Prey patches, when present during the VPR and CTD casts, were at least an order of magnitude lower than that observed near feeding North Atlantic right whales (Baumgartner and Mate 2003, Baumgartner et al. 2003). In 2009, one of the tagged whales (event 5) made repeated dives into a cold, salty water mass, and these dives were characterized by longer bottom times than previous dives (Baumgartner 2009). Upon review of the VPR casts with the dive profiles, a reasonably high abundance of euphausiids was observed in proximity to this whale (Baumgartner Section IV: this volume, see Fig. IV-13d), yet the whale did not demonstrate feeding behavior. In 2010, bowhead whale movements did not appear to be associated with any fine-scale oceanographic features on the shelf. Colder and fresher conditions prevailed to the east (events 5, 9 and 10), and warmer saltier water likely of Pacific origin were predominant in the western part of the study area (events 6 and 8); however, the tagged whales were found in both of these conditions and in some cases, crossed over the boundary between these two water masses (events 7, 8 and 9). Both along-shelf (event 10) and cross-shelf (events 5, 6 and 9) movements were observed (Baumgartner 2010).

On a broader scale, multiple water masses were observed each year, and zooplankton community composition varied between years and hydrographic/geographic regions (Ashjian et al. Section IIIB: this volume). Greatest chlorophyll concentrations were present both in melt water and in the upper portion of the Winter Water (WW) because of the greater nutrient concentrations found in those water masses. With the exception of periods when the krill trap (see below) had advected euphausiids onto the shelf, greatest abundances of euphausiids were found in the offshore regions, presumably in the WW at depth. Acoustic Doppler Current Profiler data from moorings at the shelf break indicated that these euphausiids were upwelled onto the shelf along the Beaufort Shelf break from the WW rather than from the shallower ACC. In Barrow Canyon, these krill are preferentially associated with cold, salty WW. It is inferred from this association that these krill are advected from the Bering Sea and across the Chukchi Sea via currents other than the warm, fresh ACC. It is now thought that euphausiids are resident in the WW found at depth below the ACC and offshore (Ashjian et al. Section IIIB: this volume).

<u>Krill trap</u> – Short-term variability in conditions on the shelf, including plankton abundance and composition, are tied to the direction and strength of local winds (Okkonen Section IIIA: this volume). In certain combinations, this affects krill concentrations (the "krill trap"), that is, when weak or southwesterly winds follow moderate-to-strong, upwelling-favorable easterly winds, there is a convergence of ACC waters from Barrow Canyon with Beaufort shelf waters, leading to the trapping and aggregation of krill on the western Beaufort shelf adjacent to the southeastern edge of Barrow Canyon. Therefore, it appears that krill are more likely to be present in higher densities on the western Beaufort shelf during weak-wind active krill trip conditions than during upwelling wind conditions (Okkonen Section IIIA and Ashjian et al. Section IIIB: this volume). The krill trap was active the greatest proportion of days (45%) in 2009, and was active for ~10% fewer days in the other four years (Table VI-5).

Objective 5: Characterize oceanographic features on a "coarse scale" relative to the study area.

Oceanographic conditions near Barrow are complex and are characterized by the juxtaposition of two oceanographic regions – the Chukchi and Beaufort Seas – and several water masses (Ashjian et al. Section IIIB: this volume). A submarine canyon (Barrow Canyon) just offshore markedly impacts local conditions. Relatively warm, fresh Alaska Coastal Water (ACW) from the Bering Sea flows northward through the Chukchi Sea and exits the oceanographic shelf through Barrow Canyon with annual mean transports varying according to atmospheric conditions in the Arctic. Variability in the northward transport of ACW introduces variability in fluxes of heat, salt, nutrients, and plankton entering the Arctic, in turn impacting the Arctic ecosystem; in which, there is a close coupling between water mass type and biological characteristics. Dramatic changes in sea ice extent suggest this region is highly susceptible to climate change. Both long-term (inter-annual) and short-term (days or weeks) variability are important in establishing the presence of a favorable feeding environment for bowhead whales near Barrow. The period of the study, 2007-2012, coincides with a period of dramatic physical change in the Arctic and particularly in the western Arctic. The BOWFEST sampling years encompassed some of the lowest total summer sea ice extents in satellite-documented history, with 2012 and 2007 being the lowest and second lowest years on record, respectively (Table VI-5). All years of the field study occurred during a period of on average declining sea ice extent in the Western Arctic, although there was individual variation both among years and locally in the Barrow area. These ice conditions were reflected in the hydrographic conditions in the BOWFEST study area.

Conclusions

The BOWFEST study area, northeast of Point Barrow, is characterized by complex bathymetry with shallow shelf waters bordering a deep marine canyon. The canyon provides a conduit for relatively warm water and biological matter into the Arctic Basin as well as onto the Beaufort Shelf. Further complicating the nature of the area, sea ice varies from complete coverage in the winter to partially or totally absent in the summer, and the extent has been changing inter-annually. This variety in habitat characteristics may be elemental to the rich marine fauna found in the area, and accordingly, bowhead whales exploring feeding opportunities throughout the summer. Not only is the Barrow region important during the summer months for some bowhead whales, but also during the fall as whales depart the Beaufort Sea, as an additional feeding area for maintaining (for sub-adults) and even replenishing (for larger age classes) their energy stores before reaching wintering grounds in the Bering Sea.

The BOWFEST results are also supported by the multiyear BOEM-funded Bowhead Whale Aerial Surveys where some of the highest densities (whales/transect km) of bowhead whales in the western Beaufort occurred in the Barrow area (Clarke et al. 2013). BOEM-funded satellite telemetry studies found some tagged bowhead whales spending remarkably long periods (one up to 32 days) near Barrow, presumably feeding, even after transiting 725 km west to Wrangel Island before returning to Barrow region (Quakenbush et al. 2010). Clearly, bowhead whales are travelling, prospecting, searching, and feeding near Barrow during the summer and fall, primarily in shelf waters, but also in Barrow Canyon, taking advantage of changing prey assemblages and oceanographic conditions.

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Sheffield, G., and C. George. Diet studies. Section VB. In: Shelden, K.E.W., and J.A. Mocklin, eds. 2013. Bowhead Whale Feeding Ecology Study (BOWFEST) in the western Beaufort Sea. Final Report, OCS Study BOEM 2013-0114. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115-6349.

BOWFEST ANNUAL HIGHLIGHTS (2007-2012)

Table VI-1. Visual surveys (annual highlights from BOWFEST 2007-2012):

Year	Aerial	Local boat	Other observations	Other marine mammals observed
2007	Many bowheads Aug. 23-24 tightly grouped on 20 m isobath, none for the rest of the survey, 0.003 sightings/km. Feeding behavior (observed-photo) 50%-37%. Muddy whales.	No surveys	Bowheads near Kaktovik in early Aug. Oceanographic vessels detected few bowheads.	A humpback whale seen near Barrow. Many ringed seals seen inshore near Barrow. Belugas in Barrow Canyon, gray whales along the slope.
2008	Some bowheads along the 20 m isobath; most near the Barrow Canyon shelf break; a few in deeper waters to the east; 0.017 sightings/km. Feeding 7%-16%. Muddy whales.	Modest sightings per unit effort; 32% of sightings were of feeding whales. Mean water depth 45 m.	Several mother/calf pairs seen near Kaktovik the first week of Sept.	Gray whales in deep waters (mean depth 109 m) during boat based surveys.
2009	Lowest effort of all years due to weather, but same sighting rate as 2008 (0.017 sightings/km). Bowheads along the 20 m isobath and a few in the Canyon and near the shelf break off Barrow. Feeding 21%- 23%. Muddy whales. One whale remained at least two days in the study area.	Highest sightings per unit effort for all study years. Feeding (67%), many surface feeding. Mean water depth 26 m.	Bowheads seen near Barrow all summer. In July, feeding 0.5 km off Barrow in Chukchi Sea. Mother/calf pair near Kaktovik mid-Sept.	A humpback whale seen by the aerial team among a group of gray whales. Polar bears arrived early at Kaktovik (in July). Gray whales seen on the shelf (50 m) during boat based survey, tightly grouped on the slope NW of Barrow during aerial.

Table VI-1. Visual surveys (annual highlights from BOWFEST 2007-2012):

Year	Aerial	Local boat	Other observations	Other marine mammals observed
2010	Highest sighting rate (0.027 sightings/km), feeding intensely on Sept 17, closer to shore than in other years and spread across the shelf, a few in the canyon. Feeding 28%-51%. Open mouth/echelon feeding behavior.	Second highest sightings per unit effort. Feeding (54%). Mean water depth 25 m.		Highest number of harbor porpoise seen of any year during boat surveys (10). 20+ belugas seen in Kaktovik lagoon first week of Sept. All gray whales southwest of Barrow during aerial survey. Boat based gray whales mean depth 63 m.
2011	Greatest effort but lowest sighting rate (0.002 sightings/km). Bowheads in deep water (>100 m), most in Barrow Canyon, a few east in deeper shelf waters. Feeding 11%-22%. Two whales remained at least 5 days in the study area.	Greatest effort but lowest sightings per unit effort of the study period. Very late arrival; few seen during fall whaling. Feeding (29%). Mean water depth 56 m.	Mother/calf pair near Kaktovik the first week of Sept.	Highest number of beluga sightings of all years of aerial survey. Gray whales mean depth 78 m during boat surveys.
2012	No aerial survey.	Only one day with many whales. Whales seen on the outer edge of the shelf (mean water depth 41 m). Feeding (5%-26%).		Gray whales mean depth 79 m during boat surveys.

Table VI-2. Zooplankton sampling and bowhead whale tagging (annual highlights from BOWFEST 2007-2011):

	Broad-scale			Fine-scale
Year	**Krill trap**	**Community composition**	**Krill abundance**	**Tagging and other observations**
2007	Active for 10 days.	Lots of small copepods on the Barrow shelf, especially *Pseudocalanus* spp.	Good year for large krill (from ring net samples).	No tagging events, whales not in the study area late August to mid-September.
2008	Active for 11 days. Not many krill on the shelf.	Shelf community contains high proportion of *Pseudocalanus* spp.	Most krill seen offshore; a good mix of juveniles/adults vs. furcilia.	No successful tagging events.
2009	Active for 14 days.	N/A	Large juvenile and adult krill dominate. Backscatter from moored ADCP was high, suggesting many zooplankton scatterers.	4 tagging events, two with prospecting behavior. Only year euphausiids made up the majority of zooplankton sampled in presence/absence of whales. Large wash up of euphausiid (adults) near Barrow.
2010	Active for 11 days (possibly the17th- see other observations).	Zooplankton on shelf dominated by *Pseudocalanus* spp.	Lots of euphausiid furcillia in Barrow Canyon, less abundant on the shelf (from ring nets).	8 tagging events, one with prospecting behavior. Gelatinous zooplankton made up majority of samples in presence/absence of whales. On Sept. 17, large numbers of echelon feeding bowheads.
2011	Active for 10 days (though also see other observations).	Relatively high abundances (proportion of total) of benthic larvae compared to other years. Echinoderm larvae present.	Few krill on the shelf (mostly juveniles on the shelf; furcillia in Barrow Canyon). Backscatter from moored ADCP was low consistent with the observation of low krill abundance of the 3 years of ADCP data.	Any krill that made it on the shelf were likely carried back into Barrow Canyon (based on mean flow). One tagging event, gelatinous zooplankton and some large copepods made up majority of samples in presence of whales.

Table VI-3. Subsistence hunt (annual highlights from BOWFEST 2007-2012):

Year	Barrow fall hunt and sample highlights	Kaktovik highlights	Energetics	Other observations
2007	Seven bowheads landed from Oct. 7-11, stomachs examined, copepods and euphausiids in stomachs.	Three whales landed, stomachs examined, copepods found in large volume.	N/A	Ringed seals dropped a trophic level (see Carroll et al. 2013). Kaktovik killed a beluga the last week of August, which was considered an early beluga harvest.
2008	Twelve bowheads landed (first whale on Oct. 5). Four whale stomachs were dominated by euphausiids; copepods were dominant in one.	Three whales landed, stomachs examined, only one stomach contained prey (copepods).	N/A	Ringed seals were feeding at a low trophic level (see Carroll et al. 2013).
2009	Fifteen bowheads landed from Sept 26 - Oct 10, stomachs examined. 14 had been feeding (euphausiids); jellyfish were present in two stomachs (1 jellyfish in each whale).	Three whales landed, stomachs examined, one stomach was full of euphausiids.	Digestive efficiency was 83%, second highest during energetics study.	Ringed seals were feeding at a high trophic level (see Carroll et al. 2013).
2010	Eight bowheads landed from Oct 7-11. All had been feeding; stomachs contained copepods, fish, and amphipods (fish were identified in 6 of 8 whales examined).	Three whales landed, stomachs examined, mostly empty only benthic organisms found.	Lowest digestive efficiency of any study year (64%).	Ringed seals were feeding at a lower trophic level (see Carroll et al. 2013). Ringed and bearded seal carbon levels plummeted (lowest in 12 years).
2011	Eleven bowheads landed from Oct. 8-29 (most Oct. 24-29), 9 stomachs examined; whales were LATE! All whales were feeding. A diversity of prey types dominated the samples including isopods, mysids, copepods, amphipods, and fish. More mysids than euphausiids; copepods prevalent.	Three whales landed, two stomachs examined.	Highest digestive efficiency of any study year (84%). Forestomach caloric content was one of the highest.	Kaktovik hunt was short in duration because the whales were easily found; one dead stinker whale was recovered and landed, stomach was not examined.

Table VI-3. Subsistence hunt (annual highlights from BOWFEST 2007-2012):

Year	Barrow fall hunt and sample highlights	Kaktovik highlights	Energetics	Other observations
2012	Ten bowheads landed from Oct. 1-19, stomachs examined, 7 of the 9 volumetric samples were dominated by mysids and euphausiids, with only one sample dominated by copepods.	Three whales landed, one stomach examined.	Average digestive efficiency for the study period (77%).	The harvest period at Kaktovik was extended due to a death in the community and windy weather. Hunting ended the first week of Oct. (the second latest hunt on record).

Table VI-4. Passive acoustic monitoring (annual highlights from BOWFEST 2007-2012):

	Short-term recordings	Long-term recordings			
Year	**Inshore vs. offshore**	**Spring migration**	**Summer**	**Fall migration**	**Temperature**
2007	No data for this time period.	No data for this time period.	No data for this time period.	Fall migrants seemed to arrive in the study area from the north. Peak calling was in early Oct. All M clusters showed a decrease in calling in early Sept. More calling on western recorders.	Strongest correlation between temperature and calling. Temperatures peaked from M5, in the east, to M2, in the west, which might indicate a pulse of warm water passing from east to west over the study area.
2008	There was a greater percentage of time with calling inshore than offshore at Cape Simpson, however, there was more calling further offshore near Barrow Canyon.	No calls detected (recordings end in early March).	No data for this time period.	Peak calling was between Sept. and Nov., with the highest percentage in late Oct. At the end of the migration, east to west movement was very clear.	Temperatures remained well below 0°C for the whole fall migration.
2009	Comparison between the short-term moorings and M2 clearly show a much higher percentage of calling at inshore areas.	Sudden onset of calling in early April, with percentage of time with calls quickly reaching 100%.	All three moorings detected calls, with M5 having the highest percentage of time with calling.	Peak calling was in October.	Increase in temperature from -1 to 0°C was detected two weeks before the start of spring migration. No consistent trend in temp. seen during fall migration.

Table VI-4. Passive acoustic monitoring (annual highlights from BOWFEST 2007-2012):

Year	Short-term recordings	Long-term recordings			
	Inshore vs. offshore	**Spring migration**	**Summer**	**Fall migration**	**Temperature**
2010	For mid-September, when there was overlapping inshore and offshore effort, there was greater calling presence inshore at first, but this evens out rapidly.	First calls detected at the beginning of April. Percentage of time with calling varied throughout the spring.	Calls detected during the summer months. Presence during August is unknown due to recorder failure.	Peak in calling from mid-Sept. through mid-Oct. East to west migration movement was evident at the end of the fall migration.	Increase in temperature from -1 to 0°C was detected two weeks before the start of spring migration. Detections at all three sites dropped around mid-Nov., about a month after bottom temps reached 0°C.
2011	At the beginning of September, calling was higher offshore, while the second half of September had higher calling levels inshore.	Earliest detection of start of spring migration. All moorings immediately reached peak presence in mid/late March.	Calls detected during summer months. Western recorders had a higher percentage of time with calls than recorders in the east.	Peak presence was detected from early October until late November. East to west migration movements seen at the end of the fall migration.	There was an abrupt end to the fall migration at all three recording sites. This occurred in mid-November about a month after bottom temperatures dipped below 0°C.
2012	Calling on the inshore mooring reached 100% at the end of August and continued through mid-Sept. when the mooring was retrieved. There were no data on the closest offshore mooring for this time period.	Latest detection of start of spring migration during the study period. Detections began in mid-April and all three moorings immediately reached peak presence.	Peak presence was detected from early- to mid-July on western moorings (no data past end of July). A decrease in calls at all three moorings detected in late June.	No data for fall migration (to be analyzed as part of the CHAOZ project).	Increase in temperature from -1 to ~0°C was detected ~3 weeks before the spring migration. Calling rates dipped in June coincident with a sudden increase in bottom temp. Temp. was not inversely correlated to this calling dip (unknown if/how it was a factor - not seen in any other year).

Table VI-5. Oceanographic conditions (annual highlights from BOWFEST 2007-2012):

Year	Sea ice and ice formation	Water temperature	Currents/ transport	Salinity	Winds	Upwelling	Other observations
2007	Second lowest sea ice extent on record (for the period 1979 to 2013).	Warmest of the study years with up to 12°C off Barrow.		Highest salinity of any study year.	Predominantly east winds.	Big upwelling year.	
2008	Ice persisted locally near Barrow into mid-August.	Coldest surface water of all study years.	Low transport of Alaska Coastal Water (ACW).	Freshest upper ocean salinity of any year.		Moderate.	
2009	Sea ice extent was higher than in other years (approx. as modeled). On Aug. 18, sea ice came in from Hanna Shoal. Latest date for temp. to fall and stay below 0 (early Nov.) of any year. Also year that ice formed the latest in the study area.	Moderate.		Large amount of fresh water present, although, more fresh water was present in 2006.	Strong.		The bowhead hunt in Kaktovik was delayed in Sept due to windy conditions.
2010	Ice persisted in summer to the east of the study area.	Moderate.	Some ACW present off Barrow.	Salinity was high.	Generally weak winds.		August in Kaktovik was very foggy with calm winds.

Table VI-5. Oceanographic conditions (annual highlights from BOWFEST 2007-2012):

Year	Sea ice and ice formation	Water temperature	Currents/ transport	Salinity	Winds	Upwelling	Other observations
2011	No sea ice.	Warm year for water temp. (ACW was 8°C).	Mean flow in the upper 25m of the ACC during Sept-Oct was up-canyon to the SW, opposite its normal flow to the NE (not observed in any other year).	High salinity as well (least fresh water of study period).	Persistent winds from east.		Pickart (WHOI) mooring at 152°W: of the years the mooring was out (6-7 year record), 2011 had the weakest eastward transport.
2012	Sea ice at all-time minimum (Oct 2012 air temp was the warmest Oct on record at Barrow); consistent west winds during September and October.	Water temps were average to warm (9°C).	Some ice melt water was present.	Large amount of fresh water present (perhaps comparable to 2009 conditions). Water in Barrow area likely from Kotzebue Sound.	Strongest average winds from the south (to the north). Kaktovik was warm (mid-50s), with high winds.		Coastal sea level anomaly at Red Dog was over 50 cm (2X above average); consistent with persistent winds from the south.

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SECTION VII - SUMMARY OF PRODUCTS
(Fully or partially funded by BOWFEST)

REPORTS:

Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2007 Annual Report. From the National Marine Mammal Lab, NOAA Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115, to Minerals Management Service, 381 Elden Street, Herndon, VA 20170-4879. 36p. Contents:

Goetz, K.T., D.J. Rugh, and J.A. Mocklin. Aerial surveys of bowhead whales in the vicinity of Barrow, Alaska, August-September 2007.

Stafford, K and D. Mellinger. Passive acoustic monitoring.

Ashjian, C., S. Okkonen, and R. Campbell. Mooring and broad-scale oceanography.

Baumgartner, M., C. Ashjian, R. Campbell, and S. Okkonen. Tagging and fine-scale oceanography.

Sheffield, G. and J.C. George. Bowhead whale harvest sampling.

Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2008 Annual Report. MMS-4500000120. From the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349, to Minerals Management Service, Environmental Studies Program, Alaska Outer Continental Shelf Region, 94 East 36th Avenue, 3rd Floor, Anchorage, AK 99508-4363. 81p. Contents:

Goetz, K.T., D.J. Rugh, and J.A. Mocklin. Aerial surveys of bowhead whales in the vicinity of Barrow, Alaska, August-September 2008.

Mocklin, J.A. and D.J. Rugh. Photographic analysis of feeding whales.

Berchok, C., K. Stafford, D. Mellinger, S. Moore, and J.C. George. Passive acoustic whale monitoring.

Ashjian, C., S. Okkonen, and R. Campbell. Mooring and broad-scale oceanography.

Baumgartner, M. Tagging and fine-scale oceanography

George, J.C., and G. Sheffield. North Slope Borough research: Examinations of bowhead stomach contents and local boat surveys

Smultea, M. Preliminary list of systematic surveys involving bowhead whales in the U.S. Beaufort and Chukchi seas 1975 – 2008.

Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2009 Annual Report. MMS-4500000120. From the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349, to Minerals Management Service, Environmental Studies Program, Alaska Outer Continental Shelf Region, 94 East 36th Avenue, 3rd Floor, Anchorage, AK 99508-4363. 63p. Contents:

Goetz, K.T., D.J. Rugh, and J.A. Mocklin. Aerial surveys of bowhead whales in the vicinity of Barrow, August-September 2009.

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Ashjian, C., S. Okkonen, and R. Campbell. Mooring and broad-scale oceanography.
Baumgartner, M. Tagging and fine-scale oceanography.
George, J.C., and G. Sheffield. North Slope Borough research.

Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2010 Annual Report. MMS-4500000120. From the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349, to Bureau of Ocean Energy Management, Regulation and Enforcement, Environmental Studies Program, Alaska Outer Continental Shelf Region, 94 East 36th Avenue, 3rd Floor, Anchorage, AK 99508-4363. 99p. Contents:

Goetz, K.T., D.J. Rugh, L. Vate Brattström, and J.A. Mocklin. Aerial surveys of bowhead whales near Barrow in late summer 2010.
Berchok, C., K. Stafford, D. Mellinger, S. Nieukirk, S. Moore, J.C. George, and F. Brower. Passive acoustic monitoring in the western Beaufort Sea.
Ashjian, C., S. Okkonen, and R. Campbell. Mooring and broad-scale oceanography.
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Smultea, M., D. Fertl, D. Rugh, and C. Bacon. Summary of systematic bowhead surveys conducted in the U.S. Beaufort and Chukchi seas 1975-2008.

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Mocklin, J.A., K.E.W. Shelden, K.T. Goetz, L. Vate Brattström, and C.L. Sims. Aerial surveys of bowhead whales near Barrow in late summer 2011.
Berchok, C., K. Stafford, D. Mellinger, S. Nieukirk, S. Moore, J.C. George, and F. Brower. Passive acoustic monitoring in the western Beaufort Sea.
Ashjian, C., S. Okkonen, and R. Campbell. Mooring and broad-scale oceanography.
Baumgartner, M. Tagging and fine-scale oceanography.
George, J.C., G. Sheffield, and L. Horstmann. North Slope Borough research.

PRESENTATIONS:

2008:

Ashjian, C.J., R.G. Campbell, J.C. George, S.E. Moore, S.R. Okkonen, B.E. Sherr, and E.B. Sherr. 2008. Environmental variability and bowhead whale distribution on the Alaskan Beaufort Shelf near Barrow, AK. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2008, Anchorage, Alaska.

Ashjian, C.J., S.R. Braund, R.G. Campbell, J.C. George, S.E. Moore, S.R. Okkonen, B.F. Sherr, and E.B. Sherr,. 2008. Environmental variability and bowhead whale distribution on the Alaskan Beaufort Shelf near Barrow, AK. Oral presentation. 2008 Mar 6 Ocean Sciences Meeting, American Geophysical Union, the American Society of Limnologers and Oceanographers, and The Oceanography Society, Orlando, FL.

Ashjian, C.J. 2008. Episodic Upwelling of Zooplankton within a Bowhead Whale Feeding Area near Barrow, AK. Oral presentation. 2008 Oct 20: MMS Alaska OCS Region Eleventh Information Transfer Meeting, Anchorage, AK.

Ashjian, C.J. 2008. Climate Variability, Oceanography, Bowhead Whale Distribution, and Iñupiat Subsistence Whaling near Barrow, AK. Oral presentation. 2008 Nov 5: Symposium on Arctic Sea Ice and Climate, Woods Hole, MA.

Goetz, K.T., D.J. Rugh, and J.A. Mocklin. 2008. Aerial Surveys of Bowhead Whales in the Vicinity of Barrow, Alaska, August-September 2007. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2008, Anchorage, Alaska.

Mocklin, J.A., D.J. Rugh, S.E. Moore, K.J. Raedeke, R.P. Angliss, and W.R. Koski. 2008. Bowhead whale feeding behavior as evidenced in aerial photography. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2008, Anchorage, Alaska.

Okkonen, S., C.J. Ashjian, and R.G. Campbell. 2008. Intrusion of warm Bering/Chukchi waters onto the shelf in the Western Beaufort Sea. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2008, Anchorage, Alaska.

2009:

Ashjian, C.J., R.G. Campbell, J.C. George, S.E. Moore, S.R. Okkonen, B.F. Sherr, and E.B. Sherr. 2009. Impact of inter-annual variability in ocean conditions on bowhead feeding near Barrow Alaska. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2009, Anchorage, Alaska.

Koski, W.R., D.J. Rugh, J. Mocklin, K. Goetz, K. Trask, and J.C. George. 2009. Calibration of bowhead whale measurements from photographs using over-land and over-water calibration targets. Poster presented at the Alaska Marine Science Symposium. January 20-23, 2009, Anchorage, Alaska.

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Heimlich, S.M., D.K. Mellinger, S.L. Nieukirk, H. Klinck, K.M. Stafford, S.E. Moore, and P.J. Stabeno. 2009. Detecting bowhead whale sounds in the Beaufort Sea: Confounding sounds in a cacophony of noise. Poster presented at the 2009: Acoustical Society of America, 157th Meeting, May 18-22, 2009, Portland, Oregon.

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Mocklin, J., D. Rugh, and S. Moore. 2010. Using aerial photography to investigate evidence of feeding by bowhead whales. Oral presentation. 2010 Jan 18-22: Alaska Marine Science Symposium, Anchorage.

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Smultea, M., D. Rugh, and D. Fertl. 2010. Review of systematic surveys involving bowhead whales in the U.S. Beaufort and Chukchi seas 1975-2009. Poster presentation. 2010 Jan 18-22: Alaska Marine Science Symposium, Anchorage.

Stafford, K.M., C.L. Berchok, D.K. Mellinger, and S.E. Moore. 2010. Ambient noise in the Alaskan Beaufort Sea 2007-2009. Poster presentation. 2010 Jan 18-22: Alaska Marine Science Symposium, Anchorage.

Ashjian, C.J., R.G. Campbell, S.R. Okkonen, B.F. Sherr, and E.B. Sherr. 2010. Year-to-year variability of ocean biology across Barrow Canyon and the western Beaufort Shelf: 2005-2009. Oral presentation. 2010 Feb 22-26: AGU/ASLO Ocean Sciences Meeting, Portland, Oregon

Okkonen, S.R., C.J. Ashjian, and R.G. Campbell. 2010. Year-to-year variability of late summer hydrography across Barrow Canyon and the western Beaufort Shelf: 2005-2009. Poster presentation. 2010 Feb 22-26: AGU/ASLO Ocean Sciences Meeting, Portland, Oregon

Baumgartner, M.F., and T. Hammar. 2010. Using a new short- term dermal attachment tag to study bowhead whale foraging ecology in the western Beaufort Sea. Poster presentation. 2010 Feb 22- 26: AGU/ASLO Ocean Sciences Meeting, Portland, Oregon

Ashjian, C.J., S.R. Braund, R.G. Campbell, J.C. George, J.A. Kruse, W. Maslowski, S.E. Moore, C.R. Nicolson, S.R. Okkonen, B.F. Sherr, E.B. Sherr, and Y.H. Spitz. 2010. Environmental Variability, Bowhead Whale Distributions, and Iñupiat Subsistence Whaling near Barrow, AK. Oral Presentation. 2010 Mar 16-19: International State of the Arctic Meeting, Miami, FL

Okkonen, S.R., C.J. Ashjian, and R.G. Campbell. 2010. Sea ice as a tracer for circulation features associated with the Barrow area Bowhead whale feeding hotspot. Poster presentation. 2010 Dec 16: American Geophysical Union Fall Meeting.

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<u>OTHER:</u>

A Year in the Life of Bowhead Whales, 2013 Calendar
Okkonen, S. (editor), D.J. Jones, P. Alatalo, C. Ashjian, M. Baumgartner, R. Brower Sr., J. Clement-Kinney, R.G. Campbell, C. George, K. Goetz, Lara Horstmann, W. Maslowski, J. Mocklin, D. Rugh, L. Quakenbush, K. Stafford, and L. Vate Brattström

RELATED CONTENT [based on the Calendar but not funded by BOWFEST]:

Arctic Currents: A Year in the Life of the Bowhead Whale, animated film scheduled for release in Spring 2014. This animated film is being produced by the University of Alaska Museum of the North (Roger Topp, director; Stephen Okkonen, science editor). Although BOWFEST has not provided funding for the actual production of the film, BOWFEST-funded science content is incorporated in the film narrative. arcticcurrents.wordpress.com is a link to a blog that provides periodic updates on the film's development (written by film director Roger Topp).

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The Department of the Interior Mission

Protecting America's Great Outdoors and Powering Our Future

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.