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

2011 Annual Report

National Marine Mammal Laboratory
Alaska Fisheries Science Center (AFSC), NMFS, NOAA
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Cover Photo Credit:
BOWFEST aerial survey team
National Marine Mammal Laboratory/Alaska Fisheries Science Center
Bowhead off Barrow, Alaska
September, 2011
NMFS Permit No. 14245

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TABLE OF CONTENTS

BOWHEAD WHALE FEEDING ECOLOGY STUDY (BOWFEST) Annual Report for 2011

INTRODUCTION

The Bowhead Whale Feeding Ecology Study (BOWFEST) was initiated in May 2007 through an Interagency Agreement between the Bureau of Ocean Energy Management (BOEM) (formerly Minerals Management Service (MMS)) and the National Marine Mammal Laboratory (NMML). The study was conducted through grants and contracts awarded to scientists at Woods Hole Oceanographic Institute (WHOI), University of Rhode Island (URI), University of Alaska Fairbanks (UAF), University of Washington (UW), Oregon State University (OSU), as well as through employees at NMML. Field work was coordinated with the North Slope Borough (NSB), Alaska Eskimo Whaling Commission (AEWC), Barrow Whaling Captains' Association (BWCA), Alaska Department of Fish and Game (ADF&G), and BOEM. Marine mammal studies in 2011 were permitted under MMPA Scientific Research Permits: NMML Permit No. 14245 and Bruce Mate's Permit No. 369-1757-01.

This study focused on late summer oceanography and prey densities relative to bowhead whale (*Balaena mysticetus*) distribution over continental shelf waters between the coast and 72°N and between 152º -157º W, which is north and east of Point Barrow, Alaska. Aerial surveys and acoustic monitoring provided information on the spatial and temporal distribution of bowhead whales in the study area. Oceanographic sampling helped identify 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 will be better understood 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 program may help explain increased occurrences of bowhead whales feeding in the Western Beaufort Sea (U.S. waters), well west of the typical summer feeding aggregations in the Canadian Beaufort Sea. Understanding bowhead whale behavior and distribution is necessary to minimize potential impacts from petroleum development activities.

The following reports describe field work and the respective analyses conducted using BOWFEST funds in 2011. This was the final year of field work for this five year project.

SECTION I - AERIAL SURVEYS OF BOWHEAD WHALES NEAR BARROW IN LATE SUMMER 2011

Julie A. Mocklin, Kim E.W. Shelden, Kimberly T. Goetz, Linda Vate Brattström, and Christy L. Sims

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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 provide an estimate of temporal and spatial habitat use. In addition, aerial photography provides information on residence times (through reidentification of individual animals) and sizes of whales (through photogrammetry). Using a NOAA Twin Otter, scientists from the National Marine Mammal Laboratory (NMML) conducted aerial surveys from 25 August-17 September 2011 in the BOWFEST study area (continental shelf waters between 157° W and 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 18 sightings of bowheads (an estimated 68 whales) during 43.9 flight hours (63% of the 70 available flight hours; the survey was limited due to fog and high winds). Three Canon EOS-1DS Mark III cameras with Zeiss 85mm f 1/4 lenses were used for photography; all three cameras were secured in a forward motion compensating mount. Both a radar and laser altimeter provided altitude readings during each photograph pass over whales. A total of 263 pictures were taken of bowhead whales. Few (11%) of the bowhead sightings were described as feeding based on quick assessments by aerial observers. However, more precise records of how many whales were feeding as evidenced by mud on the body, open-mouths, and the presence of feces will be determined after examination of photographs. "Traveling" was the most commonly recorded behavior, indicating that bowheads were most likely migrating through the study area.

Introduction

Most bowhead whales of the Bering-Chukchi-Beaufort (BCB) stock migrate through the Barrow area in the spring (generally April to June) and fall (September and October) (Moore & Reeves, 1993). However, there have also been reports of whales feeding near Barrow in summer (July to September). BOWFEST was established to determine the scale of feeding near Barrow in the 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). In addition, the ecological relationship between feeding bowhead whales and relevant oceanographic parameters, such as bathymetry, currents, temperatures, and ice conditions are being examined to assess how oceanographic features might affect bowhead feeding aggregations by influencing prey distribution. Accordingly, the aerial survey component of BOWFEST was designed to document patterns and variability in the timing and locations of bowhead whales and to provide an estimate of temporal and spatial habitat use. In addition, aerial photography provides information on residence times (through reidentification of individual animals) and sizes of whales (through photogrammetry).

Methods

Study Area and Trackline Design

A trackline scheme was designed to provide different intensities in search effort across a two-part study area. The study area covers continental shelf waters from 157° W to 152° W and from the Alaska coastline to 72° N (Fig. I-1). The inner section of the study area (yellow) is 7,276 km^2, and the larger, outer section (green) is 12,152 km^2 (total = 19,428 km^2). In order to determine how to apportion survey effort within these two areas, five years of data (2000-2005) from the MMS-funded Bowhead Whale Aerial Survey Project (BWASP) were used to calculate bowhead whale density (whales per unit effort) within the BOWFEST study area. According to the BWASP data, the density of bowhead whales in the inner section was approximately six times greater than in the larger section of the study area. 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 of the study area to obtain a detection probability sufficient for determining relative densities of whales. Because oceanographic data become more difficult to collect with increased distance away from Barrow and much of the intent of BOWFEST was to compare ecological parameters relative to whale distribution, we decreased the effort for the larger section to focus on the inner area to allow more overlap between aerial observations of whales and other BOWFEST research efforts. Trackline orientation was based on the pre-determined oceanographic tracklines which ran in a northeasterly direction (66° True), approximately perpendicular to the coast. Line-transect methodology described in Buckland et al. (1993) was used to calculate total survey effort for each section of the study area based on available survey hours for this project. 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. This sampling strategy worked well in past years but in 2011, with better weather and a subsequent increase in survey flight time, all survey schemes were flown at least twice during the season (but days apart). The entire study area contained approximately 5,011 km of trackline: 3,554 km in the inner section and 1,457 km in the outer section (Fig. I-1). 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 survey line in the inner section of the study area (closer to Barrow) was determined by random selection.

In 2011, the first transect line was placed 1.5 km from the northwest corner of the inner and outer portions of the study area. We purposely used the same random value (1.5 km) to calculate placement of the first line in both sections of the study area in order to align the tracklines in the outer study area with the tracklines in the inner study area. This method, simplified flight logistics and minimized transit time between tracklines. Subsequent tracklines were parallel to the first trackline and spaced 2 km apart for the inner area and 8 km apart for the outer area (Fig. I-2).

In order to prevent overlap in survey effort due to tightly spaced tracklines, four sampling schemes were devised (Fig. I-2). 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 were spaced approximately 8 km and 32 km apart in the inner and outer sections of the study area, respectively (Fig. I-2).

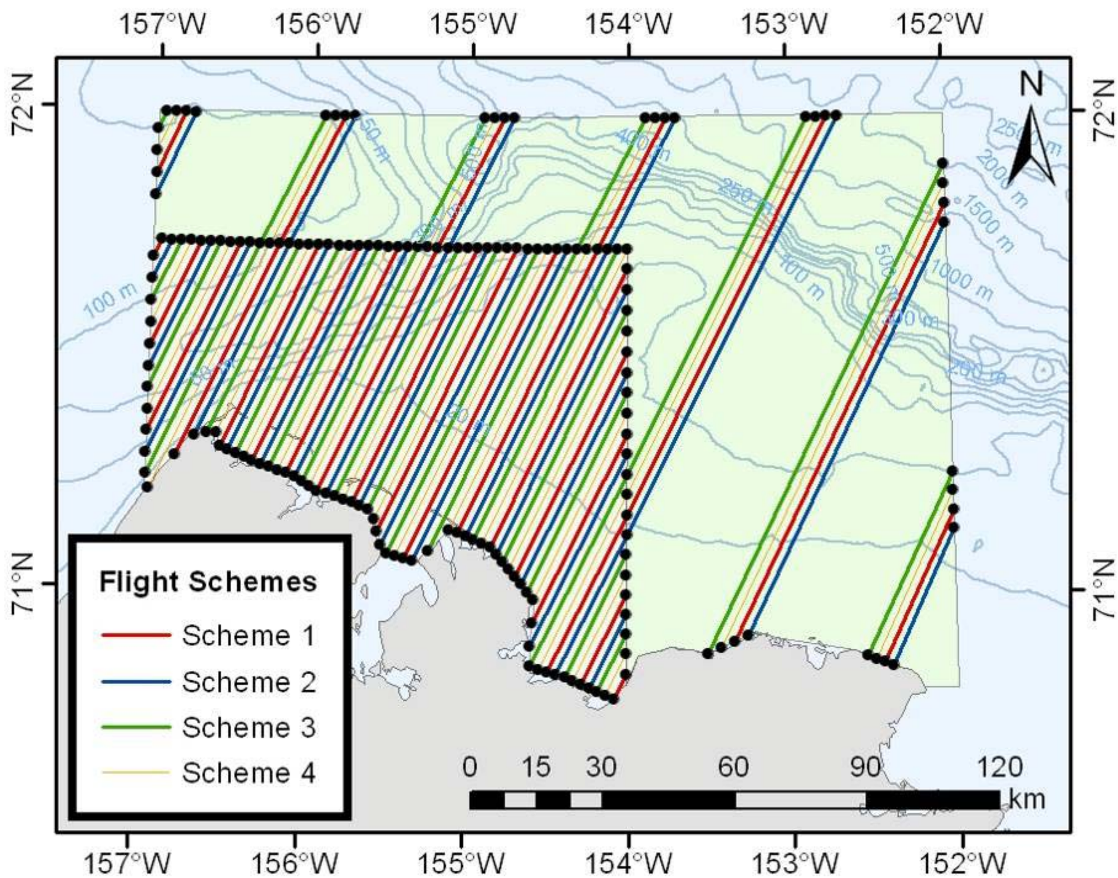

Figure I-1. *Two-part study area with tracklines designed for the 2011 BOWFEST aerial survey.*

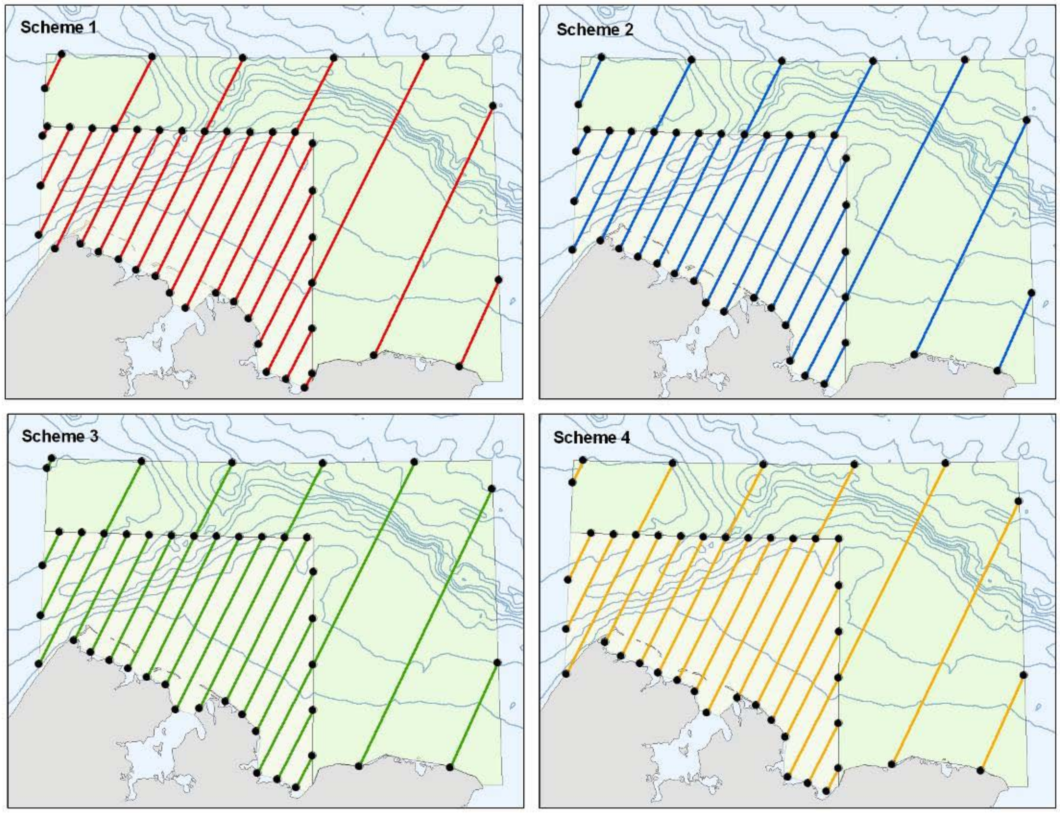

Figure I-2. *The four survey schemes for the 2011 BOWFEST aerial survey*.

Survey Protocol

BOWFEST aerial surveys were flown in a NOAA Twin Otter (*N56RF*), a plane with twin engines, high wings, and approximately 5 hours of flight endurance. In addition, the aircraft was equipped with two large bubble windows for the left and right observers and an open belly window/camera port for vertical photography. An intercom system allowed communication among observers, pilots, and data recorder while a VHF radio/satellite phone allowed communication with vessels, such as when reporting whale locations. Survey altitude was generally near 310 m (1000 ft); most aerial photographic passes were made at 213 m (700 ft), as allowed under NMML Permit No. 14245. The northeast/southwest tracklines were flown sequentially west to east (opposite the bowhead whales' autumn migration direction) in order to minimize the probability of resighting the same whale(s).

A laptop computer, interfaced with a custom-built aerial survey program, and a portable Global Positioning System (GPS – Garmin 76 CSx) recorded sighting position, weather, effort (on or off), crew position, and photo data into an Access database. Location data (latitude, longitude, speed, altitude, and heading) were automatically recorded every five seconds; all other data were entered manually, including each start and stop of a transect leg. 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. Observers used an inclinometer (0° = horizontal; 90° = straight down) to determine the searchable distance out each side of the aircraft. Visibility quality within the given inclinometer angle was documented as the best of one of five subjective categories from excellent to useless; for example, a record of "20° good" would mean that from the trackline out to 20° (0.8 km), sighting opportunities were good, and farther from the trackline (<20°) the visibility worsened and was not recorded. Areas along the trackline where observers rated visibility quality as poor or useless on both sides of the aircraft were considered off effort and, thus, unsurveyed. Date, time, observer, inclinometer angle, group size, and species were recorded for all marine mammals; in addition, for large whale sightings, observers reported calf number, travel direction, sighting cue, dominant behavior, group composition, reaction to plane, and number of nearby vessels.

Immediately upon sighting a marine mammal, each observer reported the group size and species to the data recorder. As the aircraft passed abeam of the sighting, the observer informed the recorder of an inclinometer angle and whether or not there was an observable reaction to the aircraft. The plane deviated from the trackline only when an observer reported an unidentified large cetacean sighting (in order to obtain an adequate identification). After a bowhead was reported, the trackline was typically completed before going off effort to begin photographic passes. This method allowed for a routine reporting of bowhead whales on the trackline and minimized confusion in reporting sightings while off-effort.

In addition to an autonomous radar altimeter (not connected to the pilot's altimeter) and GPS barometric altimeter, a laser altimeter (Universal Laser Sensor) was tested in 2010 and 2011, providing altitudes precise to within a few centimeters. The laser altimeter was mounted near the center camera and aimed vertically so that it could accurately determine the distance between the photogrammetric camera and a target.

Photographic Protocol

Three Canon EOS-1DS Mark III cameras with Zeiss 85mm f 1/4 lenses were used simultaneously over an open belly port designed for vertical photography (Fig. I-3A). Lenses were focused to infinity and taped to impede rotation. The cameras were housed in a Forward Motion Compensation (FMC) mount which uses a rocker mechanism to counter the forward velocity of the relative ground speed. The 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-3B). The cameras were fired using a custom built data acquisition system that automated the retrieval of data including altitude, time of camera firing, frame number, and focal length of the camera lens. Immediately prior to a whale appearing beneath the plane, a keystroke on the computer triggered the camera to continuously fire so that each consecutive image overlapped the previous photo by 60%, adjusted for altitude. All three cameras recorded RAW format, 21.0 megapixels (5616 x 3744) images and were set to shutter priority (1/1000 or faster shutter speed) with ISO at 400-800 sensitivity.

Several photographic passes were flown over each group until the observers felt that most whales in the area had been photographed. During each photographic pass, the observer provided a countdown to alert the photographer(s) when a whale was about to appear under the aircraft.

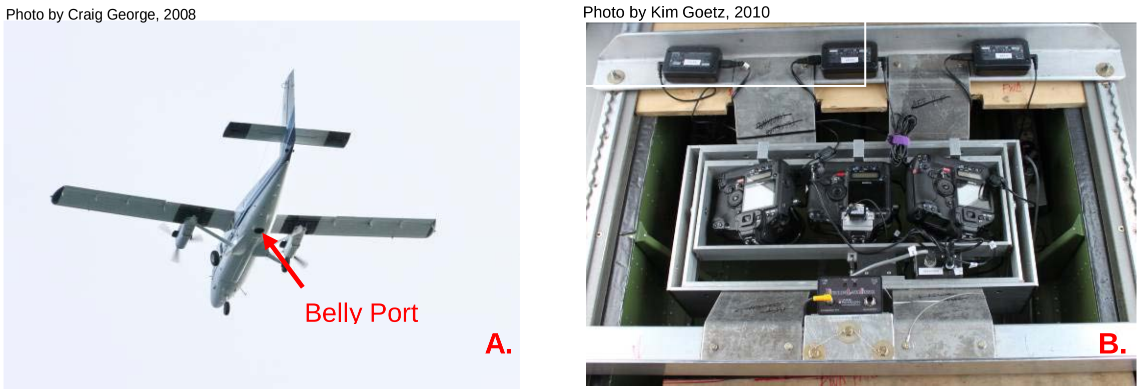

Figure I-3. *A) The NOAA Twin Otter (N57RF) with open belly port. B) The three Canon EOS-1DS Mark III cameras with 85 mm lens housed in the FMC mount.*

In addition to photographing bowhead whales, photographs were taken of calibration targets using the same camera system. The land target, provided by Craig George, North Slope Borough (NSB), consisted of painted 2" x 10" boards with precisely measured intervals that were visible at survey altitude (1000 ft) (Fig. I-4). The calibration target was laid out on an abandoned airstrip north of Barrow near the former Naval Arctic Research Lab's aircraft hangar.

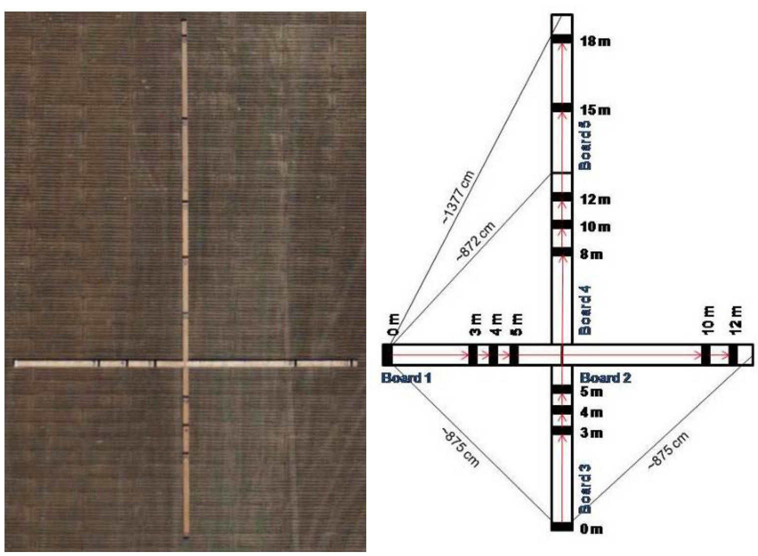

Figure I-4. *Aerial image (left) and diagram (right) of the land-based calibration target.*

To test the performance of the autonomous radar altimeter, laser altimeter, and GPS barometric altimeter, photographs of the calibration target were taken at 30 m (100 ft) intervals from 152 to 366 m (500 to 1200 ft). Since the lengths between marks on the targets are known precisely, altimeter readings can be corrected. This correction factor can then be applied to photographs of bowhead whales to provide more accurate body length estimates. Vertical photography removes angle as a variable when applying aircraft altitude to the calculation of distance between the camera and the target.

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 JPGs. Both the GPX file and the JPGs were used as inputs for RoboGEO so that the program could interpolate latitude and longitude and embed this position information into the exif metadata of each photograph. Since RoboGeo uses time 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 LGL for analysis of whale lengths.

Processing images for photo-identification of individual whales begins with cropping and labeling images into a standard format. These images are then archived in the large collections maintained by NMML and LGL. Each whale image is categorized according to identifiability, and the photo is quality-rated according to an established protocol (Rugh et al., 1998). All images will be compared to each other to determine if individual whales were photographed multiple times. Following this comparison, these whale images will be compared to others collected in previous years to establish when and where individual whales have been seen before.

Results

Survey Effort

Aerial surveys were conducted in the BOWFEST study area on 10 days between 25 August and 17 September 2011. On 11 of the possible 23 survey days, poor weather conditions precluded us from flying. On 2 other days, a "pilot down day" was scheduled to comply with NOAA regulations that pilots must have a "down day" every 7 days.

All flights were based out of Barrow, and flight times ranged from 0.8 to 5.6 hours in duration. Although 70 flight hours were originally scheduled for the project, inclement weather (fog, low ceilings, and high winds) on many days kept the aircraft grounded and only 43.9 hours were flown. Of the 40.22 hours spent on search effort over water, 24.7 hours (4670 km) were flown on systematic transects and 15.5 hours (3043 km) were flown searching off transects (i.e., transiting between transect lines, circling animals, or photographing whales) (Fig. I-5). An additional 0.8 hours were spent flying over and photographing calibration targets and 1.3 hours was spent deadheading without search effort (Table I-1). Only 0.2 hours were flown in poor or useless viewing conditions and, thus, were considered unsurveyed (Table I-1). These 0.2 hours does not take into consideration the numerous times we changed course, deviated from transects, or altered our elevation to avoid low ceilings, precipitation, or fog. Figure I-6 shows that only 58% of the survey effort was completed during relatively calm sea states (Beaufort $\leq$ 3).

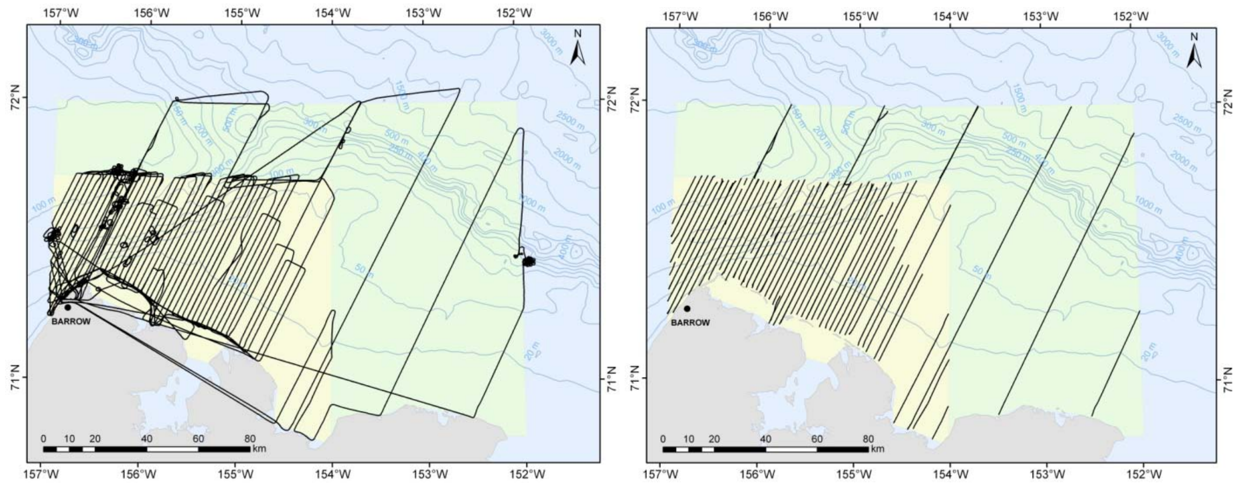

Figure I-5. *All search effort, including transect, circling, and photo effort (left) and dedicated transect effort (right) during the 2011 BOWFEST survey.*

Table I-1: *Survey effort (distance and time) for the 2011 BOWFEST aerial survey.*

EFFORT SUMMARY	DISTANCE (KM)	TIME (HRS)
On Effort - Trackline	4669.79	24.68
On Effort - Deadhead	2175.20	10.80
On Effort - Photo Mode	627.52	3.48
On Effort - Circling	240.60	1.26
Total On Effort	7713.11	40.22
Off Effort - Over Land	515.83	2.19
Off Effort - Bad Weather	33.87	0.17
Off Effort - Deadhead	308.78	1.31
Off Effort - Trackline	0.00	0.00
Total Off Effort	858.48	3.67
Calibrating Targets	136.10	0.76
Totals	**8571.59**	**43.89**

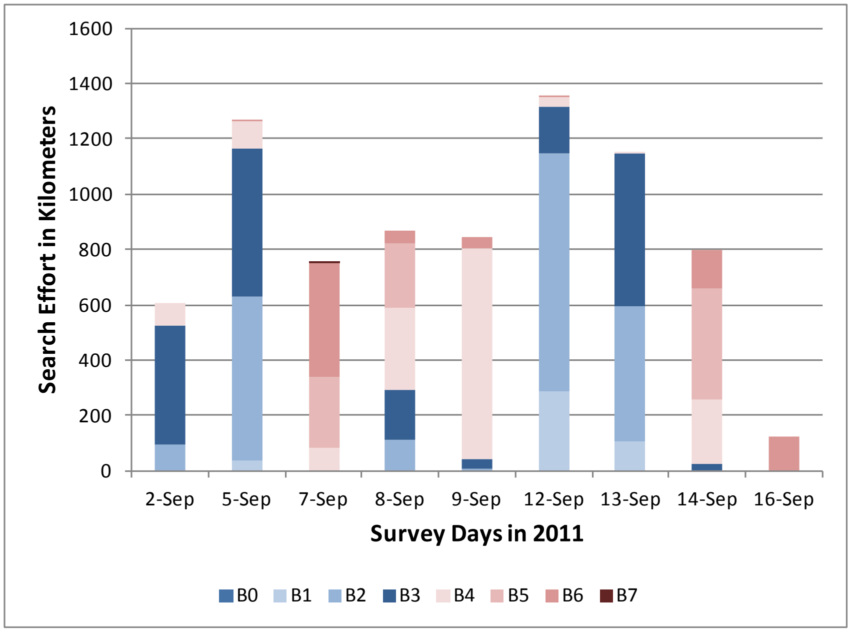

Figure I-6. *Aerial survey effort conducted under varying Beaufort sea states.*

All four of the devised survey schemes were flown during the 2011 BOWFEST survey. Approximately 721 km of transects were flown in Scheme 1 (58%) on 2, 9 and 16 September, and an additional 861 km were flown on effort while circling, photographing, or transiting between tracklines. Scheme 2 was flown during two flights on 5 and 12 September, covering 134% of the Scheme. We surveyed Scheme 3 on 7 and 13 September, completing 99% of the designated tracklines. Similarly, approximately 82% of Scheme 4 tracklines were flown on 8 and 14 September 2011 (Table I-2; Fig. I-7). Of the 5,011 km of designated trackline within the four schemes, approximately 93% were completed.

Table I-2: *Search effort per survey scheme in 2011.*

Flight Scheme	Off Transects km	Off Transects mins	On Transects km	On Transects mins	Transects Availible (km)	% Transects flown
1	860.8	264.2	721.1	228.5	1251.6	57.6
2	968.2	293.9	1677.0	529.7	1251.4	134.0
3	684.9	216.3	1243.0	397.1	1255.1	99.0
4	665.6	203.4	1028.6	325.7	1252.8	82.1
Totals	**3179.4**	**977.7**	**4669.8**	**1481.0**	**5010.9**	**93.2**

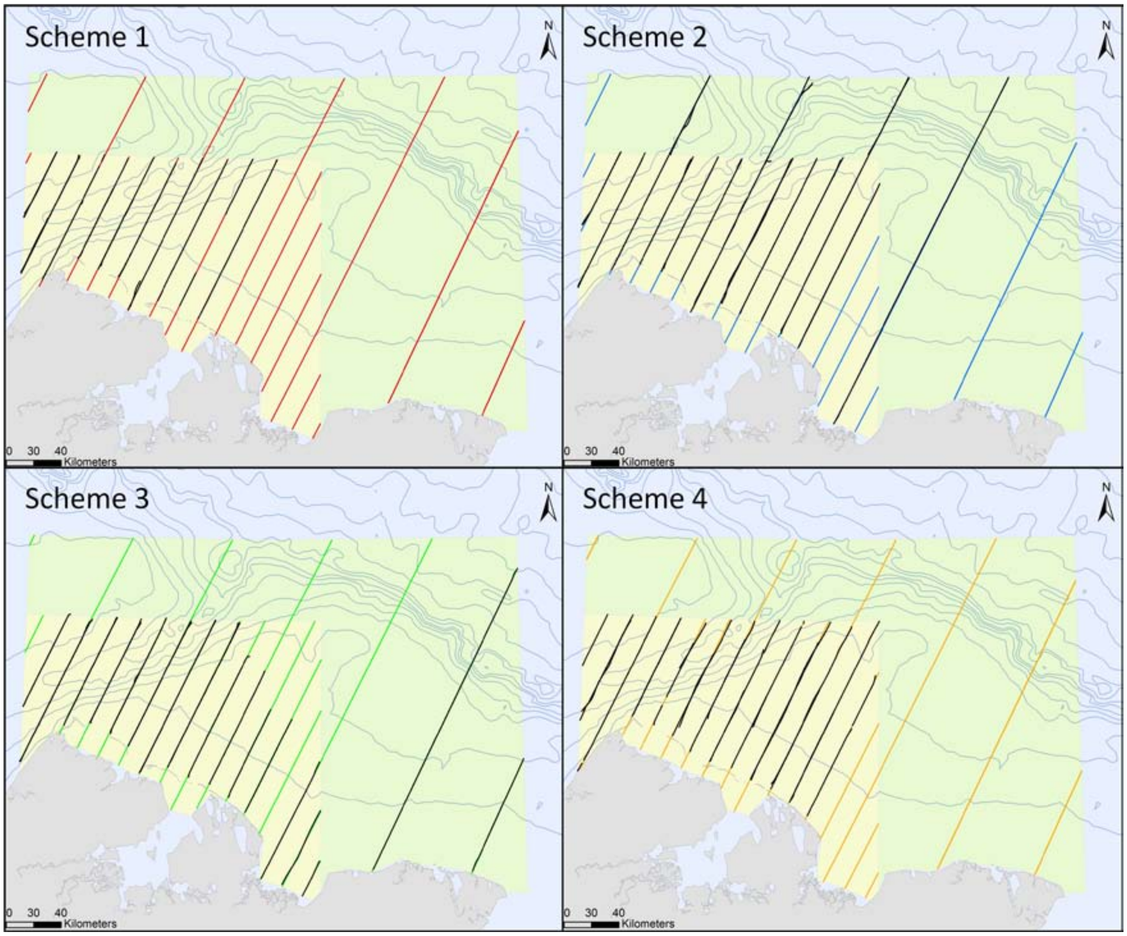

Figure I-7. *Tracklines flown (black lines) per survey scheme (colored lines) during the 2011 BOWFEST field season.*

Sighting Summary

There were 7 bowhead whale sightings (8 animals) seen on transect during the 2011 BOWFEST survey. An additional 11 sightings of bowheads (19 animals) were sighted while deadheading between designated tracklines and may be repeat sightings. After circling/photographing the bowheads, an additional 2 animals were counted on trackline and 39 additional animals were counted while off trackline, bringing the total number of bowheads sighted to 68 animals (Table I-3). Unlike the 2007 field season, when nearly all bowheads appeared to be feeding (as indicated by mud plumes and multiple swim directions), only 2 of the 18 bowhead sightings were positively identified as feeding in 2011. Examination of the photographs will later document how many bowheads had mud on their bodies, an indicator of probably feeding. Similar to 2008, 2009 and 2010, “traveling” was the most commonly recorded behavior, indicating that bowheads were most likely migrating through the study area, perhaps feeding along the way. The highest count of bowhead whales was on 13 September when we had 4 sightings of 31 animals (Fig. I-8).

Table I-3: *Summary of marine mammal sightings and numbers of marine mammals counted during the 2011BOWFEST aerial survey. The bowhead whale count with asterisks (*) include whales seen while the aircraft was circling and not on transects.*

Common Name	Scientific Name	Sightings	Count
Bowhead Whale	*Balaena mysticetus*	18	27(68*)
Gray Whale	*Eschrichtius robustus*	26	34
Beluga Whale	*Delphinapterus leucas*	95	460
Bearded Seal	*Erignathus barbatus*	21	22
Polar Bear	*Ursus maritimus*	6	6
Unid Large Cetacean		6	9
Unid Small Cetacean		1	1
Unid Seal		116	236
Totals		**289**	**795(836*)**

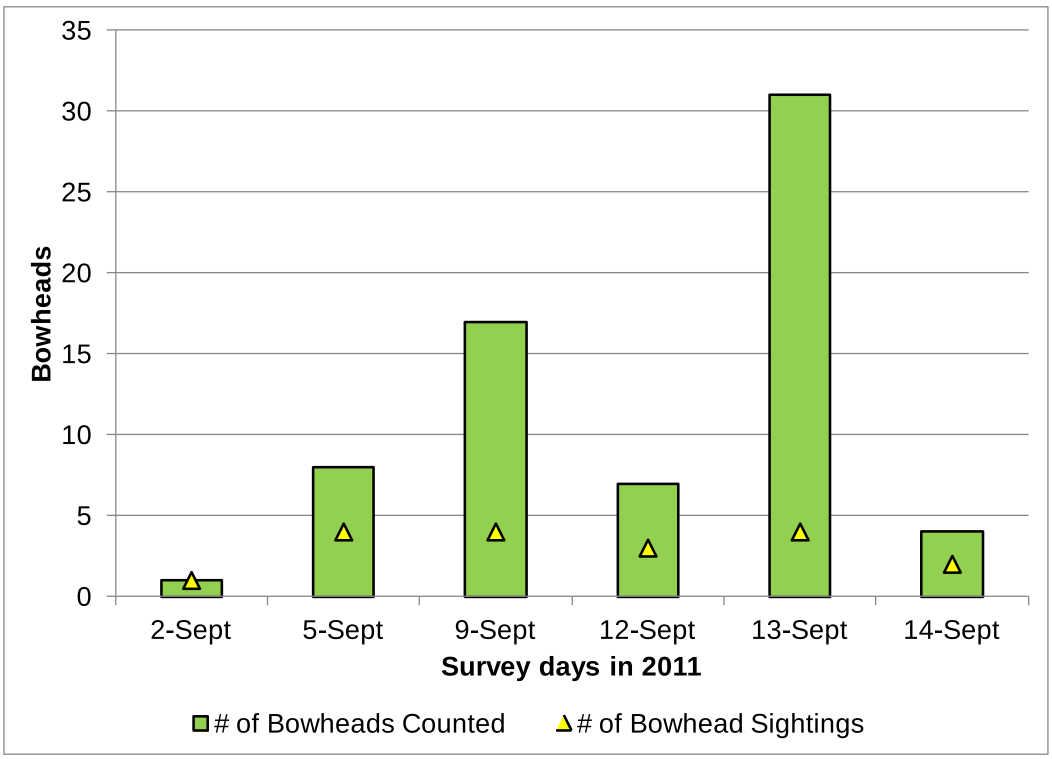

Figure I-8. *Number of bowhead sightings (yellow triangles) and bowheads counted (green bars) per survey day. Counts may include resightings between days.*

In addition to bowhead whales, there were 26 sightings of gray whales (34 whales), 95 sightings of beluga whales (460 animals), 21 sightings of bearded seals (22 seals), 6 polar bear sightings (6 animals), 116 sightings of unidentified seals (236 animals), 6 unidentified large cetacean sightings (9 animals), and 1 sighting of 1 unidentified small cetacean (Fig. I-10). The frequency of high sea states in combination with the relatively high survey altitude (1000 ft) made identifying seals to species difficult, resulting in a large number of unidentified seals.

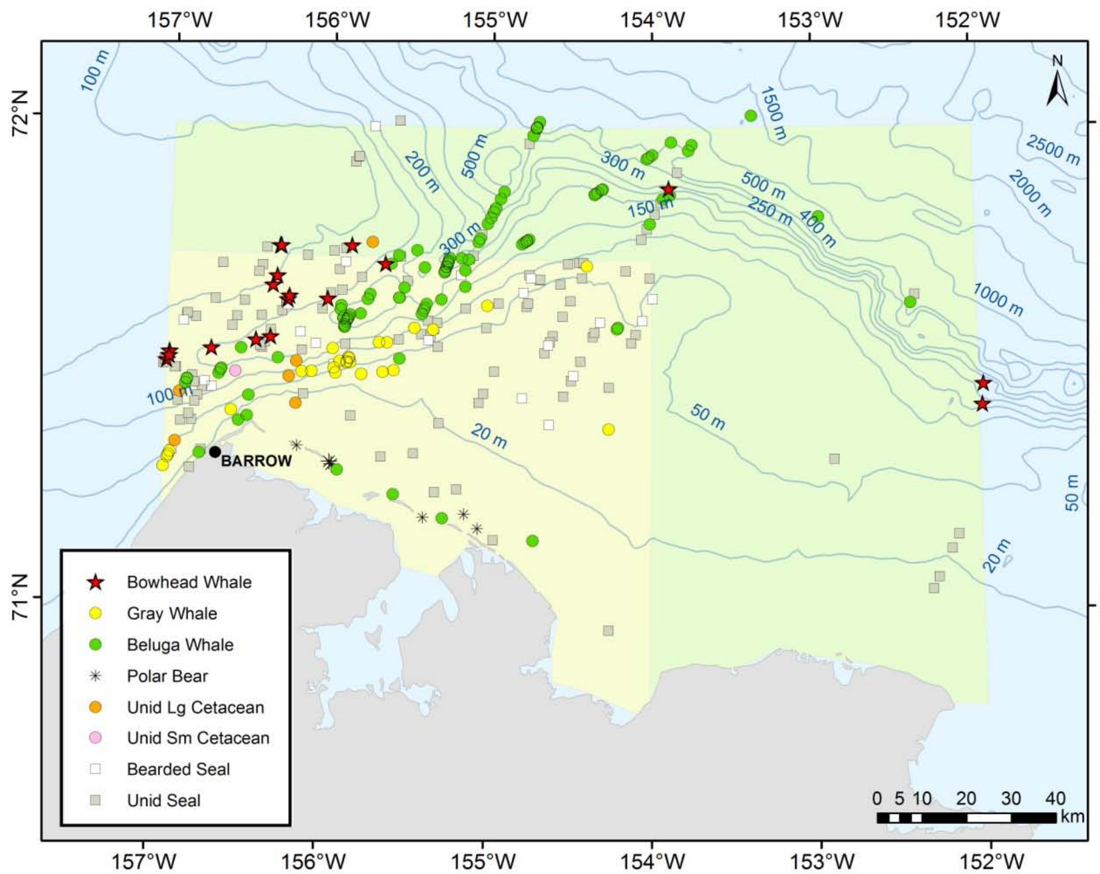

__Figure I-10.__ Map showing locations of all marine mammal sightings during the 2011 BOWFEST field season.

Photographic effort

Bowhead whales were photographed on 5 of the 10 survey days. In total, we spent 3.5 hours photographing bowheads, resulting in 263 pictures (313 bowhead images) from all three cameras (Table I-4; Fig. I-11). An additional 43 pictures were taken of the calibration target. Although there were 313 bowhead whales counted in the photographs, the number of unique bowhead whales will be less after accounting for duplicate images.

Table I-4: *Summary of pictures taken during the 2011 BOWFEST aerial survey field project.*

Date	Bowhead Pictures	Bowhead Images*	Calibration Pictures
2-Sep	2	2	43
5-Sep	19	19	0
9-Sep	54	68	0
12-Sep	16	20	0
13-Sep	172	204	0
Total	**263**	**313**	**43****

*Total number of individual bowheads counted from all pictures (e.g., one picture may have 2 or more bowhead images). **Does not include photos taken from the initial test flight.

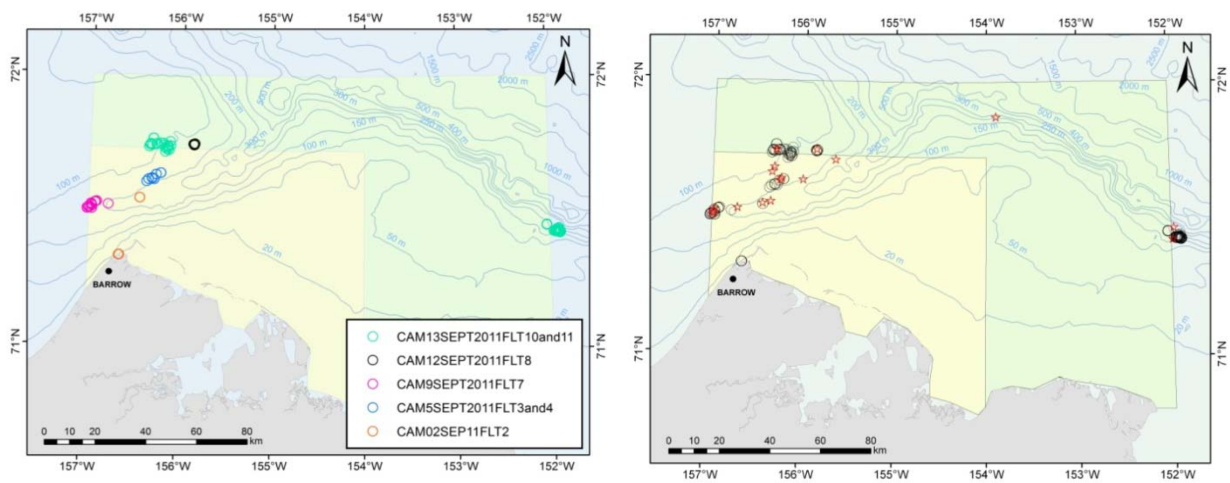

Figure I-11. *Locations where bowhead whales were photographed per survey day in the left figure; and photographic locations (black circles) relative to all bowhead sightings made during these aerial surveys in 2011 (red stars) in the right figure.*

Preliminary results from tests of the radar, laser and GPS barometric altimeters were promising; we hope to publish results from this comparison in the future. The tests showed high agreement among all three altimeters (no significant difference) (Fig. I-12). This is important for future aerial photographic survey work because we currently rely upon an old, expensive, borrowed radar altimeter. It would be cost prohibitive to replace the radar altimeter if we needed to, so continuing this analysis is imperative to ensure we have found a suitable replacement in the laser altimeter.

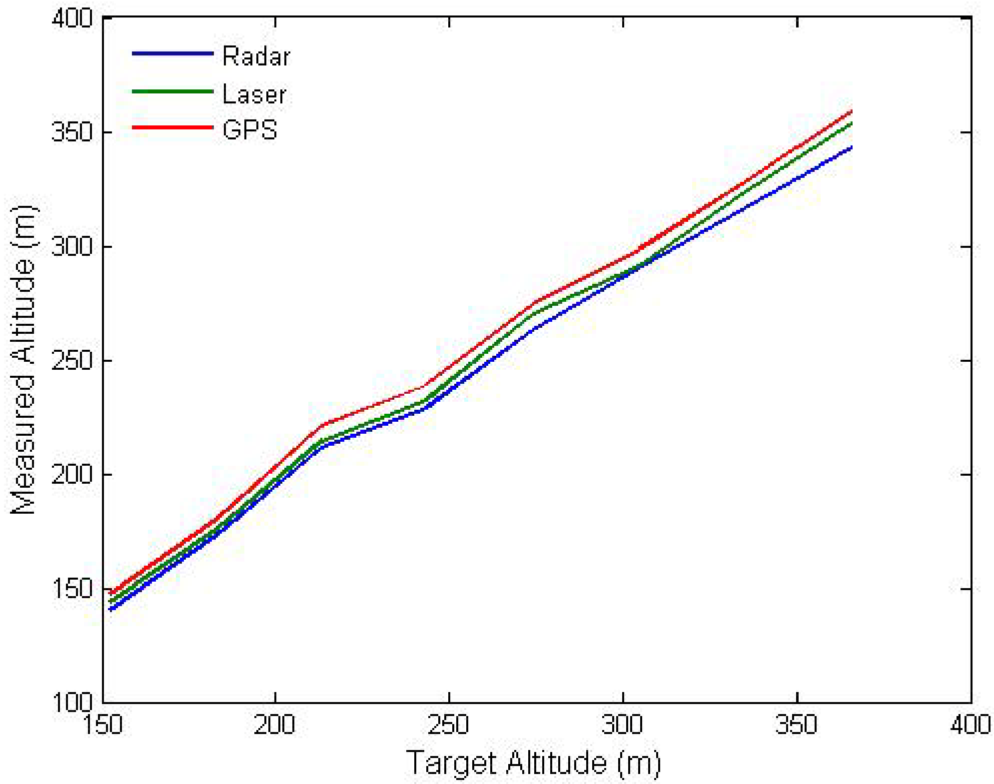

Figure I-12. *Graph showing close agreement among all three altimeters (radar – blue line, laser – green line, and GPS barometric altimeter – red line) tested during the 2011 BOWFEST field season.*

2011 Daily Reports

August 25

Aerial observers Shelden, Vate Brattström and Goetz arrived in Barrow. The aircraft (*N56RF*) also arrived piloted by Fritzler and Fuenmayor. The aerial photogrammetric equipment, such as the triple-camera FMC mount, autonomous altimeter, laser altimeter, and interfacing equipment, was installed in Anchorage prior to the survey.

August 26

Shelden, Vate Brattström and Goetz went out to the air strip to set-up and measure the calibration targets. Flight 1 occurred later in the day and was a calibration flight only. The radar and laser altimeters were not functioning properly and the cameras had issues so no useable data were collected and the experiment had to be repeated.

August 27

No flight due to fog. Vate Brattström and Goetz returned to the airstrip and re-measured the targets to ensure they hadn't moved.

August 28

No flight due to fog.

August 29

No flight due to fog.

August 30

Mandatory pilot down day, but also fog and high winds.

August 31

No flight due to fog.

September 1

No flight due to fog.

September 2

Flight 2. We began flying scheme 1 but a fog bank prevented us from surveying the northern reaches of the inner study area and the eastern portion. Viewing conditions were generally good with Beaufort 2-4. There was one sighting of a bowhead whale. In addition we also completed photographic passes over the calibration target.

September 3

No flight due to fog and low ceilings.

September 4

No flight due to fog and low ceilings.

September 5

Flight 3 and 4. We were able to complete most of the scheme 2 tracklines in the inner box including several lines in the outer box during the second flight of the day. Conditions were generally good with sea states ranging from Beaufort 1-4. There were 4 bowhead whale sightings.

September 6

Mandatory pilot down day; Sims arrived in Barrow.

September 7

Flight 5. We were able to complete most of the scheme 3 tracklines in the inner box Conditions were fair to poor, with sea states ranging from Beaufort 4-6. No bowhead whales were seen. Goetz left Barrow.

September 8

Flight 6. We were able to complete most of the scheme 4 tracklines in the inner box. Conditions were good to poor, with sea states ranging from Beaufort 2-6. No bowhead whales were seen. Snow showers and low clouds forced us to deviate from tracklines periodically.

September 9

Flight 7. We were able to complete most of the scheme 1 tracklines in the inner box. Conditions were good to fair, with sea states ranging from Beaufort 3-6. There were 4 bowhead whale sightings. Snow showers and low clouds forced us to deviate from tracklines periodically. Mocklin arrived in Barrow.

September 10

High winds and small craft advisory were forecasted so we planned a pilot down day. Shelden left Barrow.

September 11

No flight due to high winds, including a small craft advisory.

September 12

Flight 8 and 9. We were able to complete most of the scheme 2 tracklines in the inner box including several lines in the outer box during the second flight of the day. Conditions were excellent to fair with sea states ranging from Beaufort 1-3. There were 3 bowhead whale sightings.

September 13

Flight 10 and 11. We were able to complete most of the scheme 3 tracklines in the inner box including several lines in the outer box during the second flight of the day. Conditions were excellent to fair with sea states ranging from Beaufort 1-3. There were 3 bowhead whale sightings.

September 14

Flight 12. We were able to complete most of the scheme 4 tracklines in the inner box but most tracklines were truncated due to high sea states offshore. Conditions ranged from good to poor with sea states ranging from Beaufort 3-6. There were 2 bowhead whale sightings.

September 15

High winds were forecasted and a small craft advisory was in effect so we planned a pilot down day.

September 16

Flight 13. We were able to complete only parts of 2 tracklines in scheme 1; we had to deviate often due to high sea states of Beaufort 6 as well as low clouds. Conditions were bad throughout the survey area so the flight was terminated early. No bowhead whales were seen.

September 17

No flight due to high winds, including a small craft advisory. Mocklin, Vate Brattström, and Sims returned to Seattle.

Discussion

Bowhead whales are often seen in the Barrow area during the summer; however, sightings are relatively rare here compared to the eastern Beaufort Sea where most of the BCB stock is known to spend the summer (Moore and Reeves, 1993). Since the BCB stock of bowhead whales begins migrating westward out of the eastern Beaufort Sea in early September, we expected to find more bowheads towards the end of the BOWFEST field season than in the beginning. Although our aerial sighting data suggested an increase in bowhead sightings through the 2008 field season, the reverse was true in 2007 when the only bowheads we encountered were in the first two days of the survey (23 and 24 August) and none were seen after that (as late as 11 September). In 2009, there was no suggestion of an increase in sightings through the field season. Similarly, in 2010, the number of bowheads sighted varied throughout the survey and there was no obvious trend in sighting rates. In 2011 our sighting rates were consistent through the month of September but the number of bowhead whales did increase during the second and third week of the month.

Although most bowhead whales appeared to be feeding in 2007 as evidenced by mud plumes, open mouths, and the presence of feces, the bowheads seen in 2008, 2009, 2010, and 2011 were predominantly traveling through the area. Observers reported only a few clear indications of feeding whales; however, photographic examination provides a more exacting documentation of how many whales were muddied from feeding. In 2007-2009, the majority of bowhead whale sightings were located at or near the 20 m isobaths. However, in 2010, bowheads were scattered throughout the inner section of the survey area and in 2011 the whales were all seen in deeper water in excess of 100m.

There is substantial evidence that bowheads feed during the fall migration. Although past studies (Lowry and Frost, 1984; Carroll et al., 1987) concluded that bowheads feed only occasionally during the spring migration, recent research has confirmed that bowheads are feeding frequently during both the spring and fall migrations (Lowry et al., 2004; Mocklin, 2009). Based on Traditional Ecological Knowledge (TEK), aerial observations, and bowhead stomach contents, Lowry and Frost (1984) identified two feeding areas in U.S. waters; one between the demarcation line at the U.S./Canadian border and Barter Island, and another between Pitt Point and Point Barrow. Data collected from the stomach contents of bowheads taken near Point Barrow indicate that feeding is a major activity: food was found in the stomachs of three-quarters of the animals examined in September-October and one-third of those taken in the spring (Lowry et al., 2004). Photographic evaluations support seasonal feeding variation as well. Mocklin's (2009) examination of bowhead photos showed evidence of feeding in 61% of images taken in spring compared to feeding evidence in 99% of images taken in late summer. Thus, feeding appears to be both more extensive and more frequent during the fall migration than the spring migration.

To learn more about the consistency of bowhead feeding aggregations seen near Barrow during the summer, photographs collected during the BOWFEST aerial survey will be evaluated for recognizable individuals. Aerial photography has been used over the past three decades to identify individual bowhead whales (Koski et al., 2007), and to date there are over 18,000 whale images in the catalog held both at LGL in Ontario and at NMML in Washington. Reidentifiying bowhead individuals provides information on: 1) residence times (duration of individuals within the study area from day to day); 2) behavior (individual whales seen feeding or not feeding on different days, and associations between certain individuals); 3) local abundance (by using mark/recapture techniques for a group of whales photographed across several days); 4) the probability of returning to the area (when whales are recognized across several years). Furthermore, resightings of bowheads in this study can provide information applicable towards survival analysis (Zeh et al., 2000), calving intervals (Rugh et al., 1992; Miller et al., 1992), growth rates (Koski et al., 1992), population dynamics (whale lengths are an indicator of maturity classes) (Koski et al., 2006), and stock structure (via resighting rates within and between various seas) (Rugh et al., 2003; 2009). The data collected from photographic images during the BOWFEST aerial surveys will help evaluate the overall health of the BCB population of bowhead whales. Information on bowhead distribution and habitat use within the BOWFEST study area will provide a foundation for assessing the potential impact of industrial development on bowhead whales near Barrow.

Acknowledgments—The Bureau of Ocean Energy Management (formally Minerals Management Service) funded the BOWFEST program; in particular, Chuck Monnett provided guiding support and inspiration to get this large research program underway and Jeff Denton saw it through to completion. NOAA's Aircraft Operation Center provided the aircraft and crew. Our pilots in 2011, Bradley Fritzler and Francisco Fuenmayor, filled a critical role in keeping the aircraft at the preferred altitude while flying intricate patterns over moving whales. Sean Campbell provided mechanical support for the aircraft. Wayne Perryman loaned us a radar altimeter and provided technical advice, and Don LeRoi rented us the FMC mount and assisted with the camera mount installation. Craig George provided the calibration target. This study was conducted under MMPA Scientific Research Permit No. 14245.

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SECTION II - PASSIVE ACOUSTIC MONITORING IN THE WESTERN BEAUFORT SEA

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Background and Introduction

For 2011, there were three components to the field work: long-term AURAL (Autonomous Underwater Recorder for Acoustic Listening, Multi-Électronique, Rimouski, QC, Canada) recorders on deep moorings along the 100 m isobath, a short-term EAR (Ecological Acoustic Recorder, Oceanwide Science Institute, Honolulu, HI) recorder deployed on a UAF mooring frame (Okkonen), and short-term EAR recorders deployed on movable moorings.

AURAL Recorders

The long-term BOWFEST mooring work was completed during the BOEM funded CHAOZ (Chukchi Acoustics, Oceanography, and Zooplankton study) cruise aboard the F/V *Mystery Bay.* Two days of sea time were paid for by BOWFEST to accomplish these mooring operations.

All AURAL recorders were set to record at a sampling rate of 8192 kHz on a duty cycle of 6 minutes on / 14 minutes off in order to record for an entire year. This decrease in recording time was necessary because of a decrease in capacity of the D-cell batteries used. The three BOWFEST funded AURAL and the Kate Stafford (APL-UW) NSF funded AON AURAL moorings were all successfully retrieved and new moorings redeployed at the same four locations (Fig. II-1 & Table II-1, BF11_AU_01-03 & AON 2011). The AURALs have all been shipped back to Seattle and analyses of the data have begun.

As in 2010, we attempted to recover, by dragging, the three BOWFEST moorings lost off Barrow Canyon during the 08-09 season (Fig. II-1 & Table II-1). Since we were certain these moorings were stuck in the mud, we decided to add a modified scallop dredge into our dragging hook configuration. Figure II-2 shows this dredge (designed by Jessica Crance, NMML) which functions as a large rake along the seafloor. Unfortunately only one of the three moorings responded to the acoustic signal we sent. It appears the other two moorings have released from their anchors and are now long gone. We tried dragging for the one mooring that responded for about eight hours, but did not manage to get it. However, we hope that the ROV on either the R/V *Western Wind* or the R/V *Norseman II* (both run by Olgoonik Fairweather) will be able to recover this mooring this fall. We have provided them with mooring diagrams and the last fixed position. A few hours will again be allocated during the 2012 CHAOZ cruise to drag for the mooring.

We also tried dragging for Kate Stafford's lost NOPP mooring further east of the BOWFEST study area. She contributed one sea day for this attempt and for the redeployment of her AON mooring. This mooring could actually be seen on the ship's fish finder, and we did snag something once for a brief moment, but again had no luck retrieving it.

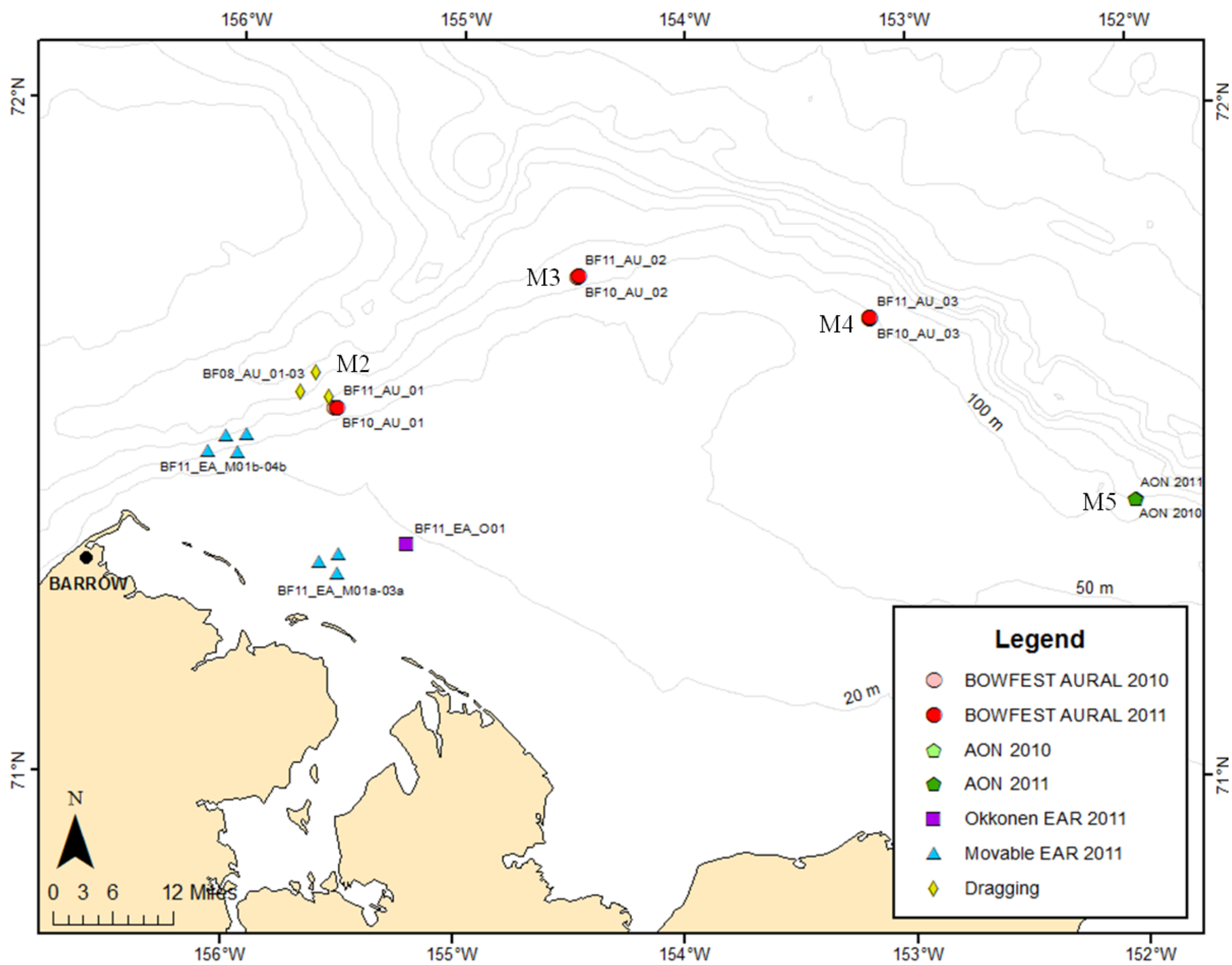

Figure II-1. *Locations of passive acoustic recorders during the 2011 BOWFEST field season. The AON moorings are external to the BOWFEST project, but their data will be included in our analysis. The M# labels represent mooring clusters, which simplifies inter-annual comparison.*

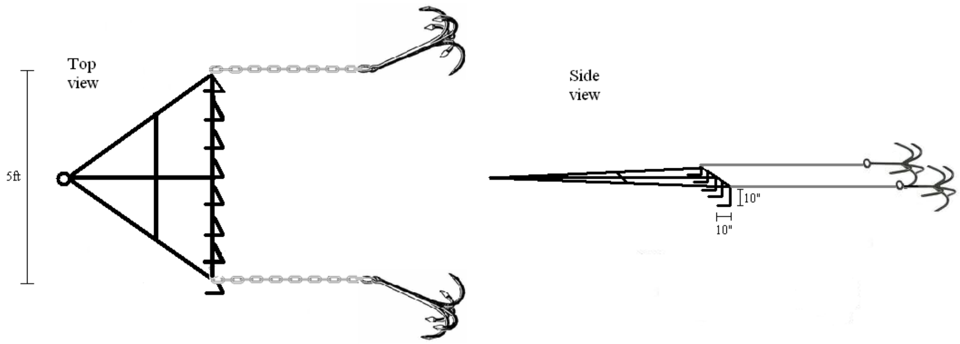

Figure II-2. *Modified dragging hook configuration for 2011. Otherwise known as the Crance Rake of Doom.*

Table II-1: *Passive acoustic recorder moorings deployed, retrieved, or dragged for during the 2011 BOWFEST field season.*

Mooring	Latitude	Longitude	Water depth (m)	Deployment date	Sampling Rate (Hz)	Duty Cycle (min on/ min off)	Retrieval date	Recorder Type	Comments
BF08_AU_01	71.5749	-155.7104	110	8-Aug-08	8192	9/20	-	AURAL	On side in mud
BF08_AU_02	71.6032	-155.6469	173	8-Aug-08	8192	9/20	-	AURAL	Lost
BF08_AU_03	71.5681	-155.5878	118	13-Aug-08	8192	9/20	-	AURAL	Lost
BF10_AU_01	71.5504	-155.5585	70	8-Sep-10	8192	9/11	28-Aug-11	AURAL	
BF10_AU_02	71.7505	-154.4830	100	12-Sep-10	8192	9/11	29-Aug-11	AURAL	
BF10_AU_03	71.6880	-153.1740	105	12-Sep-10	8192	9/11	29-Aug-11	AURAL	
NOPP 2010	71.4120	-152.0065	105	15-Sep-10	8192	9/21	29-Aug-11	AURAL	
BF11_AU_01	71.5513	-155.5512	73	28-Aug-11	8192	6/14	-	AURAL	
BF11_AU_02	71.7512	-154.4800	104	29-Aug-11	8192	6/14	-	AURAL	
BF11_AU_03	71.6887	-153.1753	108	29-Aug-11	8192	6/14	-	AURAL	
NOPP 2011	71.4120	-152.0112	179	29-Aug-11	8192	9/21	-	AURAL	
BF11_EA_O01	71.3512	-155.2292	19	18-Aug-11	12.5k	60/5	30-Sep-11	EAR	Okkonen Mooring
BF11_EA_M01	71.3210	-155.6111	-	29-Aug-11	40k	30/8	12-Sep-11	EAR	Movable Array #1
BF11_EA_M02	71.3342	-155.5314	-	29-Aug-11	40k	30/8	12-Sep-11	EAR	Movable Array #1
BF11_EA_M03	71.3051	-155.5327	-	29-Aug-11	40k	30/8	12-Sep-11	EAR	Movable Array #1
BF11_EA_M01	71.4826	-156.1169	-	14-Sep-11	40k	30/8	29-Sep-11	EAR	Movable Array #2
BF11_EA_M02	71.5066	-156.0391	-	14-Sep-11	40k	30/8	29-Sep-11	EAR	Movable Array #2
BF11_EA_M03	71.5091	-155.9470	-	14-Sep-11	40k	30/8	29-Sep-11	EAR	Movable Array #2
BF11_EA_M04	71.4822	-155.9888	-	14-Sep-11	40k	30/8	29-Sep-11	EAR	Movable Array #2/ Lost

Short-term EAR Moorings

Again we are grateful to Steve Okkonen for agreeing to attach our EAR recorder (BF11_EA_O01) to one of his short-term mooring frames. The recorder was deployed from mid-August through late-September (Fig. II-1, Table II-1), and recorded at a sampling rate of 12.5 kHz on a duty cycle of 60 minutes on/4.9 minutes off.

Frederick Brower (NSB) again led the movable mooring operations in 2011. He was able to make one deployment of a four-unit array and one deployment of a three-unit array (BF11_EA_M01-03a & BF11_EA_M01-04b: Fig. II-1, Table II-1). All units recorded on a duty cycle of 30 min on/7.8 min off at a sampling rate of 40 kHz. He again used rock-filled burlap sacks in place of the 80 pound chain link anchor this season to save on shipping costs.

Data Analysis and Synthesis

[Note: Because deployment locations and array configurations of the AURALs have changed slightly since the beginning of BOWFEST, we are framing the results in terms of mooring clusters (indicated by the 'M' labels on Figure II-1)].

David Mellinger and Sara Heimlich (CIMR/OSU) continue to work on their paper on bowhead whale call detection and classification.

Stephanie Grassia (NMML) has completed analysis of the 2007-2010 AURAL data, and the 2008-2010 movable EAR mooring data. All long-term data were analyzed yes/no/maybe for bowhead calls in three hour bins, meaning that as soon as a bowhead call was detected, the analyst moved to the next three hour bin. If no (or indeterminate) calls were detected, then the analyst had to process all of the data in that bin. The short-term data were analyzed in half-hour bins. See SoundChecker section below for a brief description of the analysis program.

Kate Stafford has analyzed her 2008-2009 and 2009-2010 NOPP data for the presence of bowheads, belugas, bearded seals, and airguns. Analysis was completed by counting the number of one hour segments with the presence of call/airgun signals per day.

NMML's newest postdoc, Ellen Garland, joined us this spring and has started to look at recordings for the presence of beluga calls. Manolo Castellote, a NMML postdoc working on Cook Inlet belugas, will help to oversee that analysis.

Dana Wright, our 2011 Hollings Scholar Intern, has completed her analysis of the Okkonen EAR data from 2008-2010. The 2008 EAR was located at 71.2292N x 154.5258W. The 2009 and 2010 EARs were both located at 71.3515N x 155.2291W (Fig. II-3). All EARs were deployed at a depth of ~20m. She has looked at the data in half-hour segments and marked each segment with a yes/no/maybe to the presence of bowhead calls (included in the results section below). She has also finished categorizing (Fig. II-4) all bowhead calls detected from the 2008 and 2009 field seasons into 11 distinct call types using XBAT Extensible Bioacoustics Tool (Cornell University).

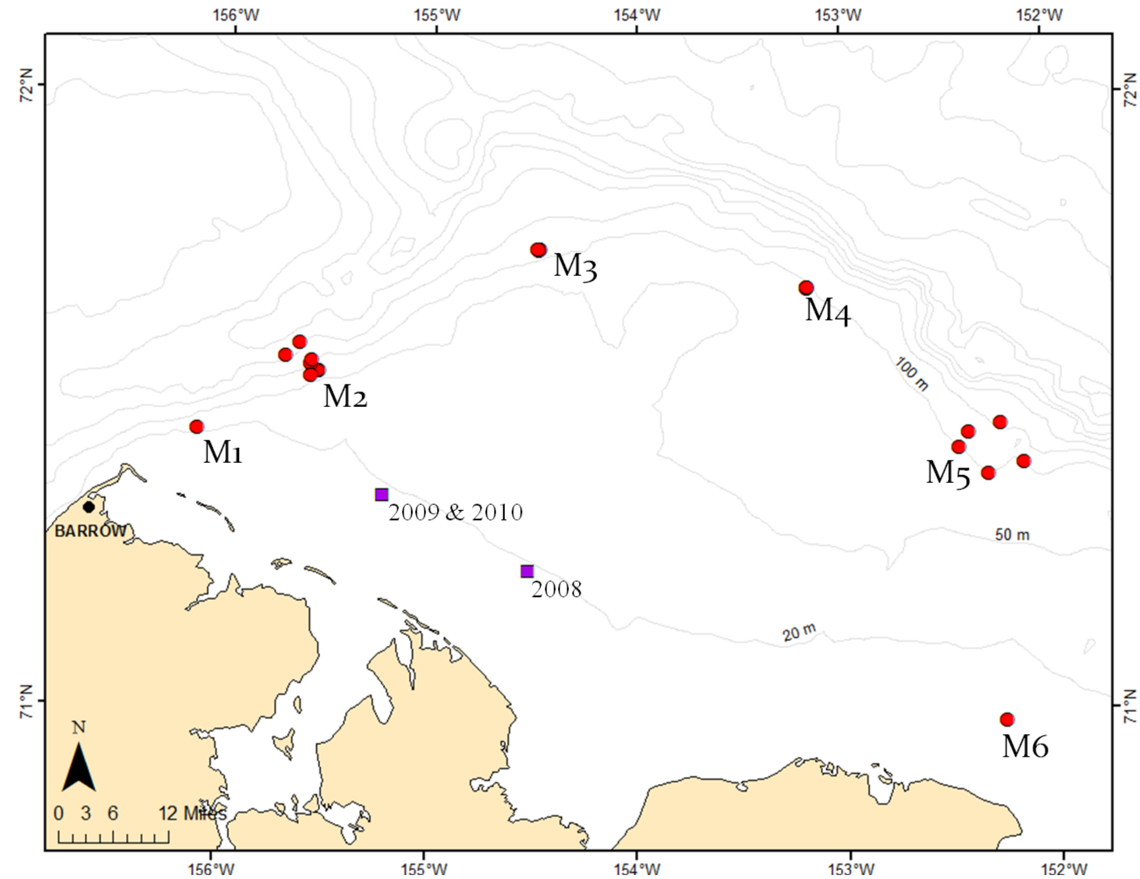

Figure II-3. *Location of the 2008-2010 Okkonen EAR moorings relative to the AURAL recorders. Red circles=AURAL. Purple square=Okkonen mooring with EAR recorder.*

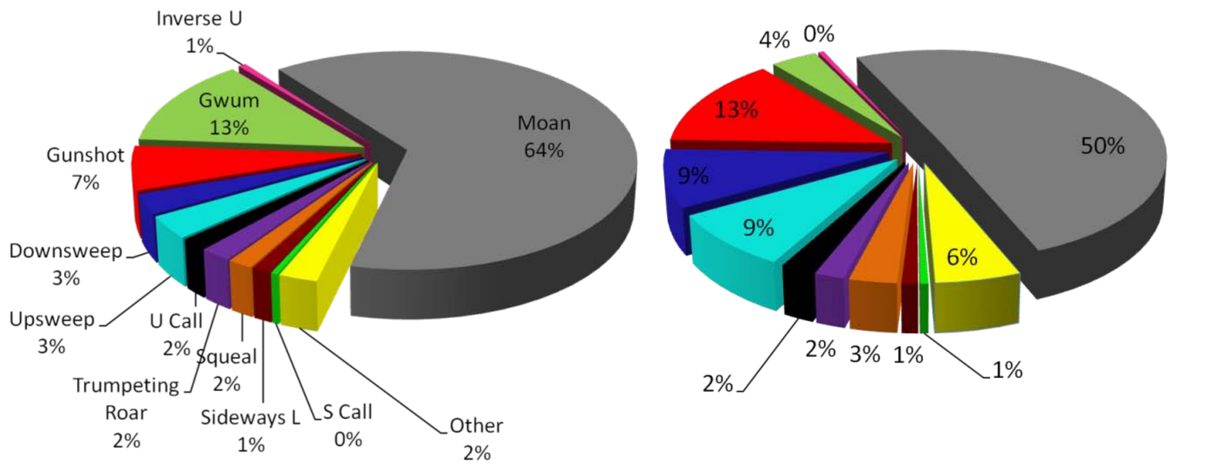

Figure II-4. *Percent total bowhead whale calls by call type in 2008 (left, 9,869 calls total) and 2009 (right, 12,645 calls total)*

SoundChecker Analysis Program

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 of the species. Despite reports of other institutions having developed effective bowhead whale call detection algorithms, further inquiry has revealed that these organizations employ large teams of analysts to essentially hand browse their data for bowhead calls, many times analyzing only a fraction of the recordings. In the cases where auto-detectors are used, these analysts are still needed to verify the results.

We are finding it extremely difficult to come up with autodetection parameters that effectively catch the majority of a particular call type in all locations for all recorder types and seasons, without catching a majority of calls from other species as well. The amount of effort required to effectively ground truth a particular autodetection run, in addition to still having to process a majority of the files, has led us to just use a brute force method of manual analysis. However, the SoundChecker program has the option of analyzing data sets that have already been run through an autodetector (or set of autodetectors).

The trouble with any spectrogram-based sound analysis program is the amount of computational time needed to generate the spectrograms. This time increases as the frequency band of interest increases. SoundChecker, written in the MatLab programming language, 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. It consists of the spectrogram image whose title indicates the data/time/location of the sample, an information bar that shows what species/call type/analysis interval is being used as well as a counter to protect the analyst's sanity, and a variety of action buttons. In use all of the time are the Yes/No/Maybe and "No with noise" 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/Maybe/ No with noise answers or the first image file of the next time interval for Yes answers. The No with noise button is used when background noise is so loud that it prevents possible calls from being detected. There is also an option to go back to a previous image if a correction is needed. If a shorter analysis interval is desired, it is simple to re-run that recorder at the shorter interval – the images already assigned to Yes/No/Maybe/No with noise will be skipped over, allowing for faster re-analysis.

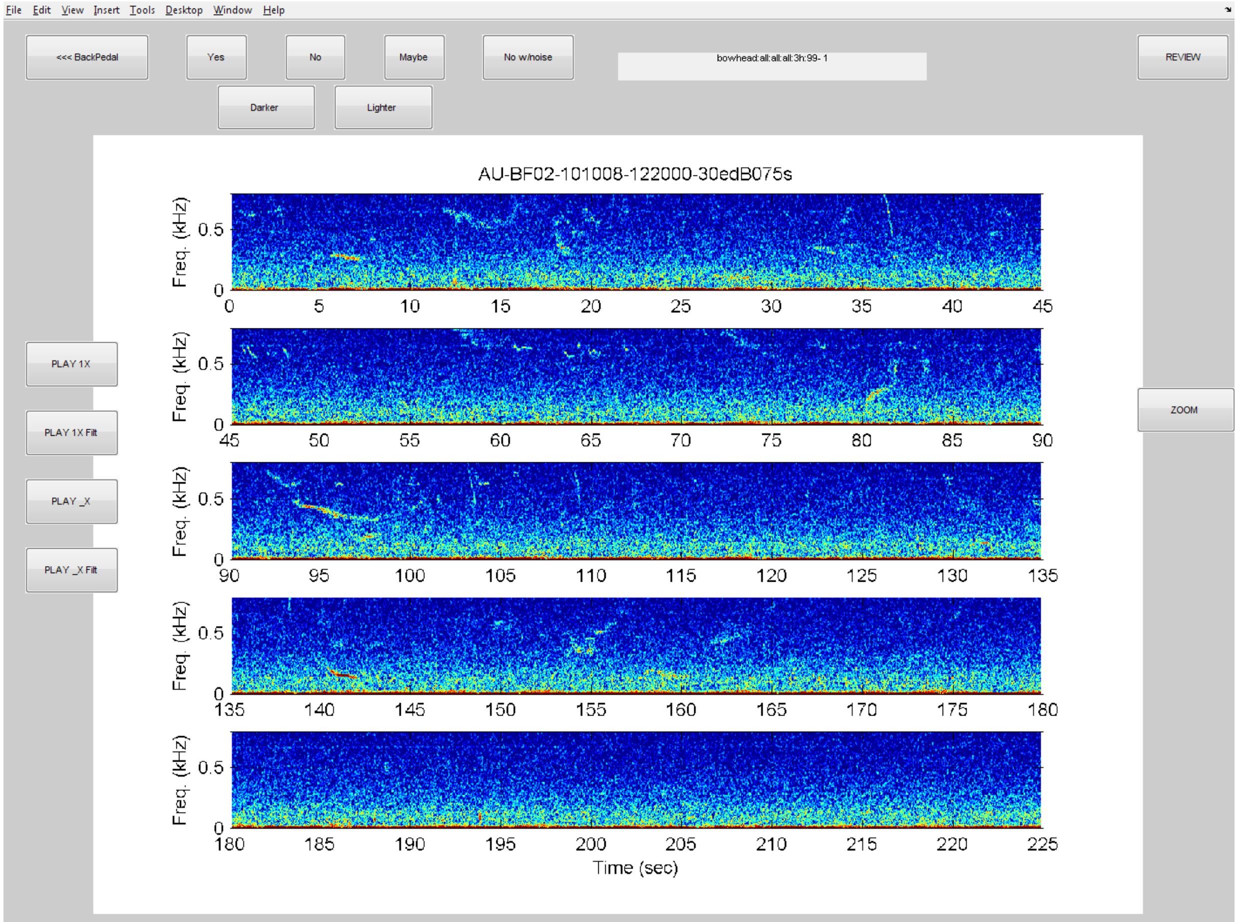

Figure II-5. *SoundChecker analysis interface. Spectrogram shown is for a BOWFEST mooring deployed in 2010 and represents 225s of recordings starting at 12:20:00 UTC on 08 October 2010. The upper information bar shows that this analyst is looking for bowhead whale calls in 3hr analysis intervals and is on the first spectrogram of their analysis session. Present are bowhead whale and ice seal calls. SoundChecker was written in the MatLab programming language.*

Since many sounds are difficult to determine just visually, there is a set of playback buttons that can be used on sections of the image file selected with the cursor. A set of darker/lighter buttons also allows the analyst to change the contrast of the image to increase the detectability of faint calls. To this end, there is also a zoom button that allows for a more detailed view of selected sections of the image. The save button (found within the pop-up window from the zoom button) allows an image file and its related wave file clip to be saved to our expanding library folder of known species calls and our increasingly expanding folders of unknown signals. Furthermore, there is a review mode button (see Fig. II-6) that lets the analyst jump back to a specific time/date image and retain the playback/contrast/zoom functions without altering the Yes/No/Maybe/No with noise responses. This is particularly helpful during the many meetings we hold to try and determine the source of many of the signals detected.

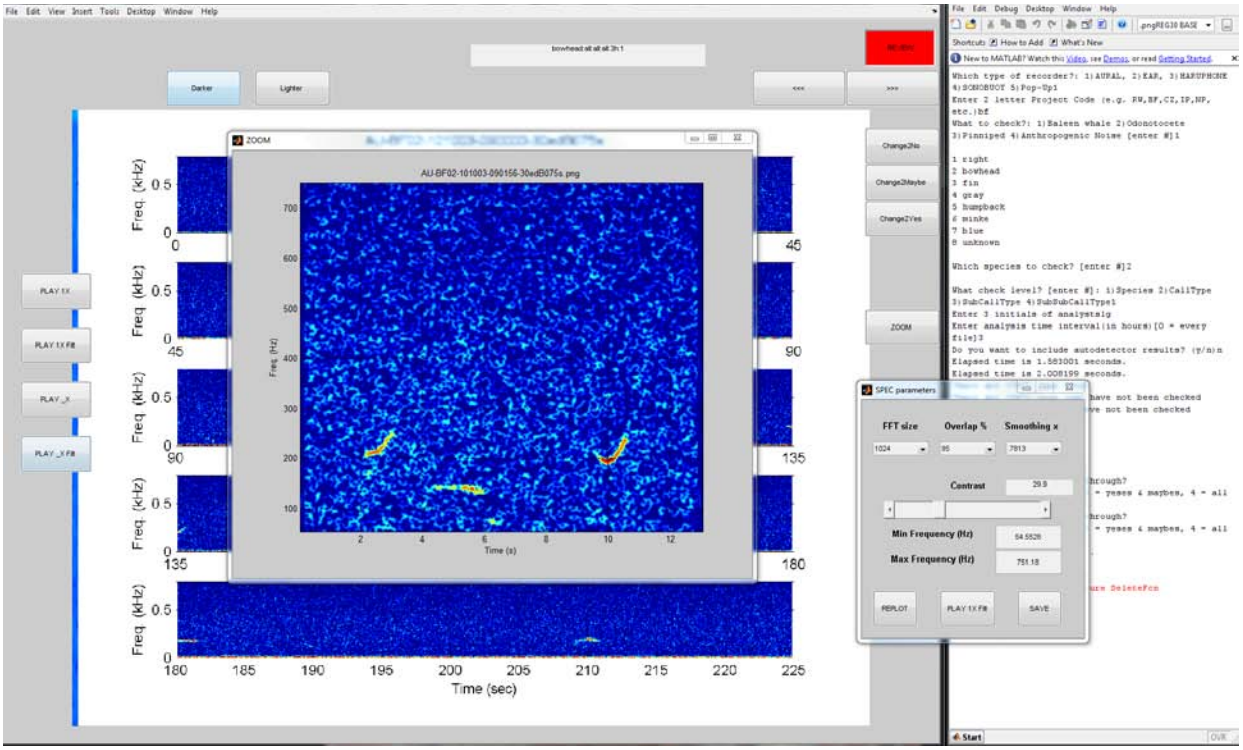

Figure II-6. *SoundChecker analysis interface in review mode with a zoom option selected. Spectrogram shown is for a BOWFEST mooring deployed in 2010. The zoom clip shows some bowhead calls occurring at approximately 09:01:56 UTC on 03 October 2010.*

So far, this method is proceeding faster than expected, with the worst case recorders taking around 3 weeks for one analyst to process a year's worth of data. The benefit we are finding with this method is that because we can view an entire 3-4 minute chunk of data at a time, we are getting a good overview of all the call types that are out there – not just those in a particular frequency band or those with particular characteristics. Furthermore, viewing the call in this longer-term context is extremely helpful for making decisions on the signal source. Because the results from this analysis are in a consistent form, further analysis of the results can be automated, including plot generation and correlation to other biophysical parameters.

Results

[Note: Because deployment locations and array configurations of the AURALs have changed slightly since the beginning of BOWFEST, we are framing the results 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 shown from the mooring with the largest data set. All graphs use data that are averaged by week to allow for easier interpretation. All numbers given for individual moorings are done with daily averages. For this report peak presence was defined as anytime when greater than 50% of daily time intervals had detections of bowhead calls.]

2007

In August 2007 six AURALs were deployed; four along the 100m isobath and two inshore (Fig. II-7, see Figs. II-8 & II-9 for larger versions of data plots). The inshore AURALs deployed at M1 and M6 were used as short term recorders and were only deployed in 2007.

These two recorders were deployed for one month, from mid-August to mid-September; M1 was lost to ice. The four recorders along the 100m isobath (M2-M5) were deployed for one year, however an error in the 2007 version of the AURAL programming software caused the recorders to stop recording after 8 months.

Bowheads were first detected in the BOWFEST study area at M3 on August 22nd and last heard consistently at M2 on October 31st (a handful of calls were heard on M3 and M4 over winter). The peak presence of bowheads on M5 was between September 21st and October 10th, while M4 reached peak presence from October 2nd to 29th, M3 from September 27th to October 29th, and M2 from August 27th until October 30th. Very few bowheads were heard in early September. The western portion of the study area had a higher percentage of time intervals with calls. We were also able to track the migration of the whales as they moved from east to west.

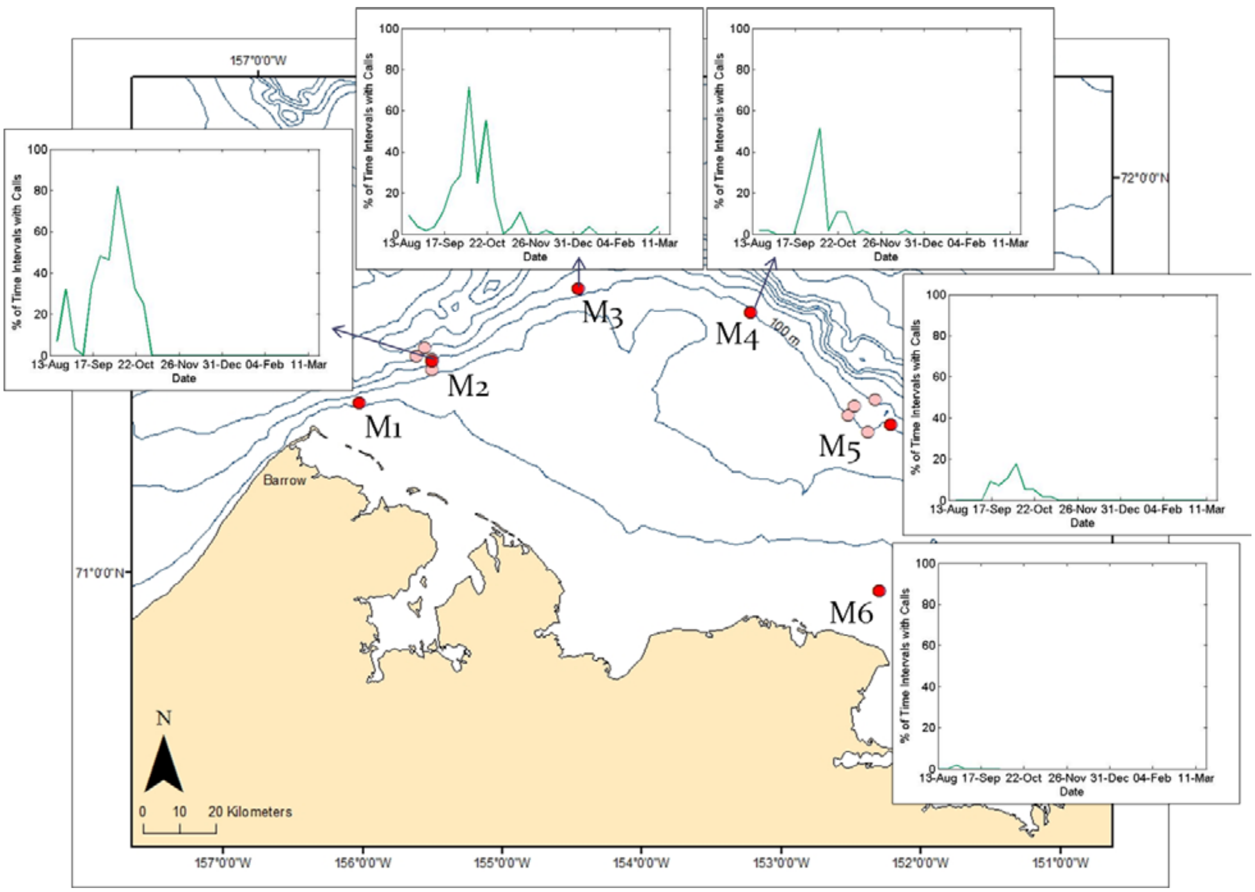

Figure II-7. *Results and locations for moorings during 2007. See Figures II-8 and II-9 for a larger version of data plots. The moorings at M1 and M6 were only deployed for one month. M1 was lost at sea. M2-M5 were deployed for one year and recorded for eight months. Red circles=active year AURAL. Pink circle=past or future AURAL location.*

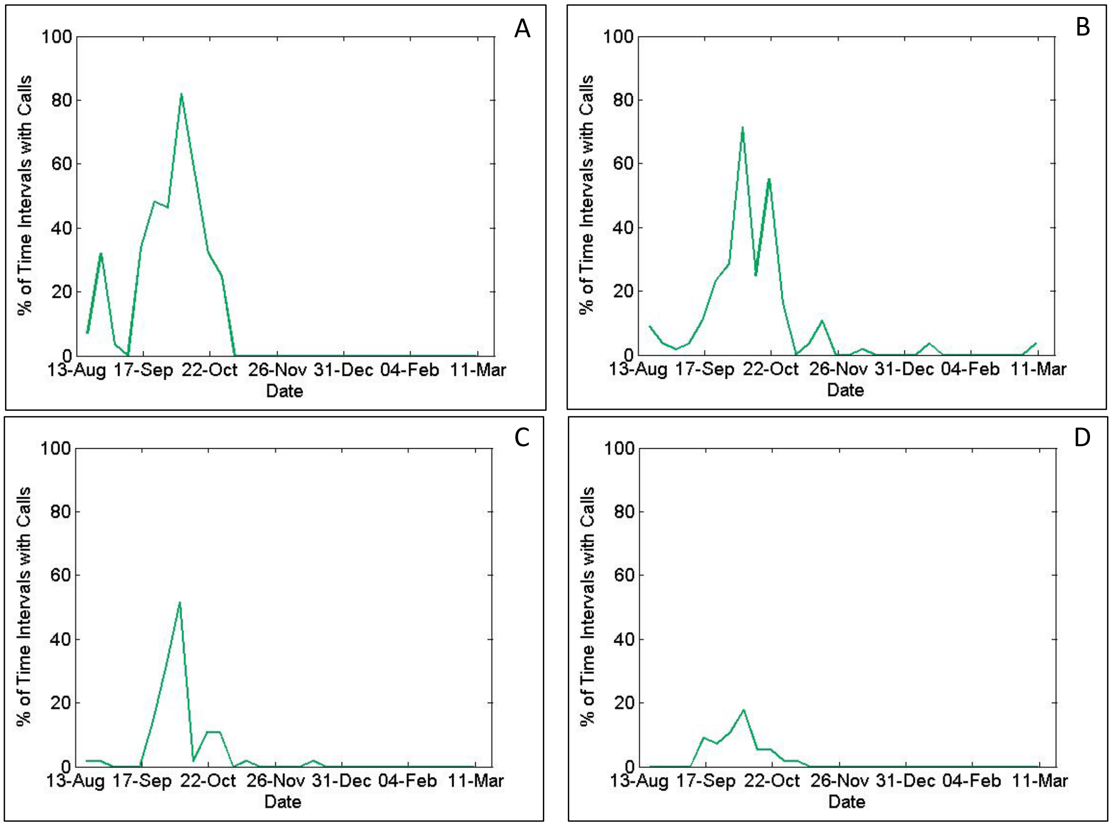

Figure II-8. *Percentage of time intervals per week with calls for the 2007 long-term recorders. A) M2 B) M3 C) M4 D) M5.*

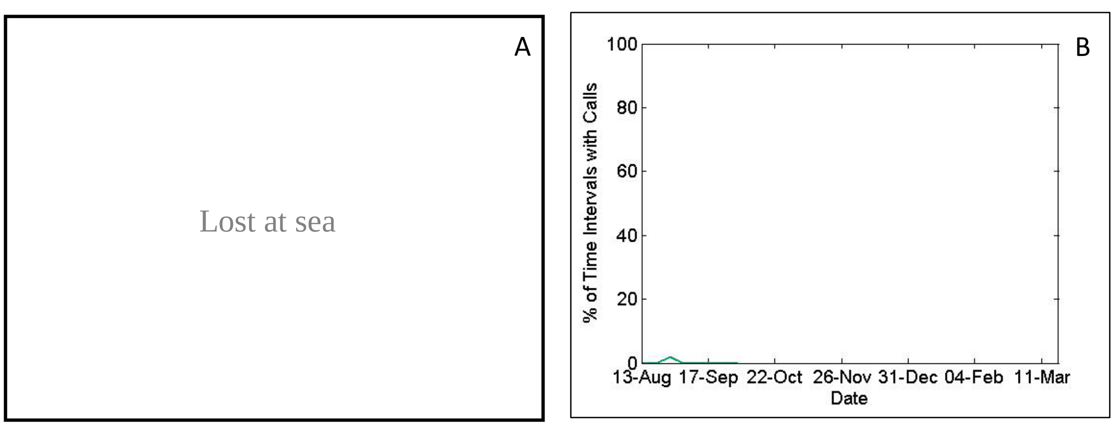

Figure II-9. *Percentage of time intervals per week with calls for the 2007 short-term recorders. A) M1 B) M6.*

2008

In August 2008, five year-long AURALs were deployed, three at M2 and two at M5 (Fig. II-10, see Fig. II-11 for larger version of the data plot). M3 was occupied by Kate Stafford's NOPP-A1 mooring and M4 was not deployed due to lack of ship time available on the USCGC *Healy*. Since 2009, we have been unable to recover any of the three moorings deployed at the M2 location even though the acoustic releases on two of the moorings were responding to our transmitted acoustic signals. During the fall migration, bowheads were first detected at M5 on August 20th and last heard on November 13th. Peak presence was reached at M5 between September 5th and October 31st. Luckily, in 2008, one of the two AURALs deployed at M5 recorded for a full year. Bowheads were detected on their 2009 spring migration starting April 13th until July 31st, with their peak presence falling between April 13th and July 30th. Data from M3 were unavailable for this report.

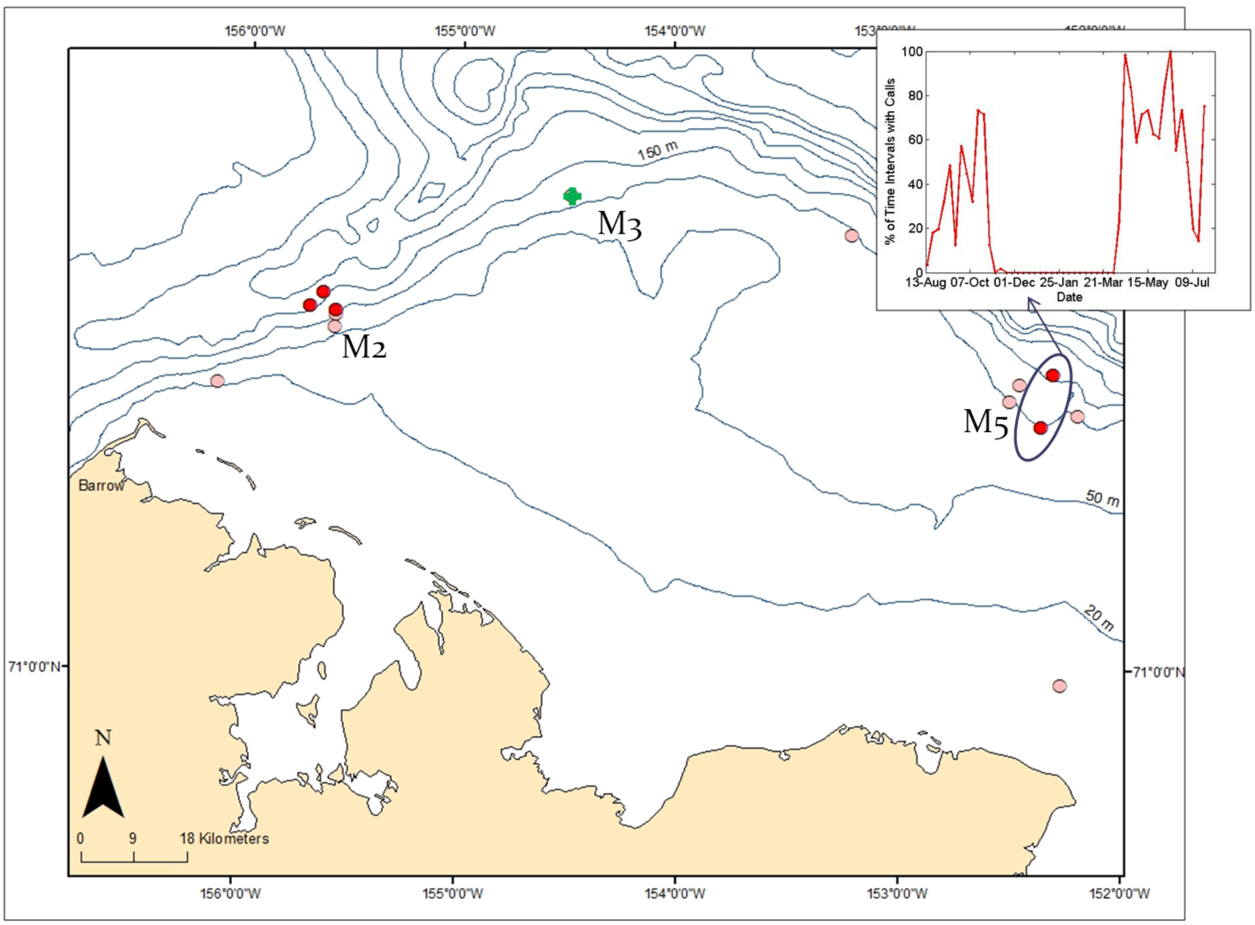

Figure II-10. *Results and locations for the long-term moorings during 2008. See Figure II-11 for a larger version of the data plot. All three recorders at M2 were lost at sea. Data for M3 unavailable for this report. Red circles=active year AURAL. Pink circle=past or future AURAL location. Green cross= Stafford NOPP mooring.*

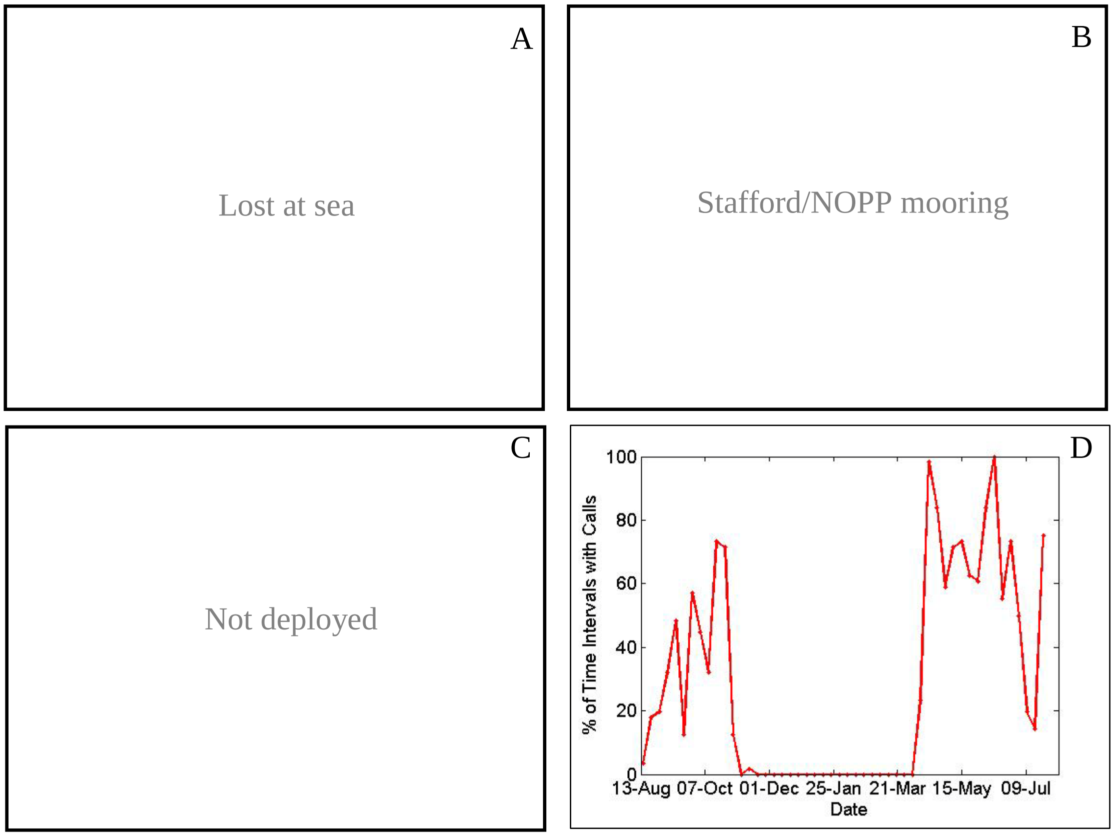

Figure II-11. *Percentage of time intervals per week with calls for the 2008 long-term recorders. A) M2 B) M3- Stafford/NOPP C) M4 D) M5.*

Between August 19th and September 13th six EAR recorders were deployed (Fig. II-12, see Fig. II-13 for larger version of the data plot). The EARs were deployed in shallow waters; two (one of which failed to record) were deployed on Steve Okkonen's short-term moorings and four were deployed in movable arrays. Bowheads were heard on the fixed mooring from August 21st through its recovery date of September 10th, with a peak presence detected from August 21st to September 10th. The movable arrays recorded bowheads from August 30th until their recovery on September 13th. These moorings detected the peak presence between September 2nd and September 13th. The EARs recorded a higher percentage of time with bowhead calls during their deployment than the AURAL at M5. The increase of time with calls in the west also coincides with the timing of a 'krill trap' that was set off Barrow around September 8th.

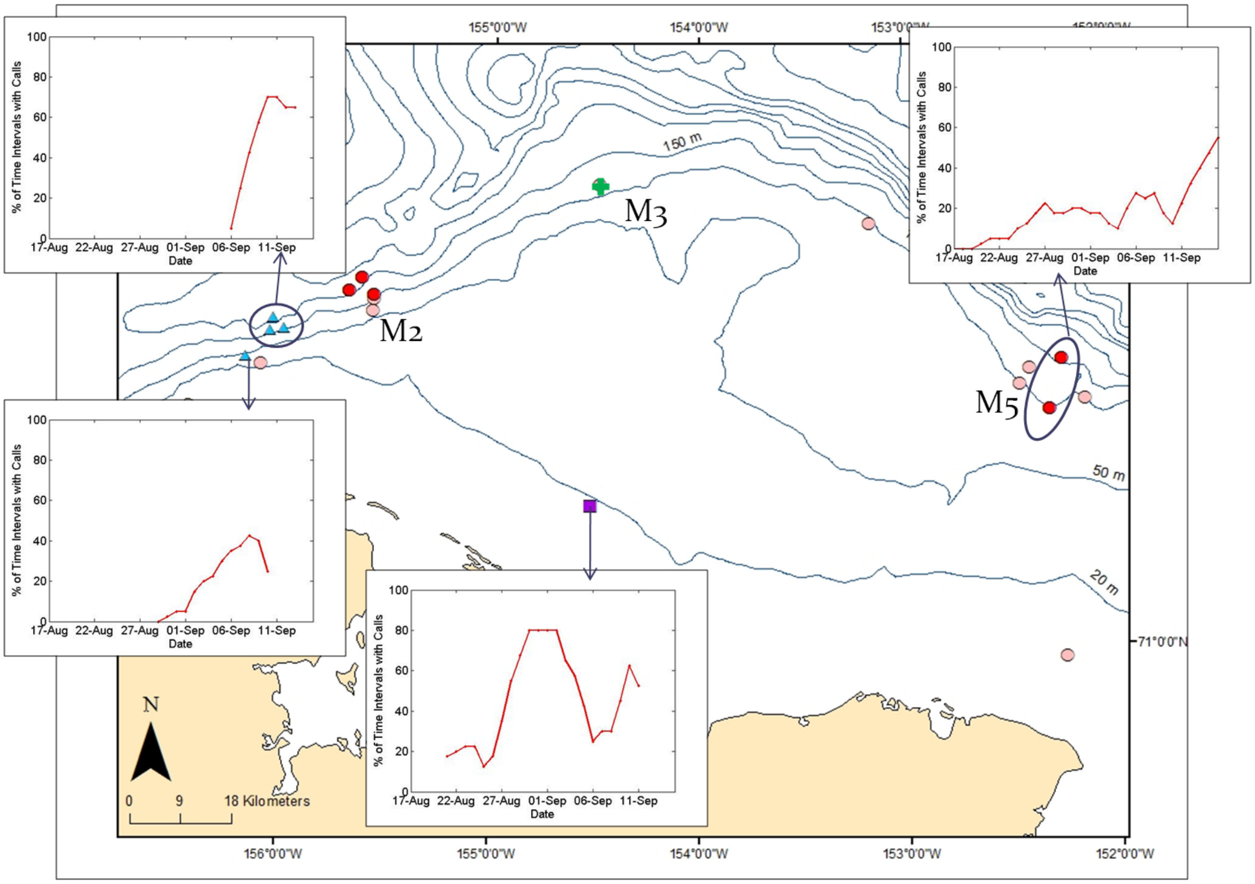

Figure II-12. *Results and locations for all moorings during 2008. See Figure II-13 for a larger version of the data plots. All three recorders at M2 were lost at sea. Data for M3 are unavailable for this report. Red circles=active year AURAL. Pink circle=past or future AURAL location. Blue triangles=movable array. Purple square=Okkonen mooring with EAR recorder. Green cross= Stafford NOPP mooring.*

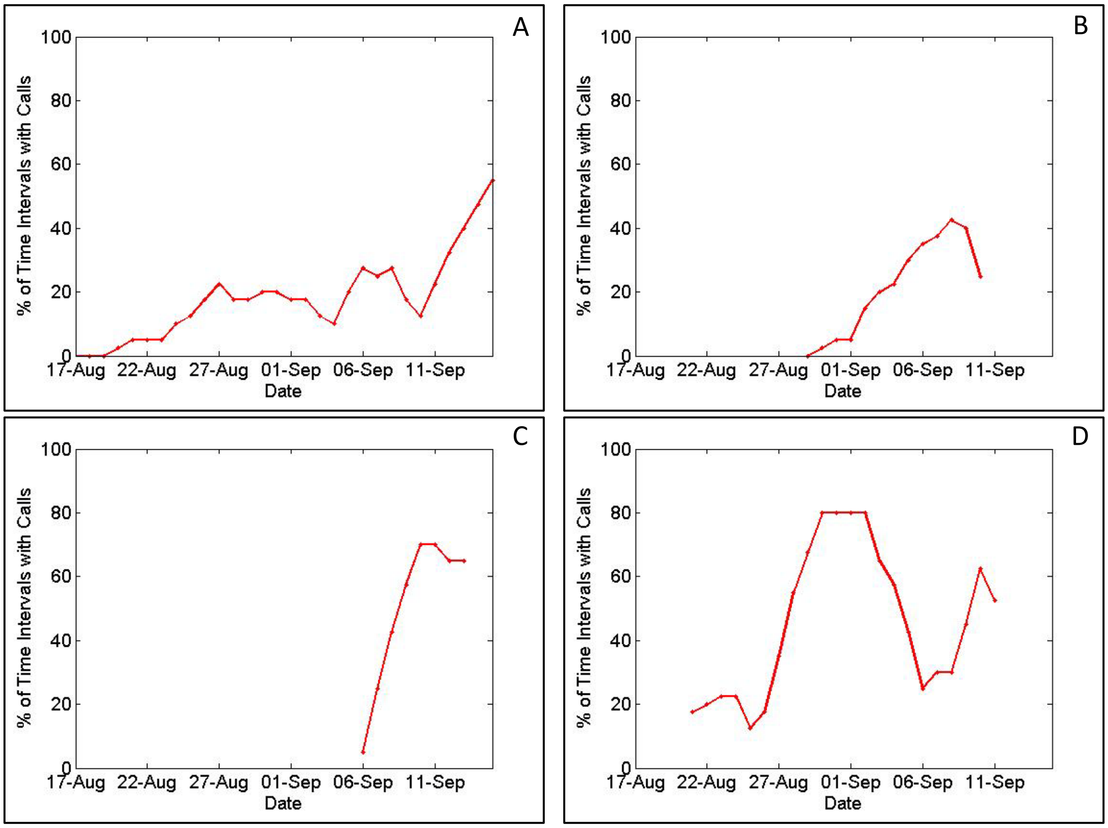

Figure II-13. *Percentage of time intervals per week with calls for the 2008 short-term recorders and M5 during the same time period. A) M5 B-C)Movable array D)Okkonen mooring.*

2009

In August 2009, four year-long AURALs were deployed, one at M2, two at M5, and M3 was occupied by Kate Stafford's NOPP-A1 mooring (Fig. II-14, see Fig. II-15 for larger version of the data plot). M4 was not deployed again due to time constraints on the USCGC *Healy* cruise. Bowheads were first detected at M3 on August 1st and last heard consistently in early November, with a handful of detections over winter at M2 and M3. Peak presence was detected at M5 between August 4th and November 4th, M3 from August 1st until November 4th, and finally M2 from August 7th until November 8th. In 2010 bowheads were detected on their spring migration starting February 4th (M3) and were detected until the moorings stopped recording in August. M3 reached peak presence from April 7th until July 23rd and M5 April 30th until July 22nd. In the fall of 2009 the percentage of daily time intervals with calls was greater in the west than the east. The opposite was true in the spring of 2010 with the eastern mooring having a greater percentage of time intervals with calls.

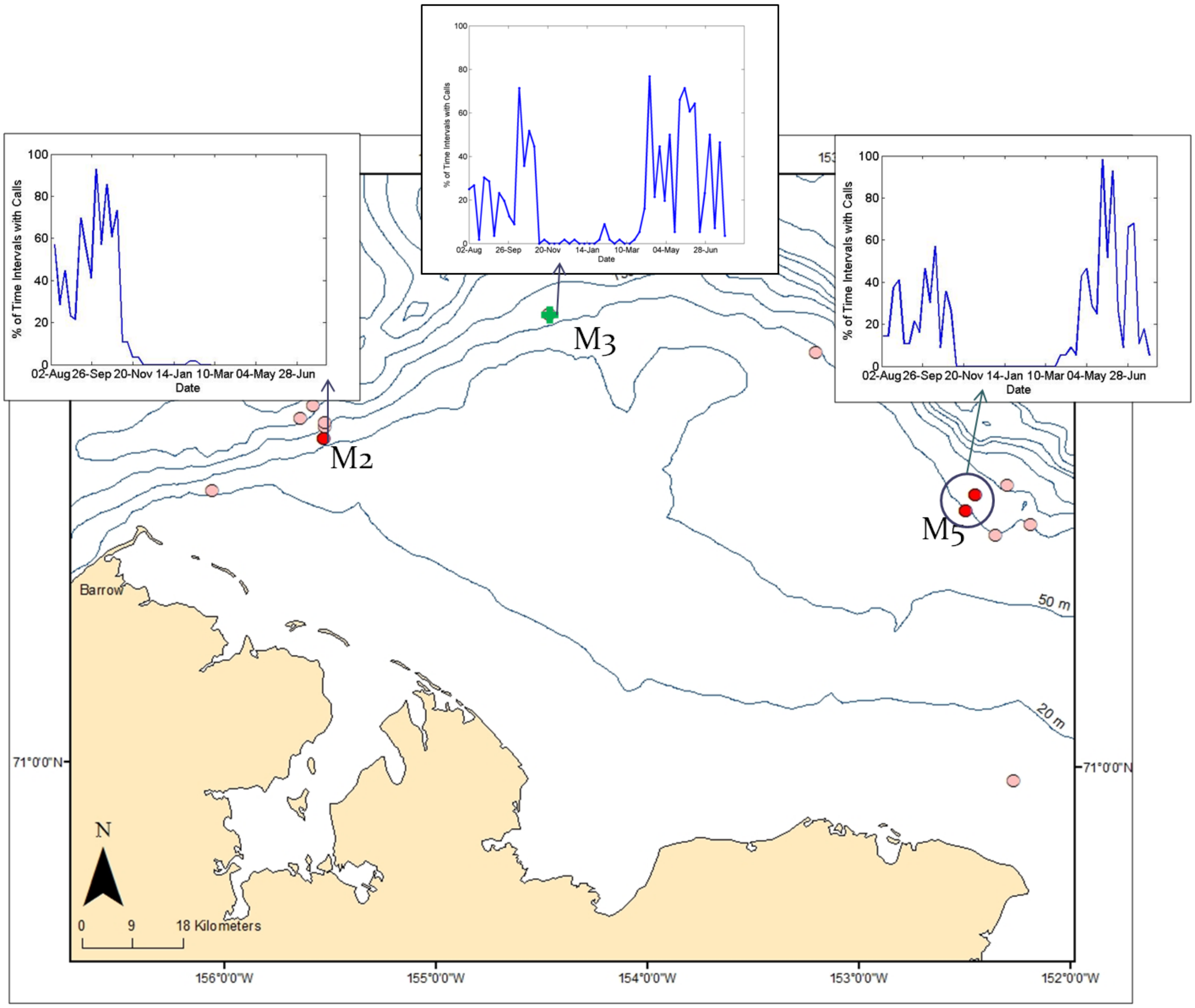

Figure II-14. *Results and locations for the long-term moorings during 2009. See Figure II-15 for larger version of the data plots. Red circles=active year AURAL. Pink circle=past or future AURAL location. Green cross= Stafford NOPP mooring.*

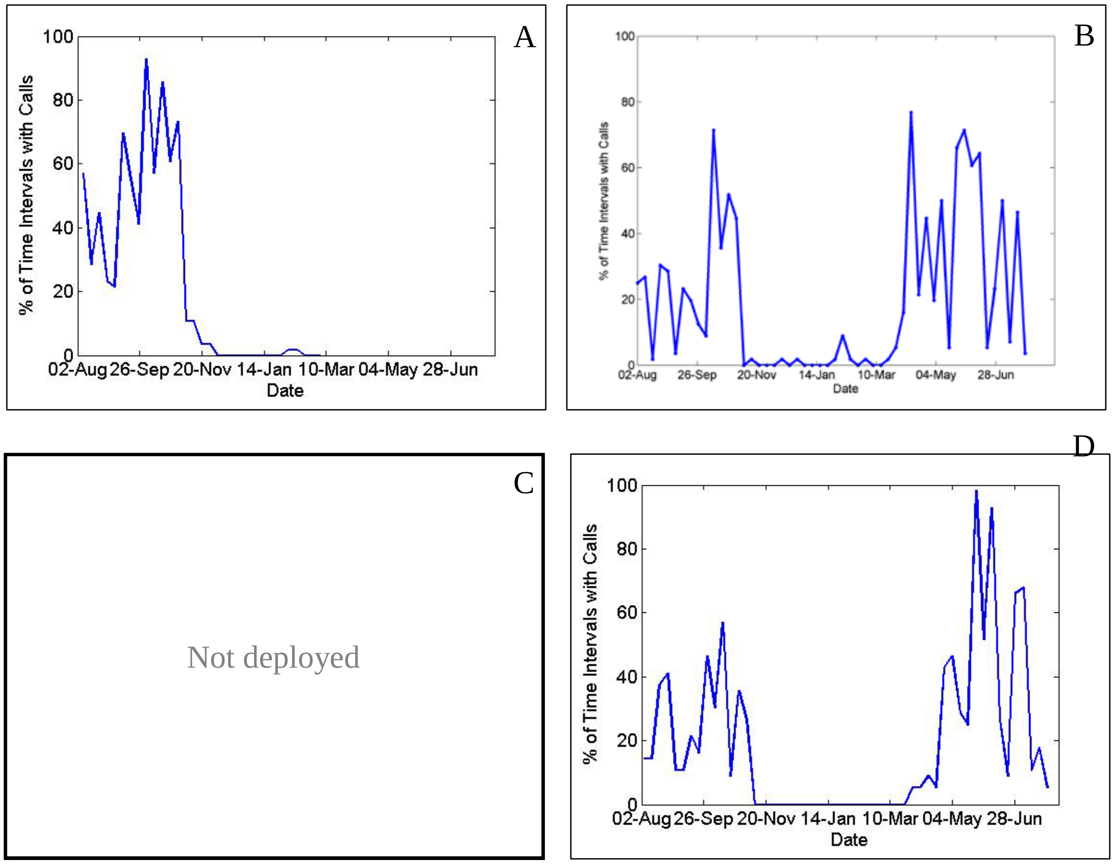

Figure II-15. *Percentage of time intervals per week with calls for the 2009 long-term recorders. A) M2 B) M3- Stafford/NOPP C) M4 D) M5.*

Between August 21st and October 6th seven EAR recorders were deployed (Fig. II-16, see Fig. II-17 for larger version of the data plot). The EARs were deployed in shallow waters; one was deployed on Steve Okkonen's short-term mooring and six were deployed as movable arrays. Bowheads were heard on the fixed mooring from August 21st through its recovery date of September 15th with the peak presence from August 21st to August 31st. The movable arrays recorded bowheads from August 26th until their recovery on October 6th. These moorings reached peak presence between August 26th and October 5th. When compared to the long-term data from M2 we can see an increase of percentage of time inshore from mid-August to mid-September, with percentages roughly the same from mid-September until early October when the short-term moorings were recovered.

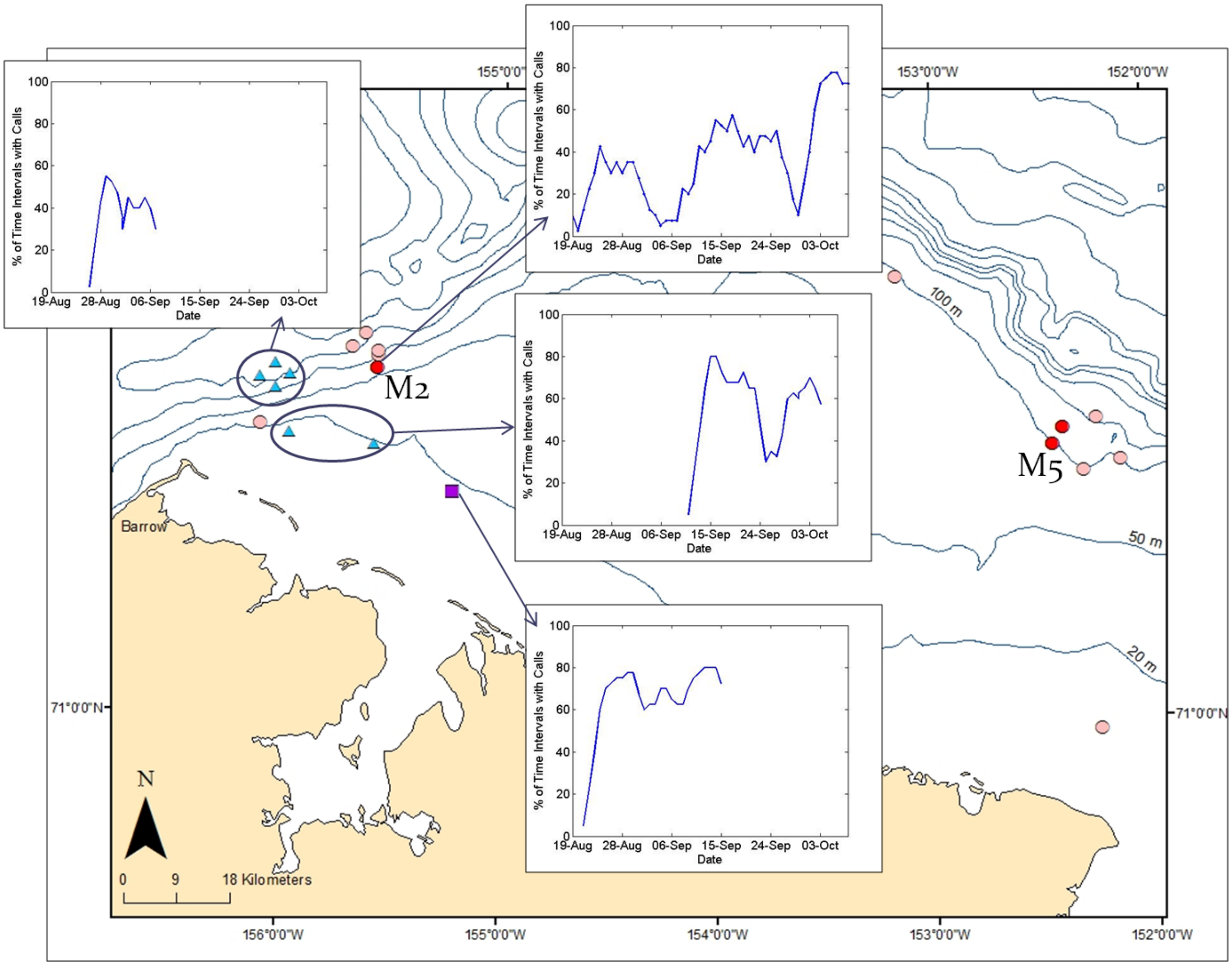

Figure II-16. *Results and locations for all moorings during 2009. See Figure II-17 for a larger version of the data plots. Red circles=active year AURAL. Pink circle=past or future AURAL location. Blue triangles=movable array. Purple square=Okkonen mooring with EAR recorder.*

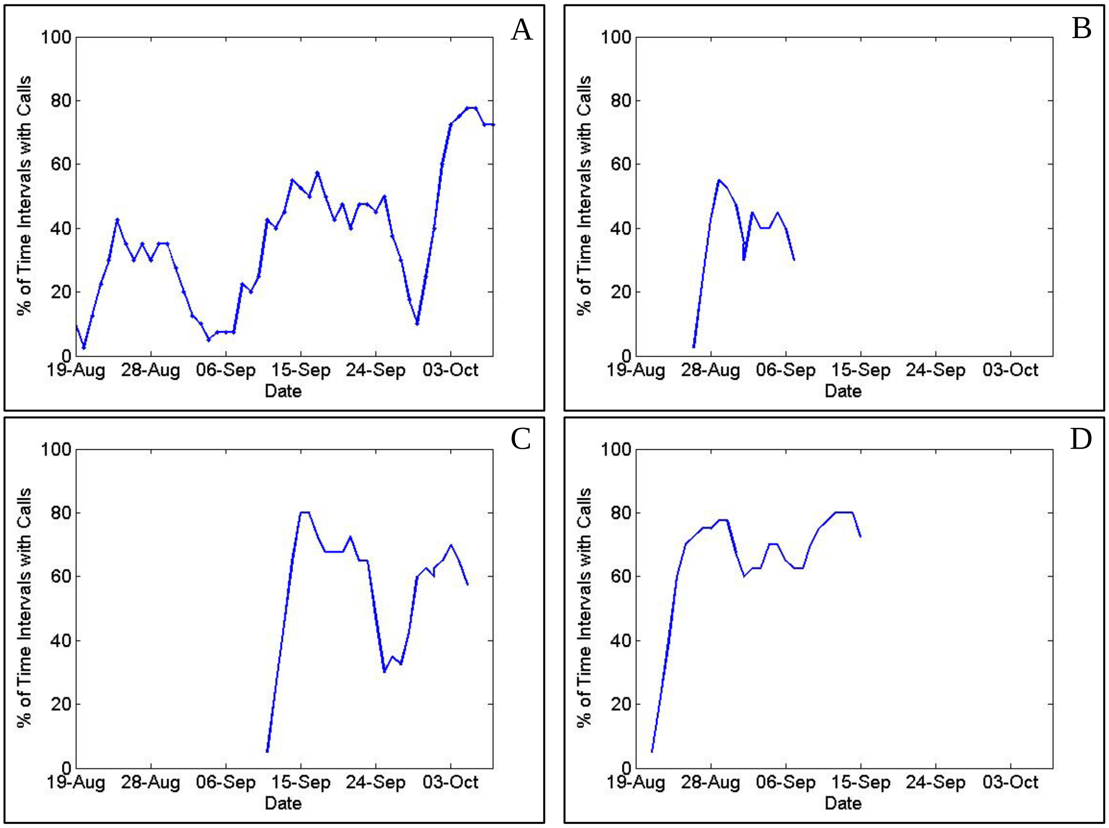

Figure II-17. *Percentage of time intervals with calls per week for the 2009 short-term recorders and M2 during the same time period. A) M2 B-C)Movable array D)Okkonen mooring.*

2010

In September 2010, three year-long AURALs were deployed; one at M2, one at M3, and one at M4 (Fig. II-18, see Fig. II-19 for larger version of the data plot). M5 was occupied by Kate Stafford's AON mooring. Analysis of these moorings is currently underway.

Between August 19th and September 23rd, six EAR recorders were deployed (Figure II-18). The EARs were deployed in shallow waters; one was deployed on Steve Okkonen's short-term mooring frame and five were deployed as movable arrays. No bowheads were heard on the fixed mooring, which only recorded for 8 of the 29 days it was deployed. The movable arrays recorded bowheads from August 29th until September 8th. Only one of these moorings (the EAR closest to Barrow) detected enough calls to define the peak presence, which occurred from August 30th and September 8th. One of the movable arrays recorded no bowheads.

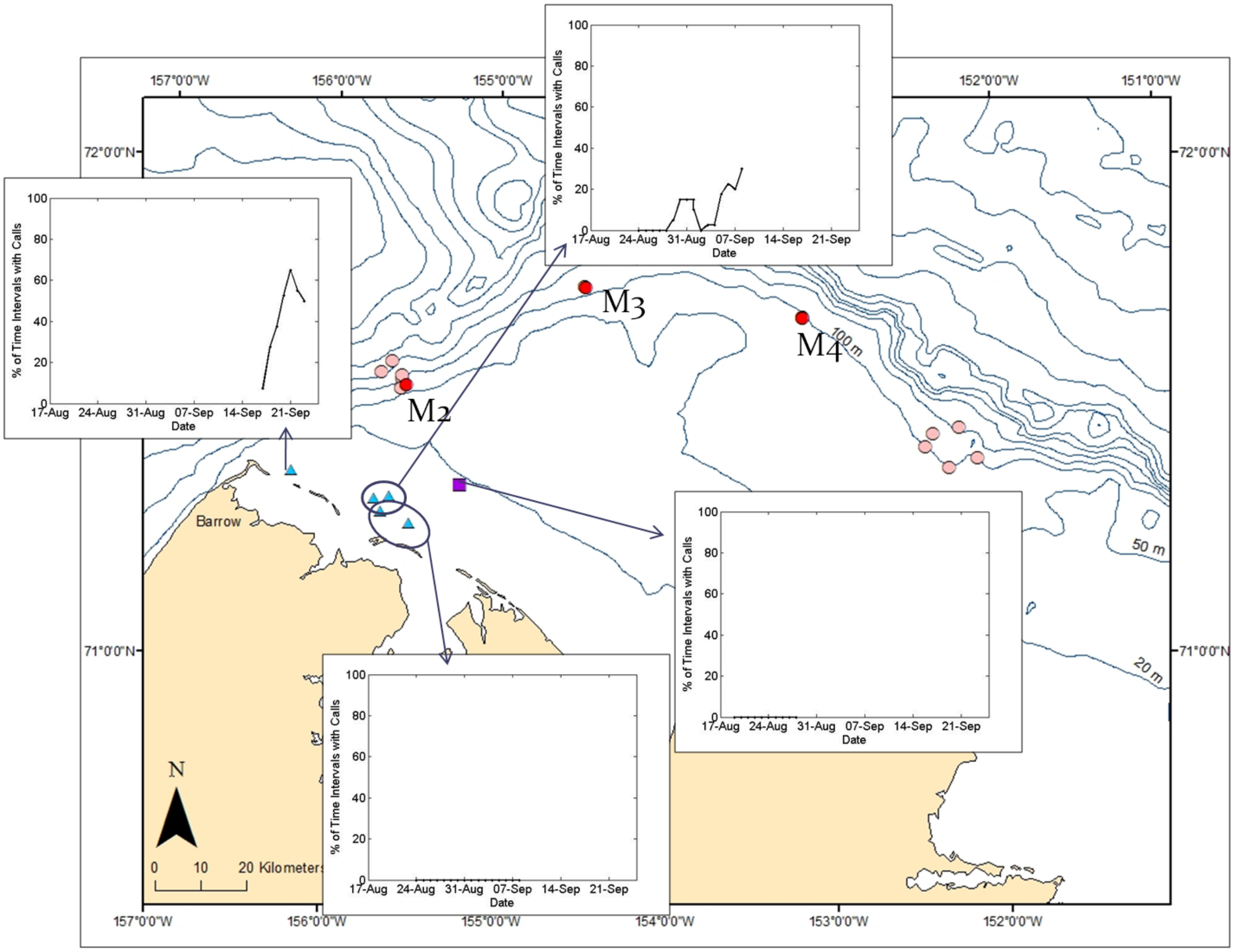

Figure II-18. *Results and locations for all moorings during 2010. See Figure II-19 for a larger version of the data plots. Red circles=active year AURAL. Pink circle=past or future AURAL location. Blue triangles=movable array. Purple square=Okkonen mooring with EAR recorder.*

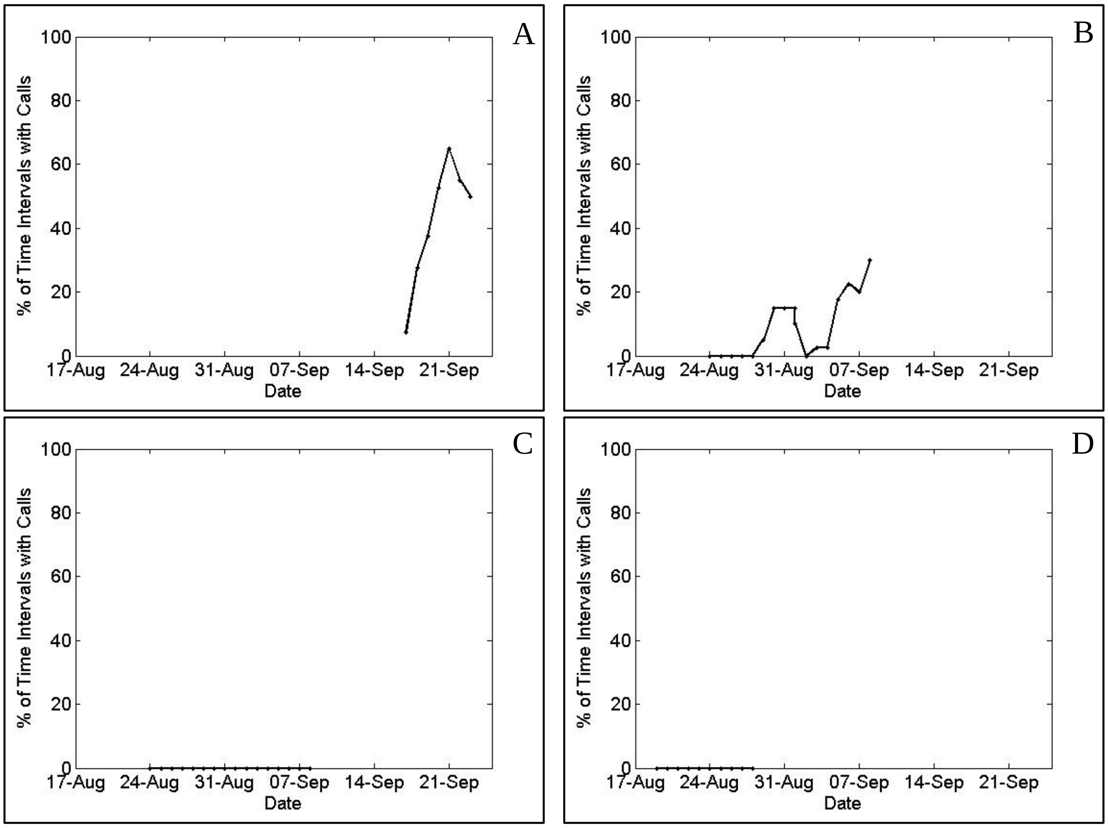

Figure II-19. *Percentage of time intervals with calls per week for the 2010 short-term recorders. A-C)Movable array D)Okkonen mooring.*

NOPP

Kate Stafford has analyzed her 2008-2009 and 2009-2010 NOPP data for the presence of multiple species. This mooring occupied the M3 location during both BOWFEST seasons. The 2008 mooring recorded from August 16, 2008 until July 27, 2009 and the 2009 mooring from August 1, 2009 until August 15, 2010. Preliminary results are shown in Figure II-20 through Figure II-23.

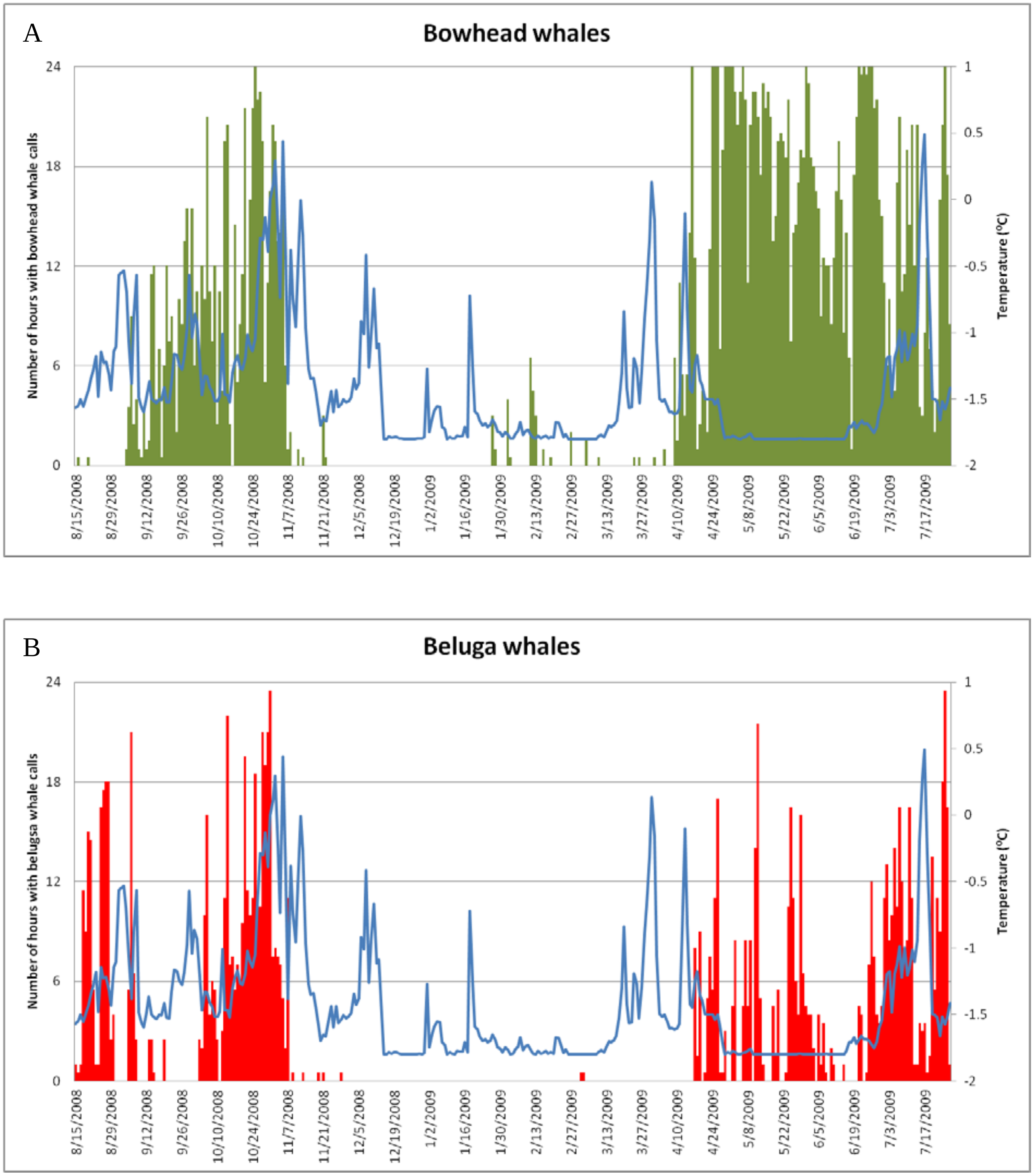

Figure II-20. *Results from Kate Stafford's 2008 NOPP mooring. A)Number of hours per day that bowhead calls were detected (green) vs. temperature (blue). B) Number of hours per day that beluga calls were detected (red) vs. temperature (blue).*

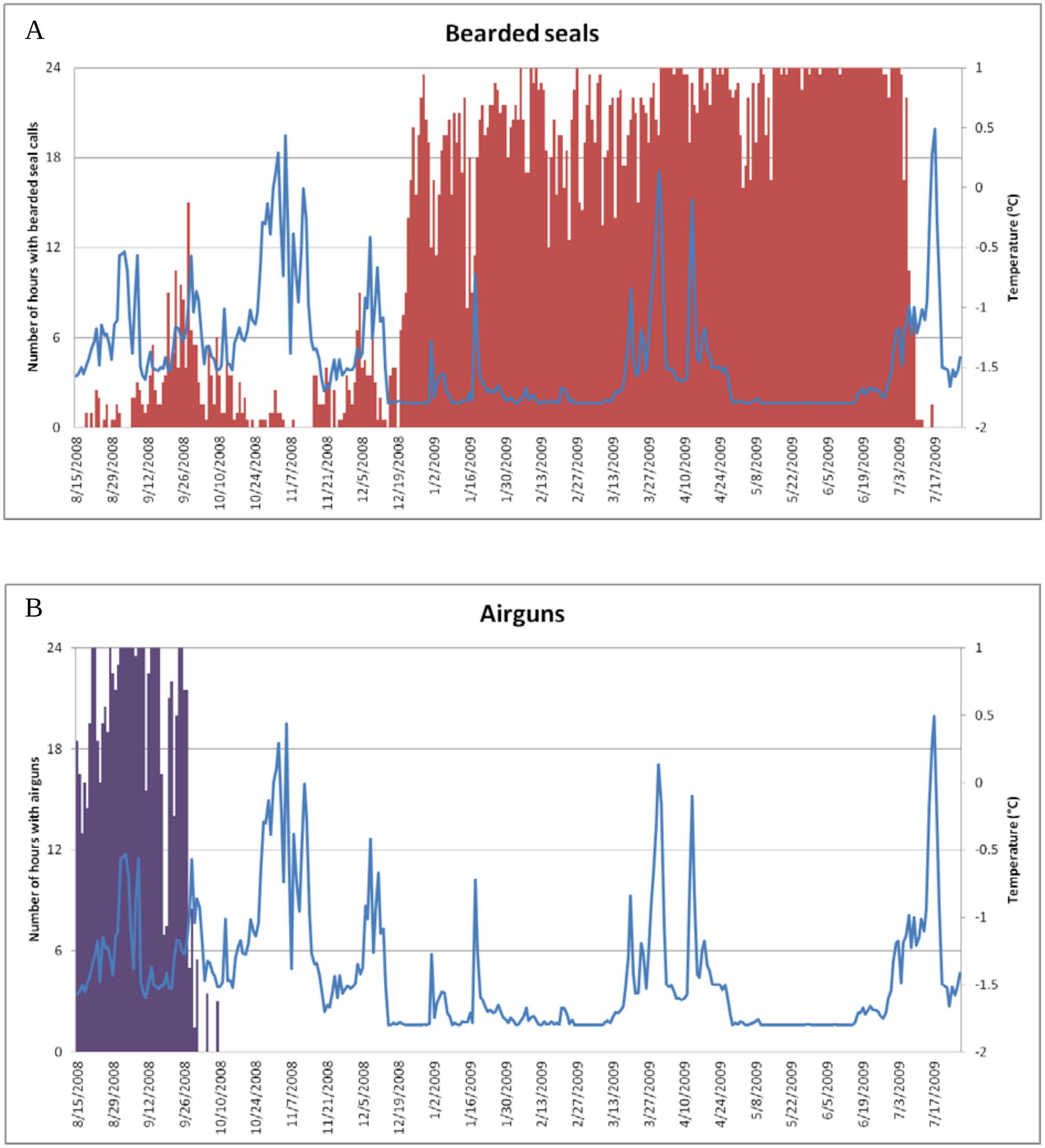

Figure II-21. *Results from Kate Stafford's 2008 NOPP mooring. A)Number of hours per day that bearded seal calls were detected (maroon) vs. temperature (blue). B) Number of hours per day that airguns were detected (purple) vs. temperature (blue).*

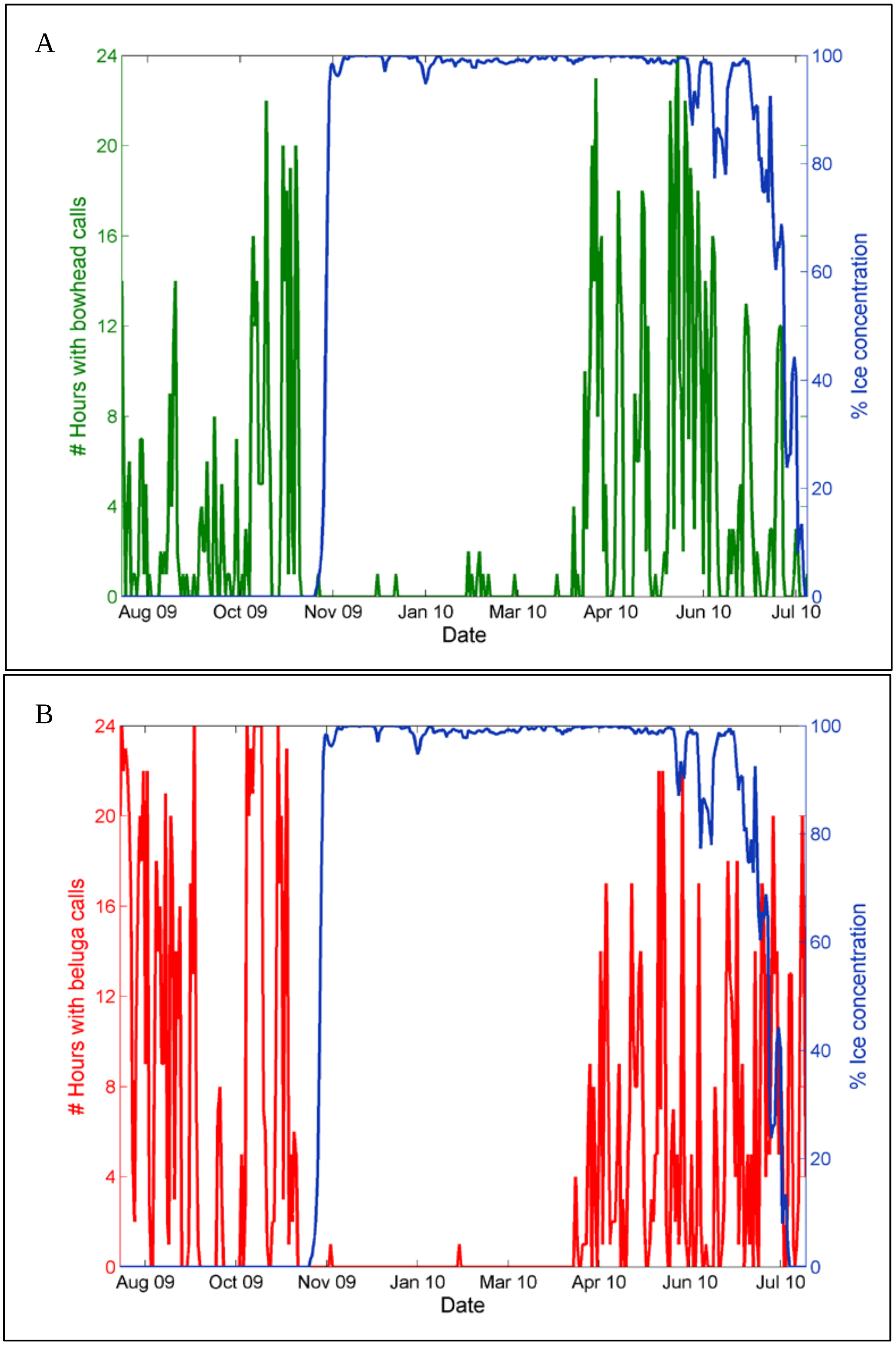

Figure II-22. *Results from Kate Stafford's 2009 NOPP mooring. A)Number of hours per day that bowhead calls were detected vs. percent ice concentraion.B) Number of hours per day that beluga calls were detected vs. percent ice concentration.*

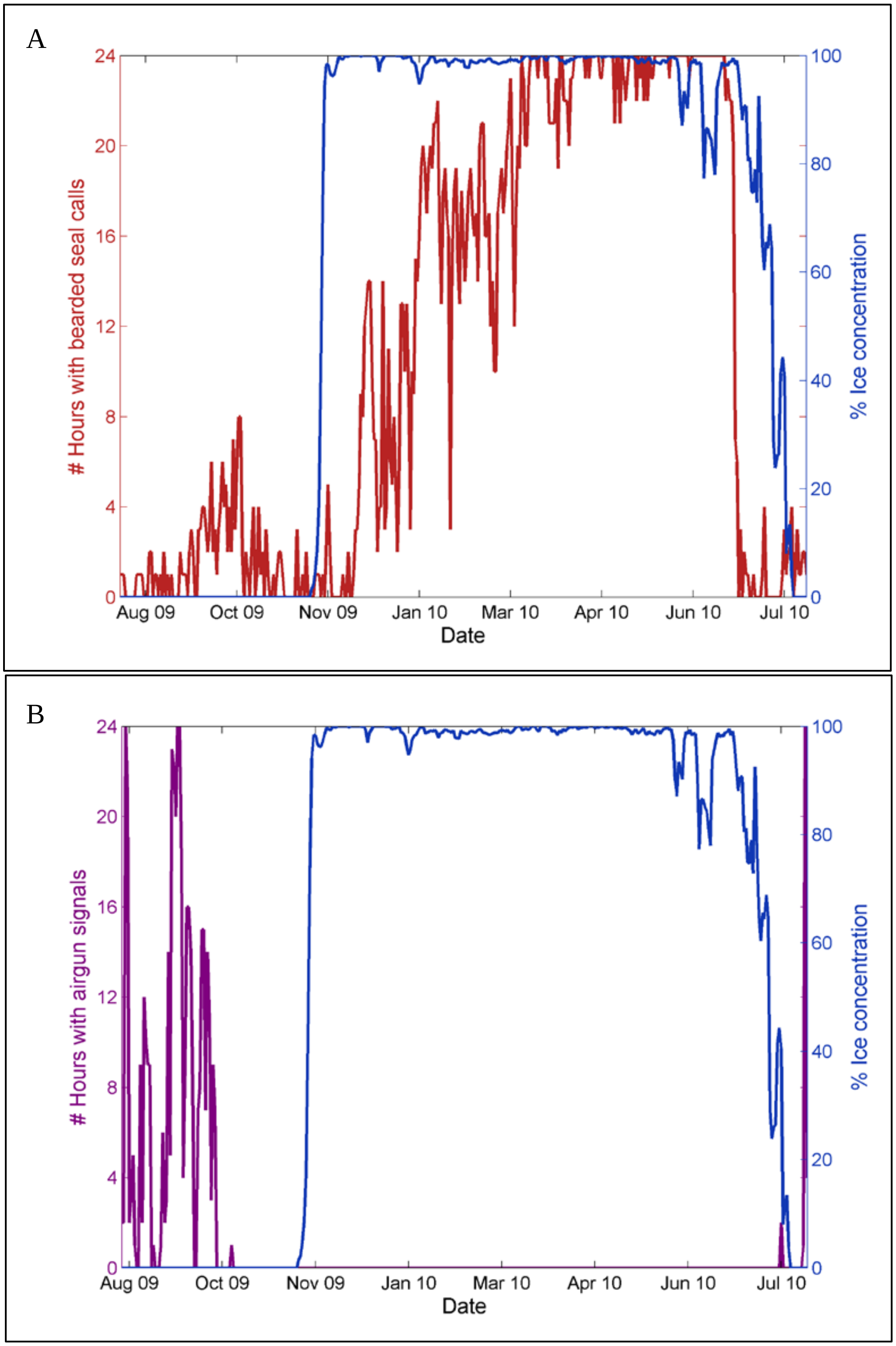

Figure II-23. *Results from Kate Stafford's 2009 NOPP mooring.*
A)Number of hours per day that bearded seal calls were detected vs. percent ice concentraion.
B) Number of hours per day that airguns were detected vs. percent ice concentration.

SECTION III - MOORINGS AND BROAD-SCALE OCEANOGRAPHY

Carin Ashjian[1], Robert Campbell[2], and Stephen Okkonen[3]

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Introduction

This was the final, and again successful, field year for the oceanographic mooring and broad-scale oceanography component of the BOWFEST program. Both components were greatly enhanced by our companion NSF-supported Arctic Observing Network (AON) project. The AON project provided a substantial portion of the operating costs of the R/V *Annika Marie* and of the logistic support (shipping, supplies, lodging, & meals) for the field team in Barrow. The project benefited also from assistance from our colleague R. Pickart (WHOI) who turned around the Barrow Canyon year-round mooring during his cruise on the USCGC *Healy* in October.

There were two main activities in the field this year: 1) Turnaround of year-round moorings on the October USCGC *Healy* cruise and from the R/V *Annika Marie* in August and 2) Oceanography and bowhead whale prey distribution (broad- and fine-scale) and short-term mooring deployments on the Beaufort Shelf during August – September. Equipment for the mooring cruise was loaded onto the USCGC *Healy* in Seward, AK in July 2011. The equipment for the shallow water moorings and the CTD was shipped to Deadhorse, AK to be loaded onto the R/V *Annika Marie* for deployment during the transit of the boat from Deadhorse to Barrow for fieldwork. The remaining field equipment was shipped to Barrow, AK. Oceanography field team members included Carin Ashjian, Bob Campbell, Steve Okkonen, and Phil Alatalo. UAF Graduate Student Heather McEachen and WHOI Postdoctoral Scholar Joel Llopiz also participated in the fieldwork. Arrangements for lodging and transportation in Deadhorse were made by Phil Alatalo. The R/V *Annika Marie* was chartered from Oceanic Research Services, Inc. by WHOI with funds from both BOWFEST and AON. Laboratory, lodging, and staging facilities in Barrow were procured through a paid-for-service agreement with the Barrow Arctic Science Consortium.

The team (Ashjian, Campbell, Okkonen, Alatalo) participated in the BOWFEST meeting that was held in March 2012 in Seattle, WA at which results from the five field years were reviewed, a plan for the final synthesis year was developed, and ties between program components were identified.

MOORING COMPONENT

Stephen Okkonen

Four oceanographic moorings were deployed during the 2011 field season to investigate the relationship between the overlying wind field, local currents, and the presence of zooplankton. Deployment locations are indicated by blue asterisks in Figure III-1. Moorings B-D

(Table III-1) were deployed by the R/V *Annika Marie* for the BOWFEST project while Mooring A, deployed by the USCGC *Healy* for the AON project, complements the objectives of the BOWFEST project. Moorings C and D were recovered during September near the end of the BOWFEST oceanographic fieldwork near Barrow.

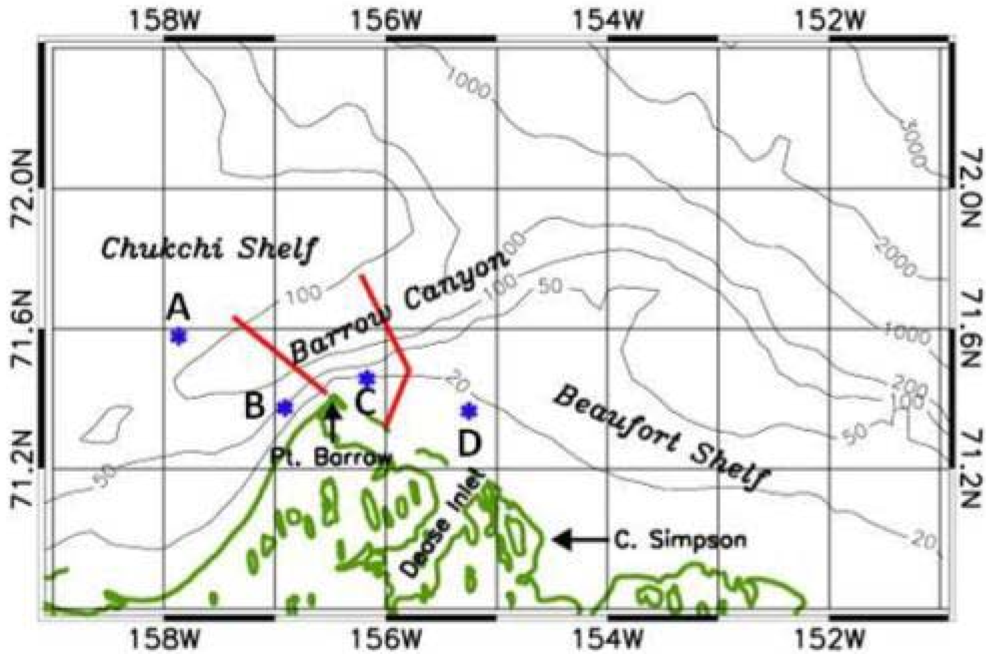

Figure III-1. *2011 oceanographic mooring deployment locations.*

Table III-1: *Mooring characteristics.*

Mooring	Depth	Instrumentation	Deployment	Recovery
A	70m	Current speed & direction, temperature, salinity	10 September 2010	08 October 2011
B	70m	Current speed & direction, temperature, salinity	19 August 2010	18 August 2011
C	15m	Current speed & direction, temperature, salinity	18 August 2011	13 September 2011
D	19m	Current speed & direction, temperature, salinity	18 August 2011	29 September 2011

Initial Results

According to the conceptual 'krill trap' model (Ashjian et al., 2010; Okkonen et al., 2011), weak or southwesterly winds that follow moderate-to-strong, upwelling-favorable easterly winds 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. The Barrow area wind record (Fig. III-2) shows that there were occurrences of upwelling-favorable winds (blue vectors) followed by weak winds (red vectors) during the 2011 BOWFEST field season. Based on the krill trap model, we expected that krill would be retained and aggregated on the western Beaufort shelf and that bowhead whales would be observed feeding. However, no bowheads were observed during the 2011 BOWFEST field season. In fact, bowhead whale groups were not observed in the Barrow area until late October 2011.

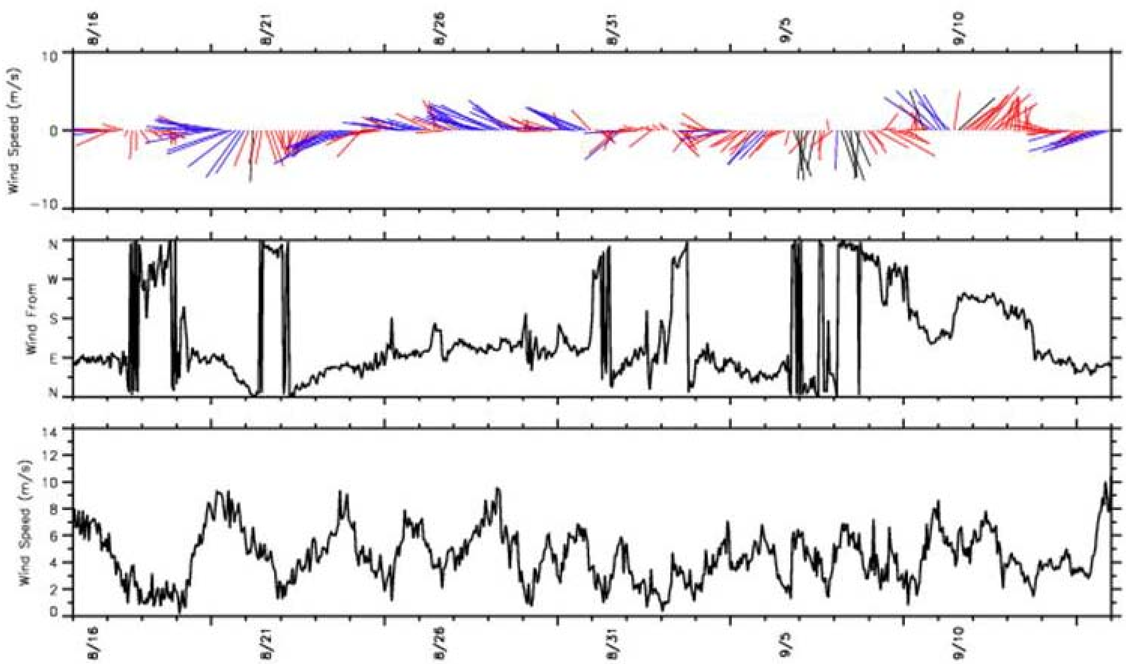

Figure III-2. *Winds at Barrow in 2011, showing vectors (top), direction (middle), and speed (bottom). Blue vectors depict winds that promote upwelling onto the western Beaufort shelf. Red vectors depict weak wind conditions that lead to aggregation of krill, if present, on the western Beaufort shelf.*

Moored acoustic Doppler current profilers (ADCP) deployed as part of the BOWFEST project and the NSF-funded AON project allow us to investigate possible causes for the late arrival of bowheads to the Barrow area. Year-to-year estimates of relative krill abundance at mooring locations were made by comparing the diel vertical migration (DVM) signatures inferred from time series of relative acoustic backscatter measurements acquired by moored ADCPs. Yearly bulk estimates of krill abundances on the western Beaufort shelf (mooring D, see Figure III-1 for location) were derived by computing an average DVM signal for each of the late summer 2009-2011 shelf mooring deployments. The mooring D deployment and recovery dates varied by a few days from year to year, but in each year the mooring period included dates between 20 August and 15 September. For each 0.5-m depth bin and 1-hour time interval, a 27-day average acoustic backscatter signal was computed. The resulting average DVM signals are shown in Figure III-3. Because the upper water column is often populated by good acoustic scatterers such as fish and air bubbles, the backscatter values in the lower water column are taken as better indicators of relative krill abundance. Comparing the average backscatter at depths below ~7.5 m indicates that the greatest abundance of krill on the western Beaufort shelf occurred in late summer 2009 and the least abundance occurred in late summer 2011. Although not shown, average backscatter was also calculated for only the weak wind ('active krill trap') periods during the 2009-2011 shelf mooring deployments. The same relative year-to-year krill abundances were obtained; the most krill in 2009 and the fewest krill in 2011. Interestingly, whale groups were observed on the shelf by boat and aerial teams in September 2009 and September 2010, but as mentioned above, not at all in September 2011. Estimates of krill abundance from net tows also indicated that fewer krill were present on the shelf in 2011 than in 2009 and 2010 (Figs. III-12-14).

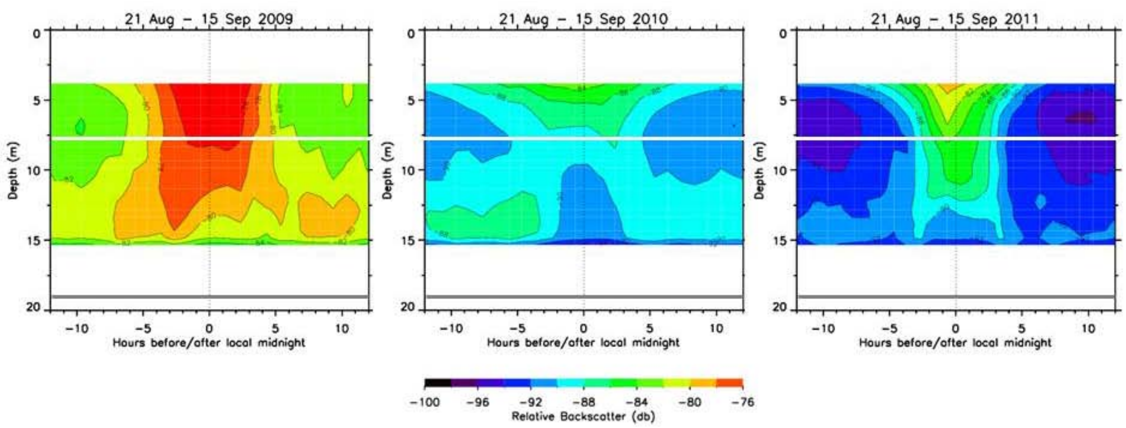

Figure III-3. *Time-averaged, ADCP-measured relative acoustic backscatter (decibels) at the Beaufort shelf mooring site D for late summer 2009, 2010, and 2011.*

Whereas the 'krill trap' mechanism is a localized phenomenon, Ashjian et al. (2010) point out that foraging opportunities available to bowhead whales near Barrow will also depend on upstream conditions: (1) the strength and persistence of northward-flowing currents that carry krill from the Bering Sea to the Barrow area (i.e., the krill transit time) and (2) the quantity, growth, and survival of krill during their northward transit.

To investigate the question of how much krill was entering the Barrow area from the south, a second ADCP mooring (mooring A, see Figure III-1 for location) was deployed in 70 m of water at 70.6ºN, 157.8ºW on the western side of Barrow Canyon in September 2010. The mooring was recovered in October 2011, serviced, and redeployed. The 13-month long ADCP record permits a bulk comparison of the krill abundance for similar time periods in different years: 11 September – 8 October 2010 and 11 September – 8 October 2011. Figure III-4 indicates that the krill abundance in the lower water column (deeper than ~27 m) upstream from the western Beaufort shelf foraging hotspot was greater in 2010 than in 2011. This result suggests that one reason the krill abundance on the western Beaufort shelf was greater in late summer 2010 than in late summer 2011 (cf. Fig. III-3) was that there were more krill potentially available to be upwelled and subsequently trapped in 2010.

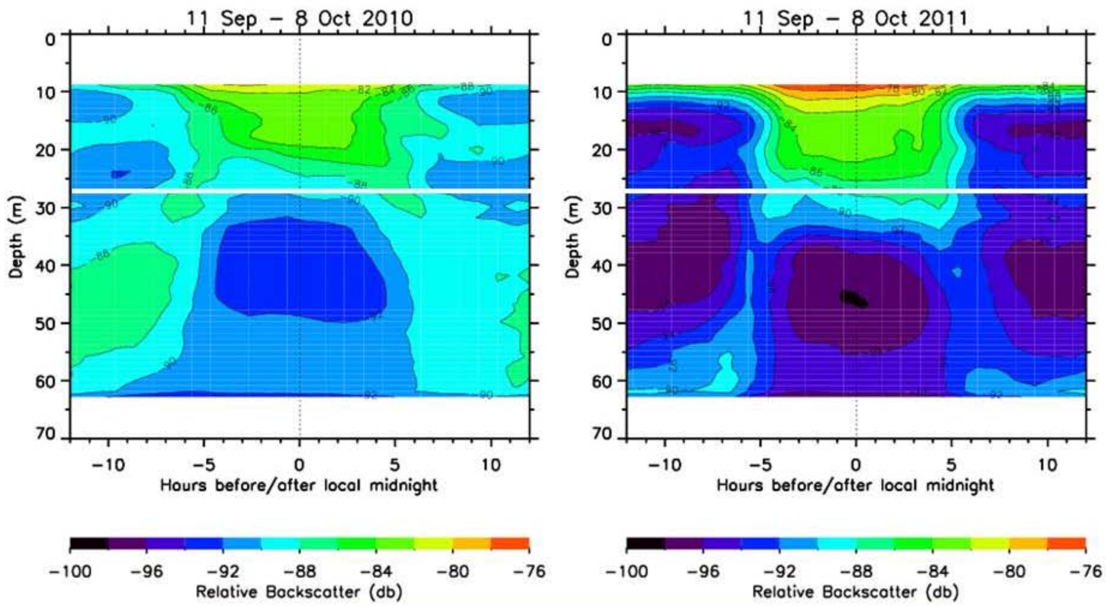

Figure III-4. *Time-averaged, ADCP-measured relative acoustic backscatter (decibels) at the western Barrow Canyon mooring site A for early autumn 2010 and 2011.*

The 2009-2011 ADCP-derived estimates of krill abundance suggest that there may be a relationship between the availability of krill on the western Beaufort shelf and the arrival times of bowhead whale groups in the Barrow area. Because Figures III-3 and III-4 indicate that krill were likely present on the western Beaufort shelf and were being carried to the Barrow area in September 2011, although in relatively fewer numbers than in prior years, and that no whale groups were seen in the Barrow area until late October, suggests that there might be a minimum threshold krill abundance on the shelf below which groups of whales are going to delay migration to the Barrow area to forage. If there is such a krill abundance threshold and meeting the threshold depends primarily on the numbers of krill being carried northward across the Chukchi Sea, then interannual variability in the times at which bowheads arrive at Barrow is a function of upstream conditions (e.g., krill brood strength, transit time, survival during transit). However, if meeting the krill abundance threshold on the shelf depends on the efficacy of the krill trap mechanism, then interannual variability is a function of the local wind field. Alternatively, the timing of the westward fall migration may depend on feeding conditions in the Canadian Arctic and not depend on feeding conditions at Barrow.

BROAD-SCALE OCEANOGRAPHY COMPONENT

Carin Ashjian, Robert Campbell, and Stephen Okkonen

The charter for the R/V *Annika Marie* was August 17-September 20, 2011 with the end date weather dependent (Table III-2). Six working days and 6 weather days, and mobilization days, expenses, and transit days were supported by our companion AON project. The boat transited from Prudhoe Bay on August 17-18 and returned to Prudhoe Bay on September 20. Mobilization of equipment to/from the boat in Barrow was accomplished on August 20 and September 18, respectively and in Prudhoe Bay on August 17. From August 21-September 17, there were 16 working days and 13 weather days.

Two short-term moorings were deployed on August 18; one was recovered on September 13. Bad weather precluded the R/V *Annika Marie* team from recovering the second short-term mooring prior to the end of the boat charter; this mooring was recovered on September 29 by Frederick Brower. A long-term, year-round mooring was turned around on August 19 (see mooring section). Surveys concentrated on three sampling lines that had been sampled during 2005-2010, with complete or partial surveys of Line 1 (once), Line 2 (three times), Line 4 (three times), and Line 6 (once) (Figure III-5). One of the samplings of Line 2, on September 5, was conducted completely at night to sample in darkness. The sampling of Line 1 also is a component of the 2011 Distributed Biological Observatory repeat transect sampling that was designed by the an international group of researchers as a means to gain repeated sampling at a common location. Additional sampling was conducted on the Beaufort shelf offshore of the Elson Lagoon barrier islands on E-W transects at ~5 and ~15 m. Barrow scientist Craig George, North Slope Borough-Department of Wildlife Management employee Ross Burgener, and local college student Sam George joined us for a day trip each (Table III-2).

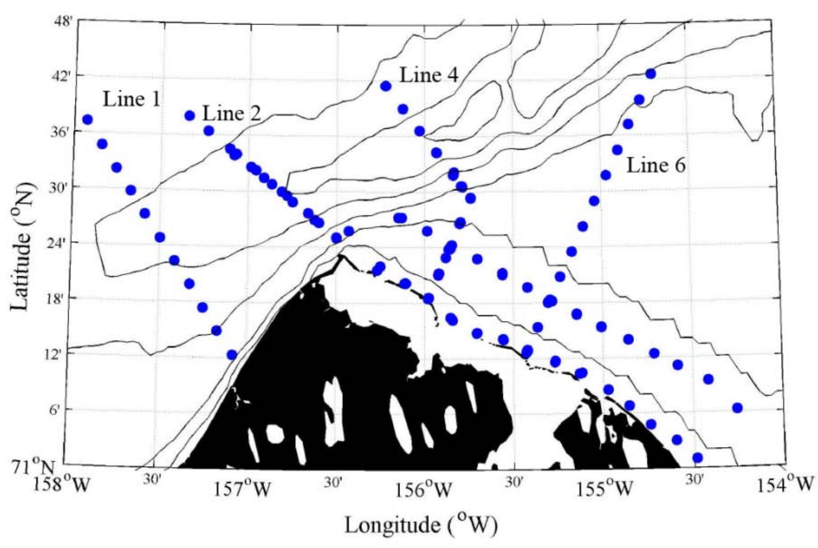

Figure III-5. *Locations of stations sampled in 2011. Underway sampling using the towed ADCP also was conducted between stations on Lines 1, 2, 4, and 6. Line 1 was included as a component of the international 2011 Distributed Biological Observatories.*

Table III-2: *R/V Annika Marie hours on the water by activity and participants in 2011.*

Date	Hours	Comment	People
17 Aug.	3	Mob/Transit	Alatalo, Okkonen, Kopplin, Fleming
18-Aug	13	Transit/Moorings	Alatalo, Okkonen, Kopplin, Fleming
19-Aug	4	Deploy Mooring	Campbell, Okkonen, Kopplin, Fleming, C. George, S. George
20-Aug		Mob	
21-Aug		Weather	
22-Aug	10.5	Line 4-Shakedown	Ashjian, Campbell, Okkonen, Alatalo, McEachen, Kopplin, Flemming
23-Aug	13	Line 2	Ashjian, Campbell, Okkonen, Alatalo, McEachen, Kopplin, Flemming
24-Aug		Rest	
25-Aug	13	Line 4	Ashjian, Campbell, Okkonen, Alatalo, McEachen, Kopplin, Flemming
26-Aug		Rest	
27-Aug	8	Line 2 Night	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
28-Aug		Weather	
29-Aug	14	Line 6	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
30-Aug		Weather	
31-Aug	10.5	Along-Shelf	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
1-Sep	15	DBO-Line 1	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
2-Sep		Weather	
3-Sep	13	Line 4	Ashjian, Campbell, Okkonen, Alatalo, Llopiz, Kopplin, Flemming
4-Sep		Weather	
5-Sep	9	Line 2 - Krill	Ashjian, Campbell, Okkonen, Alatalo, Llopiz, Kopplin, Flemming
6-Sep		Weather	
7-Sep		Weather	
8-Sep	12	Along-Shelf, East	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
9-Sep		Weather	
10-Sep		Weather	
11-Sep		Weather	
12-Sep	7	Along-Shelf	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming, C. George
13-Sep	8	Line 4	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming, R. Burgener
14-Sep	5.5	Along-Shelf	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
15-Sep		Weather	
16-Sep		Weather	
17-Sep	1.5	Attempted to go out	Ashjian, Campbell, Okkonen, Alatalo, Kopplin, Flemming
18-Sep		De-Mob	
19-Sep		Transit	Kopplin, Flemming
20-Sep		Transit	Kopplin, Flemming

The oceanographic sampling was very successful. One hundred twenty-seven (127) stations were occupied, including many with multiple types of instrument deployments or collections. Sampling at discrete stations was conducted using a CTD, ring nets, a Tucker Trawl, and Nisken bottles to collect water samples for determination of chlorophyll *a* and nutrient concentrations, for flow cytometry analyses to enumerate the abundances of phytoplankton and coccoid cyanobacteria (an indicator of Pacific Water), and for microscopic analysis for microplankton composition and abundance (a component of our companion NSF-funded Arctic Observing Network project). The acoustic Doppler current profiler (ADCP) was towed between stations on the across-shelf transects. Marine mammal occurrences also were recorded and passed on to C. George. The Acrobat towed vehicle (temperature, salinity, chlorophyll and CDOM fluorescence, optical backscatter) suffered an unfortunate collision with the seafloor that damaged the tow cable; we were unable to effect repairs and thus could not use the instrument during the remainder of the field season.

Plankton composition from a subset of the ring net tows and of the Tucker trawls has been analyzed. Samples for extracted chlorophyll concentration have been analyzed and can be used to ground-truth the fluorescence measurements from the CTD and Acrobat fluorometers. As part of our AON project, samples for nutrient concentration, flow cytometry, and microbial composition and concentration have been analyzed; samples for microzooplankton flow cytometry composition and abundance are in the process of being analyzed while nutrient concentrations have been analyzed.

Preliminary Results (2005-2011)

Hydrography

Virtually no sea ice was observed in 2005, 2007, 2009, and 2011, with 2007 being the lowest and 2011 the second lowest sea ice minima in the satellite record. The most sea ice was seen in 2006, while 2008 and 2010 showed late sea ice retreat or persistent sea ice to the east. In contrast to previous years, no bowhead whales were observed on the shelf during our 2011 sampling period. Ocean temperatures in 2011 were similar to those observed during 2005 and 2010 (Figs. III-6 & III-7), with warmest ocean temperatures at ~8°C. Significant year-to-year variability in the temperature-salinity characteristics of the waters sampled within the Barrow Canyon-western Beaufort shelf study area has been observed over the seven years (2005-2011) (Fig. III-6). The 2005, 2007, 2009, 2010, and 2011 surveys encountered very warm Pacific Water (>>4 °C), whereas the 2006 and 2008 surveys encountered much cooler Pacific Water. The presence of extensive sea ice cover in 2006 is reflected in the prevalence of sea ice meltwater; meltwater also was observed in 2008 but not significantly in the other five years. Not surprisingly, the T-S plots showing the fewest data points that were fresher and cooler than Pacific Water are from 2007 and 2011, years in which the areal extent of Arctic sea ice reached historical minima.

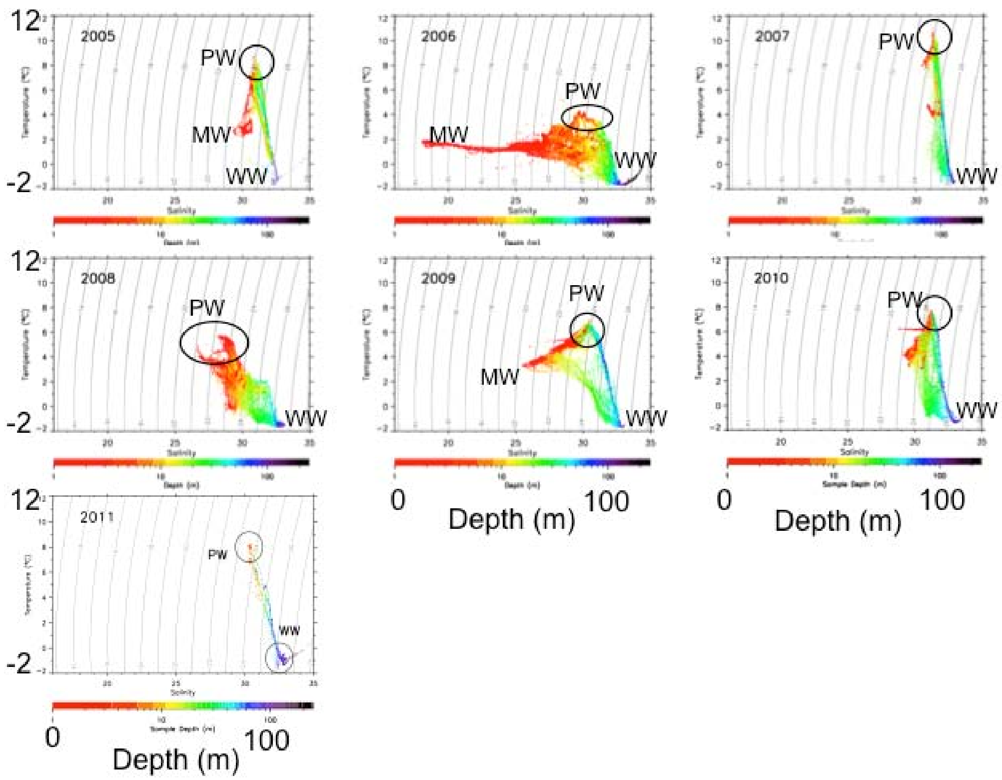

Figure III-6. *Temperature-Salinity plots of each year's aggregate (Acrobat and individual cast) CTD data. Representative water masses are Pacific Water (PW), Winter Water (WW), and Meltwater (MW). Curved lines are isopycnals (constant sigma-t). Color indicates water depth at each data location.*

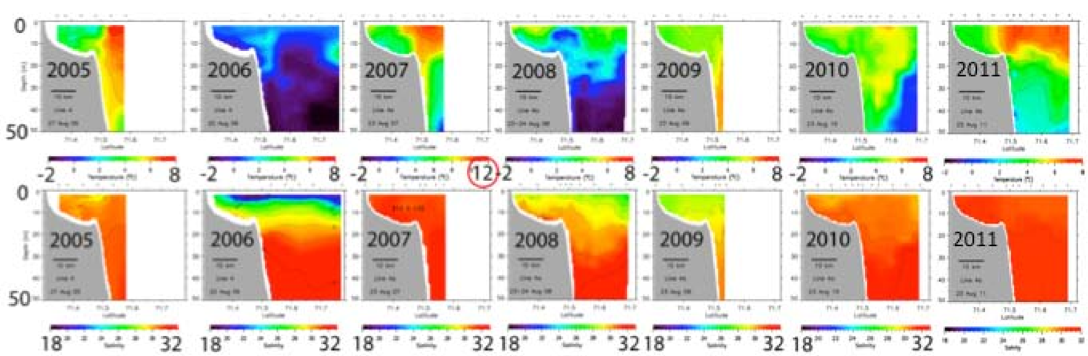

Figure III-7. *Temperature (upper row) and salinity (lower row) sections across a common transect (Line 4) of Barrow Canyon in late August of each year. Note very warm water (12 °C) observed in Barrow Canyon in 2007.*

Zooplankton/Whale Prey

Considerable interannual variability in biological oceanography and zooplankton composition and abundance has been observed between the seven years of our observations. For consideration of zooplankton abundance and composition between years, four regions in the study area were defined based on bathymetry and associated hydrography or, in the case of the Alaska Coastal Current (ACC), on the basis of hydrography alone (Fig. III-8). Stations near Elson Lagoon, in waters of 5 m or less, were designated “Coastal” and exhibit common hydrographic conditions but were easily identified using bathymetry. Stations to the west of those identified as being in the ACC were classified as being “Offshore” and were located in deep water. The ACC was identified on the basis of average water column temperature and salinity at each sampling location. Because the ACC can move eastward onto the shelf or westward off of the shelf, depending on the strength and direction of the wind, actual geographic location is not a good indication of water type along the shelf and slope. Locations where the ACC was present showed higher (>4°C) water temperatures than other locations. Samples collected on the Beaufort shelf that were not identified as being in the ACC were classified as “Shelf” samples.

Our initial work in Barrow (2005 & 2006) permitted us to identify a hypothesis where euphausiids (krill) are advected up onto the shelf during upwelling favorable winds (from the east, north-east) and are trapped there when upwelling is followed the movement of the strong, northeasterly Alaska Coastal Current up against the eastern edge of Barrow Canyon under low winds or winds from the south, preventing flow of water and intrinsic krill off of the western end of the shelf and concentrating the krill near Barrow by the prevailing westward flow on the shelf. This hypothesized “krill trap” is believed to result in the episodic formation of patches of krill and a favorable feeding environment for bowhead whales on the shelf near Barrow. To better understand and identify when the krill trap is operating, the speed and direction of the winds are analyzed to identify days of upwelling followed by days when the ACC traps water on the shelf (e.g., Figure III-2).

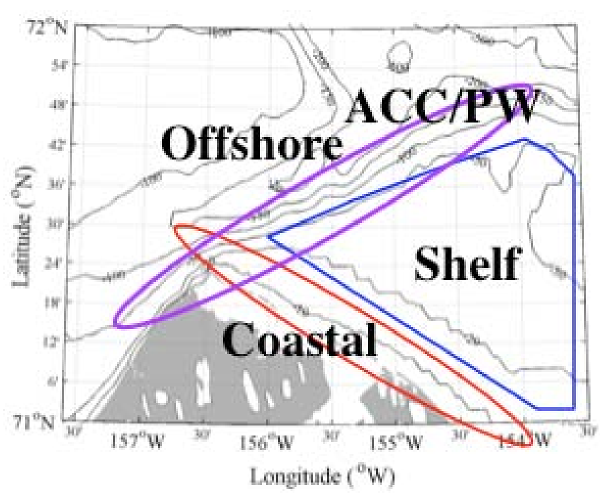

Figure III-8. *Approximate locations of the different regions into which zooplankton samples were classified.*

Total zooplankton abundance, determined from ring-net zooplankton samples (150 µm mesh nets, oblique tows) showed highest overall abundances in both the offshore and coastal regions during 2011 (Fig. III-9). Higher abundances were seen in both the shelf and ACC regions in 2007, 2010, and 2011 than in 2005, 2006, and 2008.

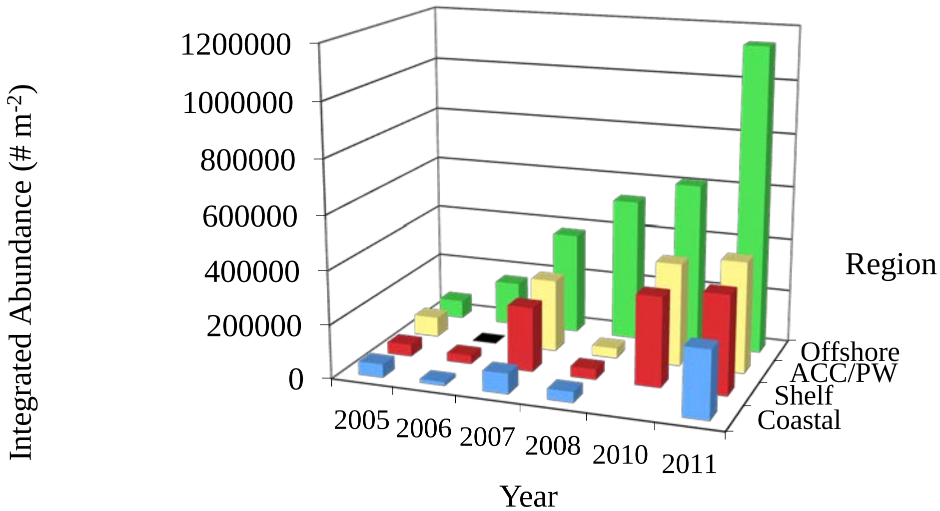

Figure III-9. *Integrated water column abundance of zooplankton from the different regions and for the different years. Sampling was conducted with 150 µm mesh, 60 cm diameter ring net. No samples with this net were collected in 2009 so no data are available for that year.*

Taxonomic composition likewise showed dramatic variation both between years and between regions within a year (Fig. III-10). For both the offshore and the shelf regions, *Pseudocalanus* spp. was always present but the relative abundance of that copepod genus varied between years. In 2007 and 2010, *Pseudocalanus* spp. dominated the shelf zooplankton but was reduced in importance in 2006, 2008, and 2011 and quite unimportant in 2005. *Pseudocalanus* spp. was never as important in the offshore region as in the shelf, but during the two "cold years" (2006 and 2008) approached 50% of the zooplankton composition. The very small cyclopoid copepod *Oithona* spp. was always prominent offshore but its importance on the shelf varied between years, being most important in 2005 and 2008 and substantially less so in other years (and especially in 2007). The anomalously warm year 2007 was marked also by a high proportion of appendicularians offshore. High proportions of benthic larvae were seen in 2011 in both regions. The large bodied copepod *Calanus glacialis/marshallae* was relatively important on the shelf at all times and offshore most years except 2011 when higher proportions of copepodid stages were observed.

Euphausiids, or krill, are important prey items for bowhead whales near Barrow. The abundance of krill on the shelf varies interannually, due in part to the effectiveness of the krill aggregating mechanism, the "krill trap". Krill abundance in the early years of the study was determined using oblique tows with a 60-cm ring net. Since 2009, a Tucker trawl also was used to collect krill since this net has no bridle in front of the net mouth (obscures the mouth) and can be towed somewhat faster (3 knots vs. 1.5 knots for the ring net) than the ring net, thus making it more difficult for krill to escape capture. Because the record with the ring net extends over a greater number of years, data from both collection tools are used in considering krill abundance.

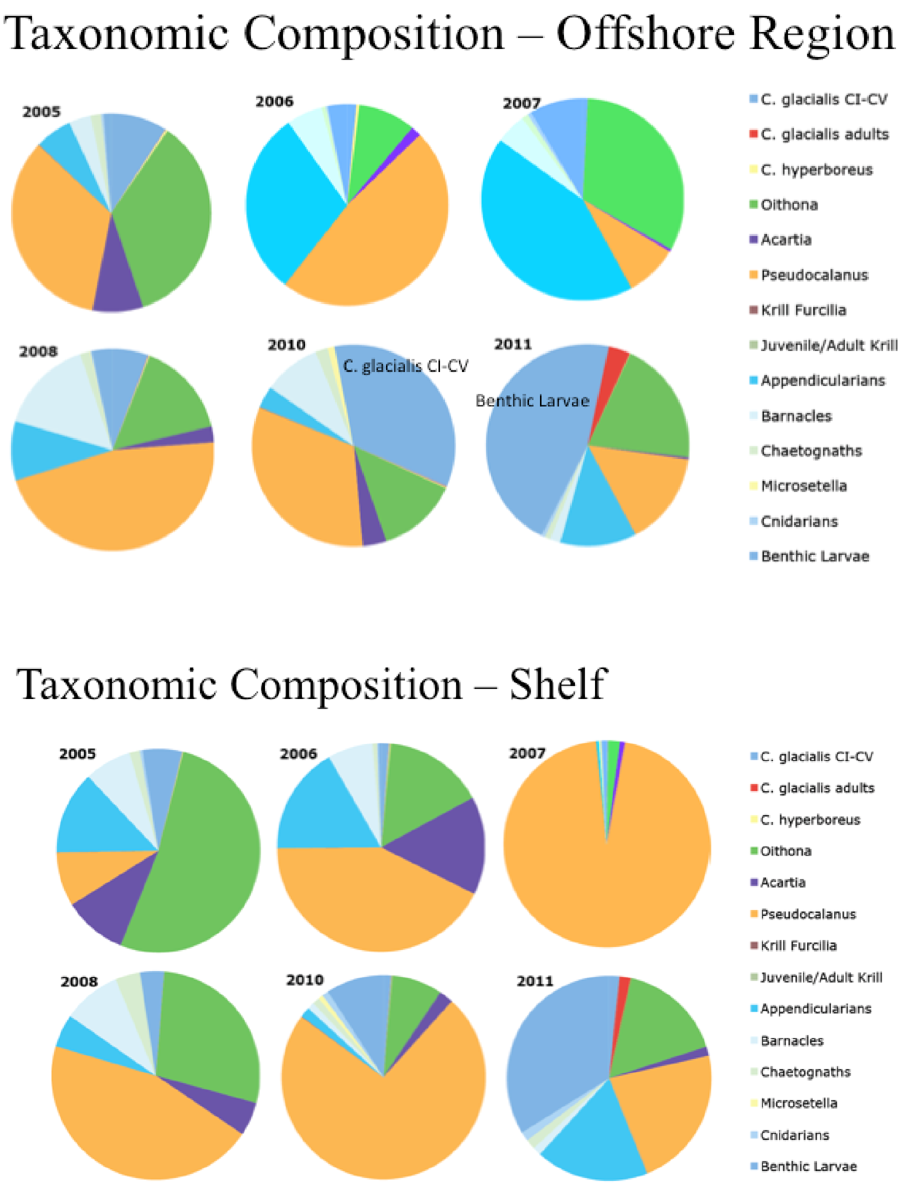

Figure III-10. *Taxonomic composition of zooplankton from the different regions and for the different years for the offshore region (upper panel) and the shelf region (lower panel). Sampling was conducted with 150 µm mesh, 60 cm diameter ring net. No samples with this net were collected in 2009 so no data are available for that year.*

Greatest abundances of krill were observed over the Canyon and seaward of the ACC (Fig. III-11). This suggests that this region may serve as the “source” for krill found near

Barrow, since we presently believe that krill are not endemic to the region and that they must be brought there from the Bering Sea in the prevailing northward flowing currents of the Chukchi Sea. Krill abundance on the shelf was enhanced during periods when the krill trap was "active" relative to when the krill trap was "inactive". Few krill were observed inshore except during when the krill trap was "active". Greater abundances of furcilia, the small younger larval stages of krill, were observed than of the larger juvenile and adults. Despite their relatively small size (in comparison with juveniles and adults), furcilia can be a useful prey item for bowheads, being larger than one of their commonly utilized prey, the large copepod *C. hyperboreus*.

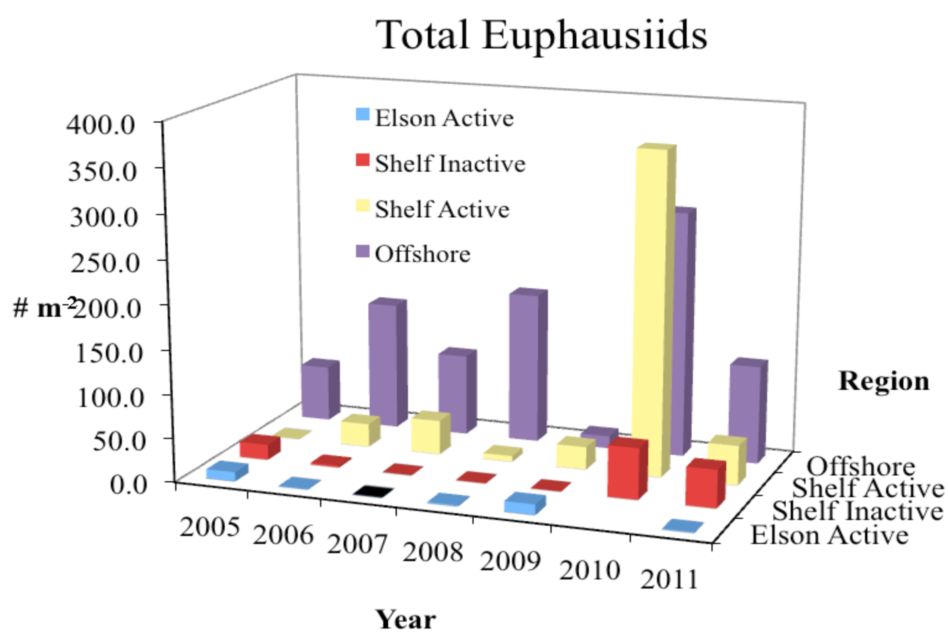

Figure III-11. *Average water column integrated abundance of krill from ring net tows in three different regions under different active or inactive "krill trap" conditions. Regions were defined as described above.*

The abundances of krill furcilia and juveniles/adults varied interannually. Data from the ring net tows regularly include the abundances of both furcilia and juveniles/adults, in contrast to data from the Tucker Trawls that may only contain abundances of the larger juveniles/adults (Fig. III-12). In 2009, furcilia were very rare. By contrast, in 2010, furcilia were much more abundant with greatest abundances found off of the shelf in Barrow Canyon. Even when the krill trap was active (red bars), furcilia abundance on the shelf was lower than off of the shelf. Nonetheless, furcilia were observed on the shelf in that year. In 2011, by contrast, few furcilia were observed on the shelf under any conditions. The larger juvenile/adult krill were observed in abundance on the shelf in 2009 but were rare on the shelf in 2010 and in 2011. Abundances were lowest in 2011.

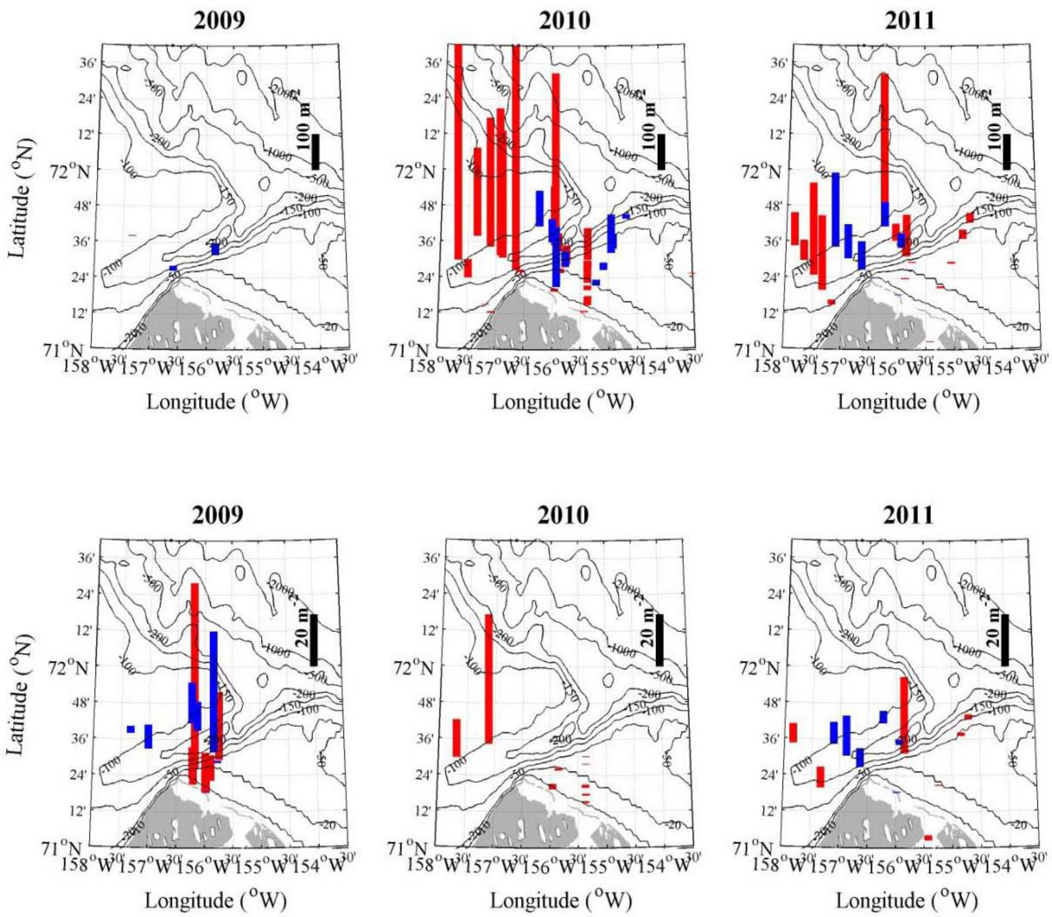

***Figure III-12**. Integrated water column abundances of krill furcilia (upper row) and juvenile and adult krill (lower row) collected using a 60 cm ring net equipped with a 500 µm mesh net. Blue indicates samples collected when the krill trap was NOT active; red indicates samples collected when the krill trap was active.*

Tucker trawl abundances of mostly juvenile/adult krill are much higher than those collected using the ring net due to the greater effectiveness of the Tucker trawl in capturing the elusive, fast swimming animals. Krill were found throughout the shelf and at the shelf break in 2009, with higher abundances on the shelf during periods when the krill trap was active (Fig. III-13). Most of these krill were juveniles or adults that were not effectively sampled using the ring net. In 2010, krill again were abundant on the shelf when the krill trap was active but most of these individuals were furcilia rather than the larger juveniles/adults. In 2011, few krill were seen on the shelf, consistent with the data collected using the ring net, and of the krill offshore, most were furcilia.

The relative importance of furcilia vs. juvenile/krill is emphasized when considering krill biomass rather than abundance (Fig. III-14). Krill biomass was much greater in 2009 than in

2010 due to the higher abundances of juveniles/adults in 2009 and the lower abundances of those larger life stages in 2010. Although not analyzed, it is clear from the abundance data from 2011 that low biomass of krill would have been available for bowheads as prey in 2011 as well, particularly on the shelf. *Calanus* spp. copepods have a higher C:N than do krill, because *Calanus* spp. store lipids for overwintering at a higher relative proportion to their total weight than do krill (Figure III-15). Therefore, *Calanus* spp. copepods are a higher energy food for the bowhead whale despite being of smaller size individually and potentially of lower total abundance and thus biomass.

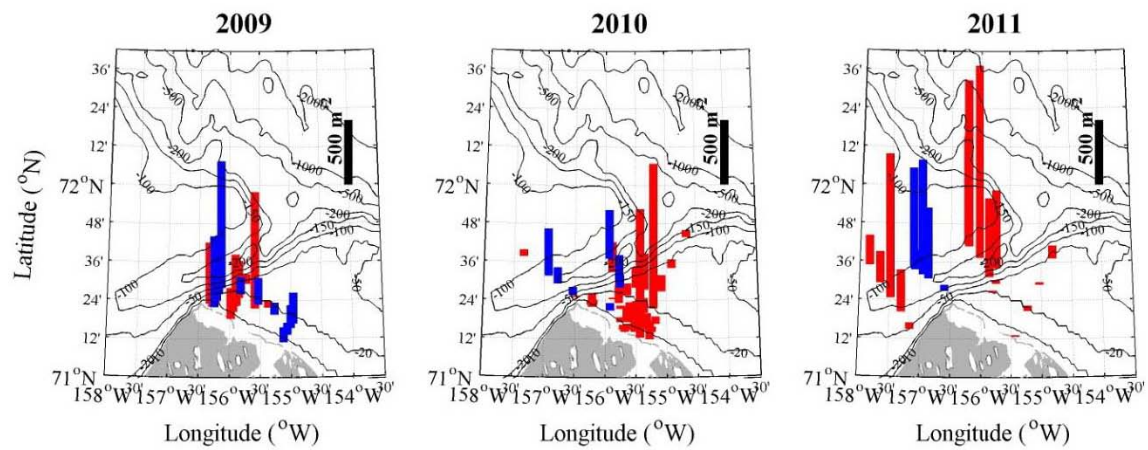

Figure III-13. *Integrated water column abundance of krill collected using a Tucker Trawl equipped with 333 µm mesh nets. Blue indicates samples collected when the krill trap was NOT active; red indicates samples collected when the krill trap was active.*

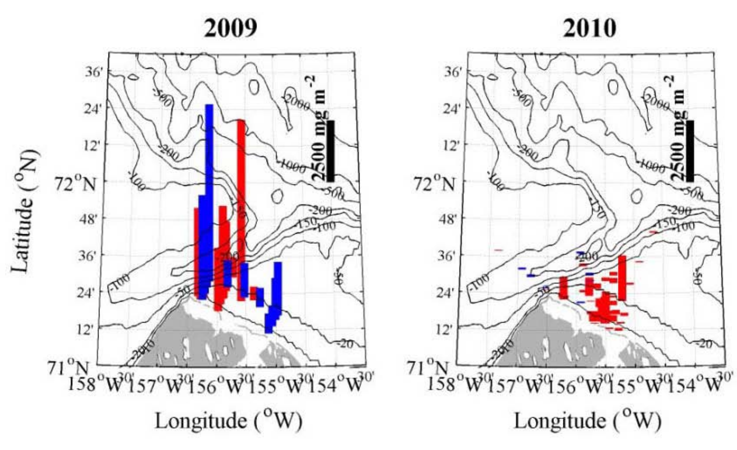

Figure III-14*. Integrated water column krill biomass collected using a Tucker trawl and estimated from silhouette analysis of the sample (e.g., Davis and Wiebe, 1985). Blue indicates samples collected when the krill trap was NOT active; red indicates samples collected when the krill trap was active.*

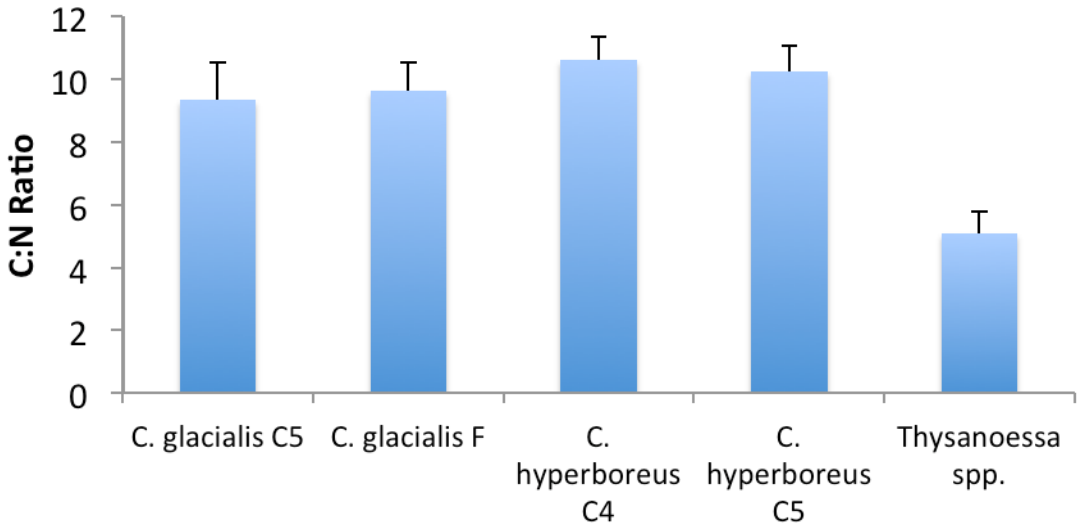

Figure III-15. *Carbon:nitrogen for common bowhead prey items: larger life stages of the copepods* *<u>Calanus glacialis/marshallae</u>* *and* *<u>C. hyperboreus</u>* *and the euphausiid/krill* *<u>Thysanoessa</u>* *spp. Carbon and nitrogen were determined for individuals that were picked from unpreserved samples, dried, and analyzed on a CN Analyzer.*

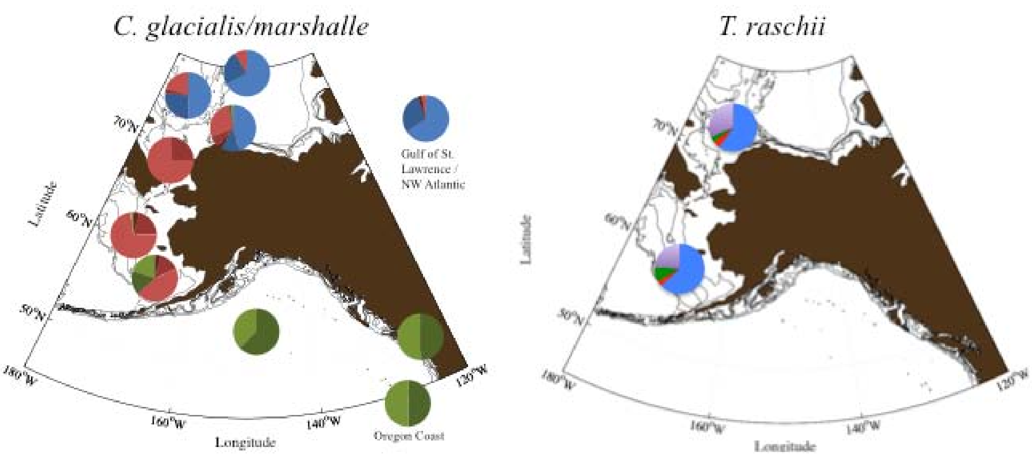

Figure III-16. *Haplotypes of the mtCOI gene showing different species (green=<u>C. marshallae</u>, red/blue=<u>C. glacialis</u>) and populations (different shades of each color) of <u>Calanus glacialis/marshalle</u> (left) and different populations (different colors) of the krill <u>T. raschii</u> at different locations in the Bering and Chukchi Seas. For reference, haplotypes for <u>C. marshallae</u> collected south of the Bering Sea and of <u>C. glacialis</u> collected in the Gulf of St. Lawrence/NW Atlantic are shown.*

It is hypothesized that the krill in the Chukchi Sea near Barrow are not endemic but are advected to that location by the dominant circulation in the Bering Sea. Similarly, circulation likely plays an important role in the distribution of species of the genus *Calanus*. *C. glacialis* and *C. marshallae* are nearly impossible to differentiate taxonomically. It has been believed that *C. marshallae* was dominant in the Bering Sea while *C. glacialis* was dominant in the Arctic.

Differentiating between these similar species and identifying pathways of advection and connectivity between populations can be achieved using molecular techniques. Our analysis of the mitochondrial COI gene has demonstrated that *C. marshallae* is confined to the southern Bering Sea and regions south of the Aleutians, that there exist both Bering Sea and Arctic Ocean haplotypes of *C. glacialis* (and thus populations), and that Bering Sea populations of *C. glacialis* appear to be advected into the Chukchi Sea in the dominant circulation. By contrast, the same haplotypes of the krill *T. raschii* are found in both the Bering and Chukchi Seas, suggesting that they originate from the same populations in the Bering Sea and that the krill found near Barrow have been advected there from the south.

Preliminary Conclusions – Broad Scale Oceanography

- Considerable interannual variability in physical and biological conditions that is related to large scale atmospheric conditions
- The krill trap effectively concentrates whale krill prey on the shelf near Barrow
- The biomass, and "value", of the krill varies with abundance and size. 2009 was of high value because larger krill were present. 2010 and 2011 had smaller krill
- Small scale physical features are associated with aggregations of krill and favorable feeding locations on the shelf
- Krill near Barrow are likely advected there from the Bering Sea: genetic analysis shows that population structure (as determined by haplotype frequency) at Barrow and in the Bering are very similar
- *Calanus* spp. copepods are a more lipid rich prey than krill
- The significance of Barrow as a feeding hotspot will depend on the frequency of upwelling and trapping of krill as well as the abundance and size of the krill
- Interannual variability in these latter factors indicates that it is not just the physical krill trap mechanism but also the upstream source that is important

Other Activities

In addition to the fieldwork and ensuing data analysis, the team has presented results of the research in several forums throughout the year. A poster describing a calendar, conceived and overseen by Okkonen and to which Campbell and Ashjian contributed, describing a year in the life of the bowhead whale was presented at the Alaska Marine Science Symposium on January 18, 2012 (Okkonen et al., 2012). Ashjan presented data collected as part of the BOWFEST-AON project at a Distributed Biological Observatory Workshop held in conjunction with the Ocean Sciences Meeting in Salt Lake City in February 2012. A manuscript (Okkonen et al., 2011) focusing on bowhead whale aggregations in association with fronts was published as was a brief note (Okkonen et al., 2012) in the Alaska Satellite Facility News and Notes.

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SECTION IV - TAGGING AND FINE-SCALE OCEANOGRAPHY

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Introduction and Methods

Our objectives for the 2011 fieldwork were to (1) attach archival tags to bowhead whales, and (2) intensively sample oceanographic conditions and prey distribution in proximity to the tagged whales. Two vessels were used for this operation, one for each objective: (1) a small ~20 ft boat contracted by BASC (the tagging boat, driven by Billy Adams), and (2) the MMS *Launch 1273*. As in 2009 and 2010, we used a short-term dermal attachment tag developed specifically for this project (Fig. IV-1).

The new tag was designed to overcome: (1) difficulties in approaching bowheads at close enough range for tagging, and (2) irregularities in the skin that made suction-cup tags ineffective. The new tag is fired from a compressed-air launcher instead of using the older pole deployment method, which increases the range of deployment considerably. The attachment consists of a solid core needle that is designed to implant in the epidermis and blubber. The implanted needle acts as an anchor for the recoverable archival tag that is attached to it via a severable tether. The tether passes through a corrosive foil release that is designed to allow detachment of the tag from the anchor after a specified time (1-3 hours). After attachment, the tagged whale is tracked via a high-frequency pinger incorporated in the tag and a hand-held directional hydrophone and receiver used to provide bearing and approximate distance to the pinger from the tagging boat. When the whale surfaces, the position is noted by the tagging boat, radioed to the *Launch 1273*, and a cast is conducted at that position with a vertical profiling instrument package consisting of a conductivity-temperature-depth instrument, chlorophyll fluorometer, turbidity sensor, and a video plankton recorder (VPR).

Results

Field operations for tagging and fine-scale oceanography took place from August 26 to September 19, 2011. The weather was quite poor for small boat work during 2011, allowing only 4 days at sea because of persistent high winds and fog. During this time on the water, bowhead whales were encountered on only one day. There was considerable effort expended to locate whales by the tagging group, the oceanography group (aboard the R/V *Annika Marie*), and the NOAA aerial survey team, yet no whales were found on the Beaufort Sea shelf within 25 nautical miles of Barrow (the operational area of the tagging team). Bowhead whales were located in Barrow Canyon during mid September; however, Barrow Canyon is a particularly challenging area to work because of strong currents that create unusually difficult wave conditions. Despite this, the weather on September 13 was very calm, and the NOAA aerial survey team located whales in Barrow Canyon, so we attempted to tag whales there. We successfully tagged one whale 42 km (23 nautical miles) from Plover Point. The tag remained attached for 96 minutes, during which the whale swam 14.7 km at an average speed of 9.1 km hr^{-1} (4.9 knots). We conducted 5 casts with the vertical profiling instrument package in proximity to the tagged whale. While the VPR detected some large copepods in the Canyon, abundances were very low and there was no evidence that the whale was feeding during the time the tag was attached.

From analyses of the 2009-2011 tagging events (listed in Table IV-1 and shown in Fig. IV-2), it is unlikely that any of the tagged whales fed during the time that they were tracked by us. This was quite surprising to us, considering the prevailing view that Barrow is an important feeding area for bowhead whales. It is possible that (1) the tagging process disrupts natural feeding behavior, or (2) the VPR is not adequately sampling the abundance of euphausiids (historically, the primary food resource off Barrow). Our experience conducting similar tagging, tracking, and sampling studies of North Atlantic and North Pacific right whales suggests, however, that these scenarios may be unlikely. We have found that automated zooplankton identification and counting instrumentation, such as the VPR and optical plankton counter (OPC), can adequately represent the abundance of the right whales' primary prey, large calanoid copepods. While the food resource off Barrow is small euphausiids, the VPR appears capable of imaging and counting these, as we observed during Event 5 during 2009, when euphausiid abundance on the Beaufort Sea shelf was very high. Behavioral disruption is also a possibility, but even if this occurred, we would *still* expect to sample high abundances of prey in proximity to the whales even in the absence of explicit feeding behavior. We did not observe this.

We also measured zooplankton abundance both in the presence ($n = 24$) and absence ($n = 20$) of bowhead whales, and using logistic regression, found no relationship whatsoever between the relative probability of whale occurrence and either euphausiid abundance ($p = 0.4029$) or large copepod abundance ($p = 0.8167$) (Fig. IV-3; similar results can also be obtained using non-parametric tests, such as the Mann-Whitney test). Regardless of whether behavioral disruption influenced our observations during the tagging events, had there been a strong relationship between bowhead occurrence and prey distribution, we would have detected it using this independent assessment. Using an identical approach of presence/absence sampling, we have previously found very strong relationships between the occurrence of right whales (both North Atlantic and North Pacific right whales) and the abundance of their primary prey, large calanoid copepods (Fig. IV-4). Even when using different methods to assess zooplankton abundance (nets, OPC, VPR) and right whale presence (sighting and acoustic surveys), a strong relationship is always apparent (Fig. IV-4). It is curious, therefore, that no such relationship was detectable for bowhead whales and euphausiids. Given the significant absence of whales in our operation area during 2007 and 2011, it appears that there is significant interannual variability in prey abundance that influences the occurrence of the whales. Even in years with moderate prey concentrations, bowheads often travel extensively on the Beaufort Sea shelf and do not occur solely in areas with high prey abundance. It is likely that the waters off Barrow are not always a rich feeding ground; however, the variability in prey abundance makes these waters worth visiting for bowheads.

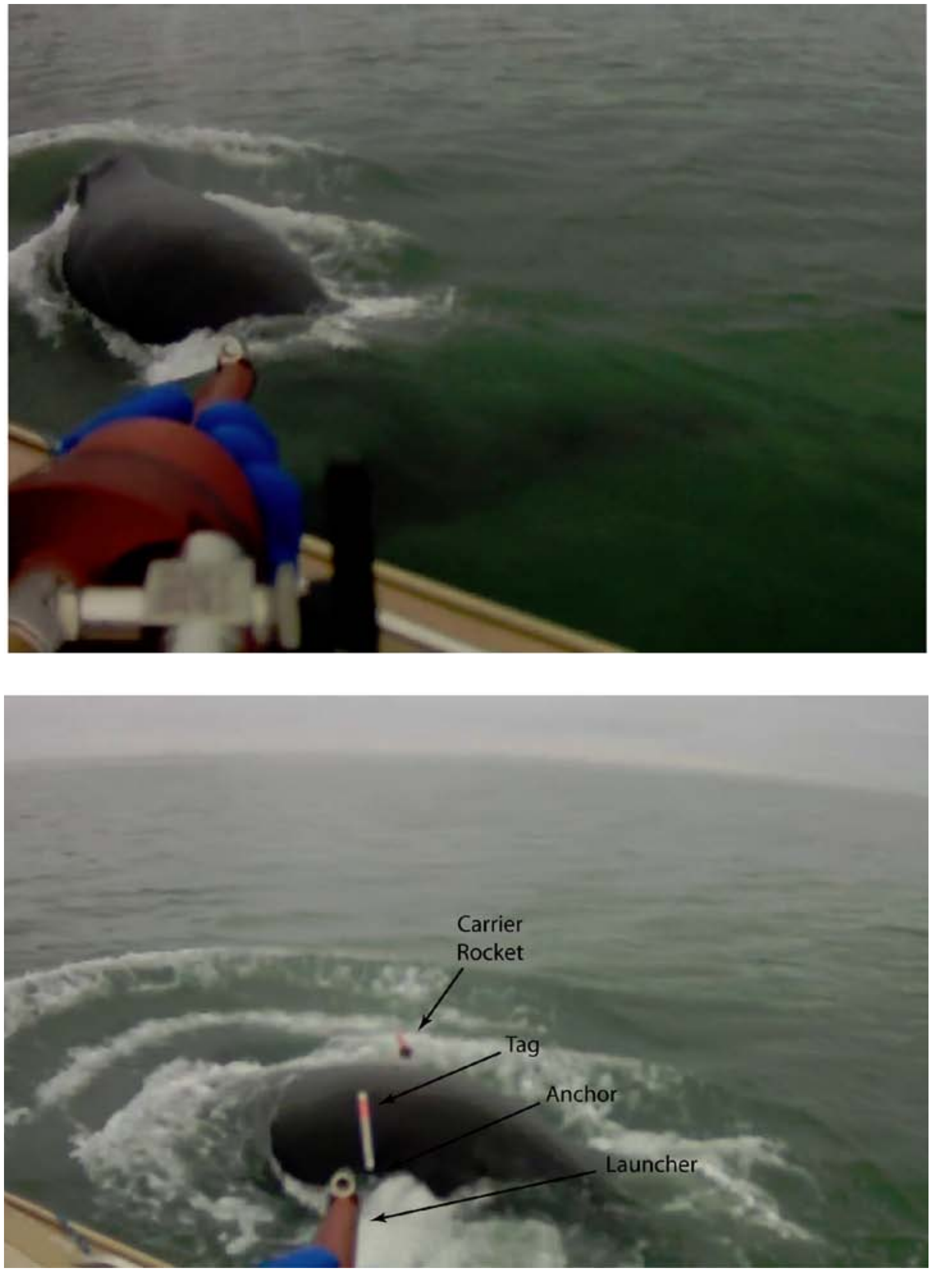

Figure IV-1. *(top) Close approach to bowhead whale immediately prior to tagging with short-term dermal attachment tag (2010, event 7). Note launcher in the foreground. (bottom) Successful attachment of projectile dermal attachment tag showing separation of dermal anchor, tag, and carrier rocket after contact with the whale. Images taken from video camera mounted two inches from tagger's right eye.*

Table IV-1: *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	Duration (min)	Distance (km)	Speed (km/hr)	No. casts
2009				
1	30	4.9	9.8	4
2	35	3.7	8.9	3
4	21	1.8	10.2	2
5	271	38.5	8.5	15
2010				
3	12	1.9	12.5	2
4	11	1.4	8.7	2
5	65	10.3	9.0	5
6	137	21.3	9.3	10
7	45	6.2	9.1	5
8	88	13.2	9.7	6
9	129	17.5	8.3	7
10	116	13.0	7.0	5
2011				
1	97	14.7	9.1	5
Average	81	15.4*	8.8*	5.5

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

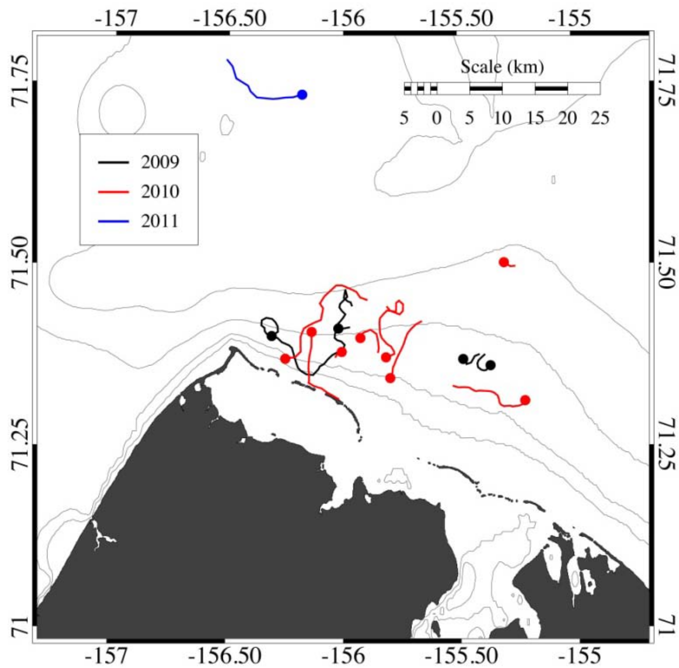

Figure IV-2. *Map of tagging locations (filled circle) and tracks (line) for all bowhead whales tagged in 2009-2011.*

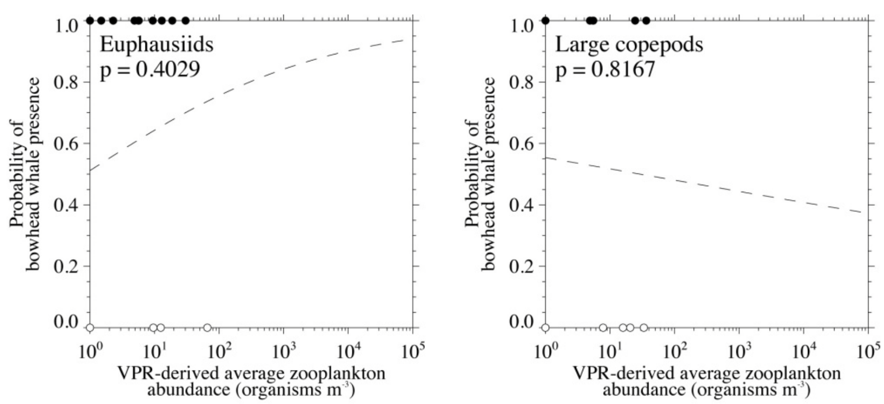

Figure IV-3. *Relationship between bowhead whale occurrence and (left) euphausiid and (right) large copepod abundance modeled with logistic regression (this study). Filled and open circles represent casts with and without whales nearby, respectively, and the dashed (non-significant) logistic regression line indicates how the relative probability of occurrence changes with zooplankton abundance. The significance of the regression is reported as a p-value.*

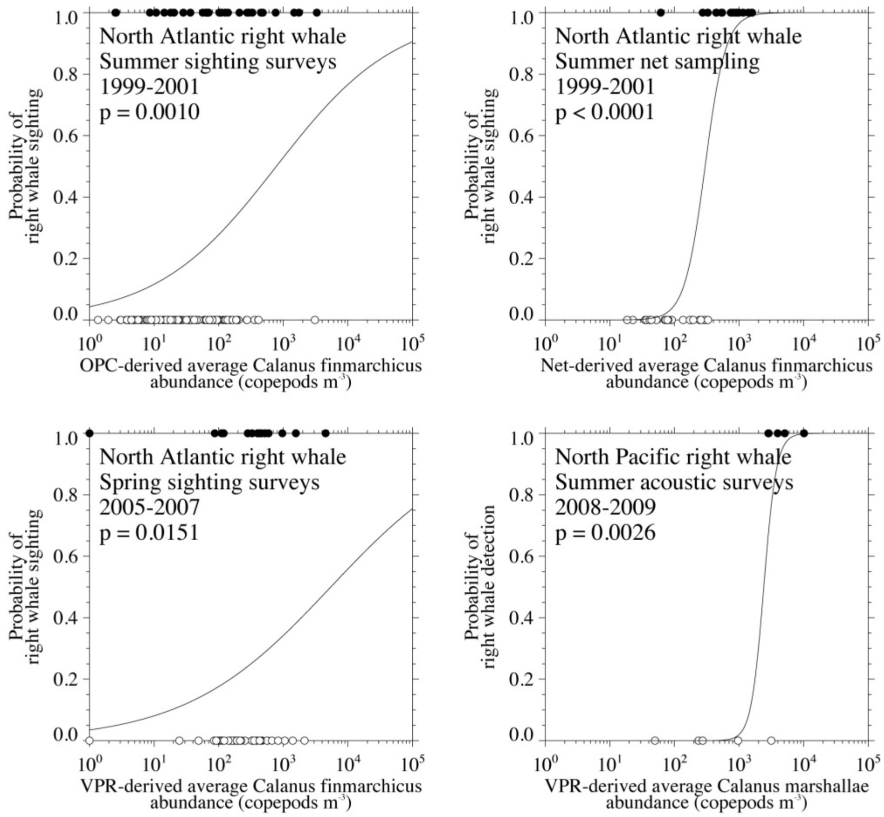

Figure IV-4. *Relationship between right whale occurrence and copepod abundance modeled with logistic regression for (upper left, upper right) North Atlantic right whales in the Bay of Fundy during 1999-2001, (lower left) North Atlantic right whales in the southwestern Gulf of Maine during 2005-2007, 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.*

SECTION V - NORTH SLOPE BOROUGH RESEARCH

J. Craig George[1], Gay Sheffield[2], and Lara Horstmann[3]

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[2]Alaska Department of Fish and Game
[3]University of Alaska Fairbanks

Introduction

The following report details the North Slope Borough (NSB) Department of Wildlife Management's (DWM) activities with the BOWFEST study through Fall 2011. The NSB's work includes sampling alimentary tracks of landed whales, boat-based whale surveys, project coordination, logistic assistance, boat-based behavioral observations of feeding whales, and more recently, bowhead digestion and energetics.

Objectives

1. Document bowhead whale prey amounts and types in the stomachs of whales landed during the subsistence hunt of bowhead whales.
2. Document locations and basic behavior of feeding whales from a boat-based platform.
3. Continue studies on bowhead digestive efficiency.

Results

Results are presented in three sections: 1) Diet studies, 2) Boat-based surveys, and 3) Digestive efficiency of bowhead whales.

1. DIET STUDIES

Stomach Examinations 2011

Examinations of stomach contents (and/or feces) of whales harvested by Eskimo hunters were made at the Beaufort Sea coastal communities of Barrow and Kaktovik as well from Gambell and Savoonga on St. Lawrence Island located in the Bering Sea (Fig. V-1). Of 27 harvested whales, postmortem exams were conducted on a total of 17 whales and samples were collected from 12 whales. Samples collected during postmortem exams came from the following locations: Barrow (Spring, n=0; Fall, n= 9) and Kaktovik (Fall, n=1), and St. Lawrence Island (Spring, n=2; Fall, n= 0).

Figure V-1. *Coastal communities from which diet samples were collected from subsistence harvested bowhead whales during 2011.*

Spring 2011

Barrow. Biological examinations were conducted on seven whales with four examined for evidence of feeding during spring 2011. None of the whales examined from Barrow contained any identifiable prey.

Saint Lawrence Island. Fecal samples were collected from two whales landed during the spring 2011 hunt and a suite of biological samples were collected from six whales. Preliminary examinations of these whales suggested feeding was occurring during the spring. Results from the analysis of fecal samples from Saint Lawrence whales are pending identification from Dr. Coyle's laboratory (UAF-SFOS).

Fall 2011

Kaktovik. Tissue samples were collected and stomach examinations were conducted on two of the three whales harvested at Kaktovik during fall 2011. Of the two harvested whales examined, one whale stomach (11KK2: a calf) contained approximately 12 liters of milk whereas, the stomach of 11KK3 contained > 20 liters of dark red liquid with large calanoid copepods in a largely undigested state (Fig. V-2). Of note, the lower intestines of 11KK3 contained much fecal material and a sample was collected.

Figure V-2. *Photo of large calanoid copepods that spilled onto the sand from whale 11KK3 when the stomach was accidentally opened during butchering.*

Barrow. At Barrow, 11 whales were landed during the fall 2011 hunt and a full suite of biological samples were collected. Examinations of nine stomachs suggested feeding took place frequently in the Barrow area.

Saint Lawrence Island. Due to the frequency and duration of severe weather events in the northern Bering Sea during fall 2011, no attempts were made to hunt bowhead whales.

Feeding status of whales for 2009-2011 at Barrow and Kaktovik

Unlike other villages, since the late 1970s whales have been routinely examined at Barrow and Kaktovik by biologists with regard to feeding status.

2009. Analysis of two Barrow bowhead stomach samples indicated that, in spring of 2009, both whales (100%) examined were feeding, another 2 whales were unexamined. In fall, 14 of 14 (100%) whales examined near Barrow were feeding (Fig. V-3) . Of the whales examined during fall of 2009 at Kaktovik, two of three were feeding (67%) and one whale's status was considered inconclusive with <10 prey items identified.

2010. Analysis of Barrow bowhead stomachs indicated that in spring of 2010, 0 of 12 whales (0%) examined were feeding, 11 were empty (92%), and one (8%) was inconclusive with <10 prey items identified. The stomachs of two harvested whales were unexamined. Of the eight whales examined for evidence of feeding during the fall 2010 harvest at Barrow, all eight (100%) contained some prey, with copepods occurring in at least 5 of those samples. Copepods appeared to be the primary prey by volume at Barrow in Fall 2010 (Fig. V-3) unlike most past seasons in which euphausiids were the dominant prey (Lowry et al., 2004). Surprisingly, of the three whales examined during fall 2010 at Kaktovik, all (100%) were inconclusive with <10 prey items identified.

2011. Analysis of Barrow bowhead stomach samples indicated that in spring of 2011, none (0%) of the four sampled bowhead whales were feeding. The stomachs of three harvested whales remained unexamined. Of the nine whales examined for evidence of feeding during the fall 2011 harvest at Barrow, all (100%) contained prey and were considered feeding (Fig. V-3). Of the two whales examined during the fall 2011 harvest at Kaktovik, one animal was a calf (11KK2), leaving 11KK3 as the one viable stomach sample from Kaktovik. The presence of several liters of relatively undigested copepods and much fecal material in the intestines of 11KK3 suggests a feeding strategy and diet similar to previous examinations of bowhead whales sampled near Kaktovik during fall.

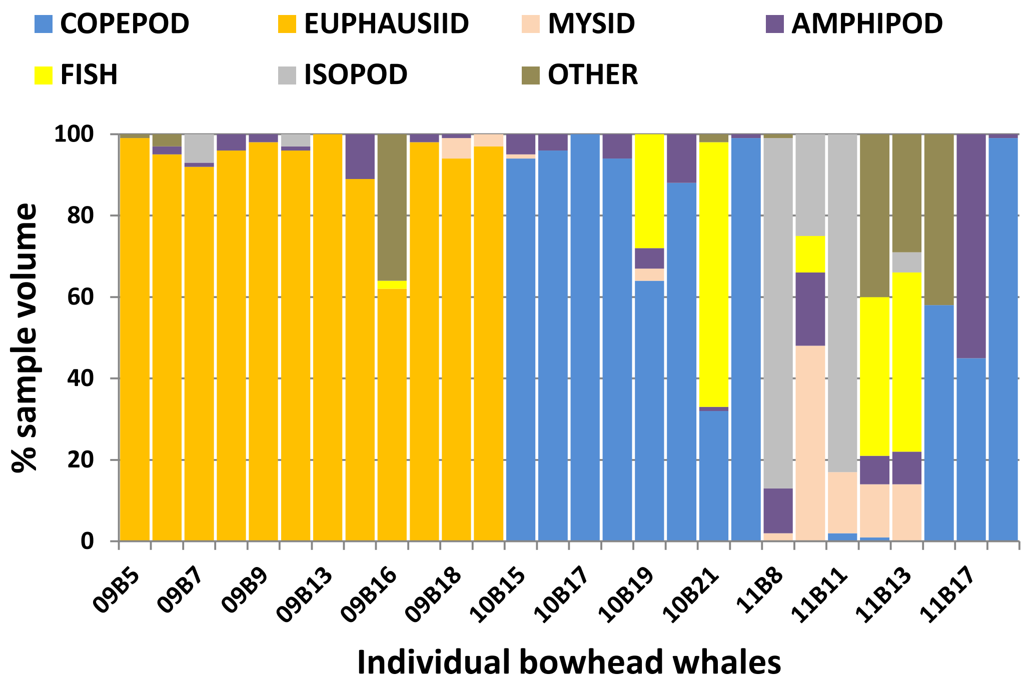

Figure V-3. Percent volume for bowhead whale stomach samples collected during fall near Barrow during 2009-2011.

2. LOCAL BOAT-BASED STUDIES

In 2011, we collected boat-survey information on whale location, number and behavior from a number of sources (Fig. V-4; Table V-1). These included surveys by locally chartered boats by the NSB, vessels associated with BOWFEST such as *Launch 1273* and R/V *Annika Marie*, local hunters, and vessels used for the gray whale tagging study. We have records for a total of 77 surveys conducted by the boats associated with the study; however, tracks were not collected for every survey. Boat surveys 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, preliminary tallies indicate only 25 bowhead whales were seen (Table V-1). This is remarkably low compared with past years (e.g., 213 bowhead whales were seen during the 2010 season). A total of 80 gray whales were seen and 57 belugas were seen.

The effort for all 2011 surveys was 623 hours which was much greater than any previous season (Table V-2). Regardless, as noted above, very few bowheads were seen. We concluded based on data from past BOWFEST seasons that bowhead abundance was exceptionally low in summer/fall 2011.

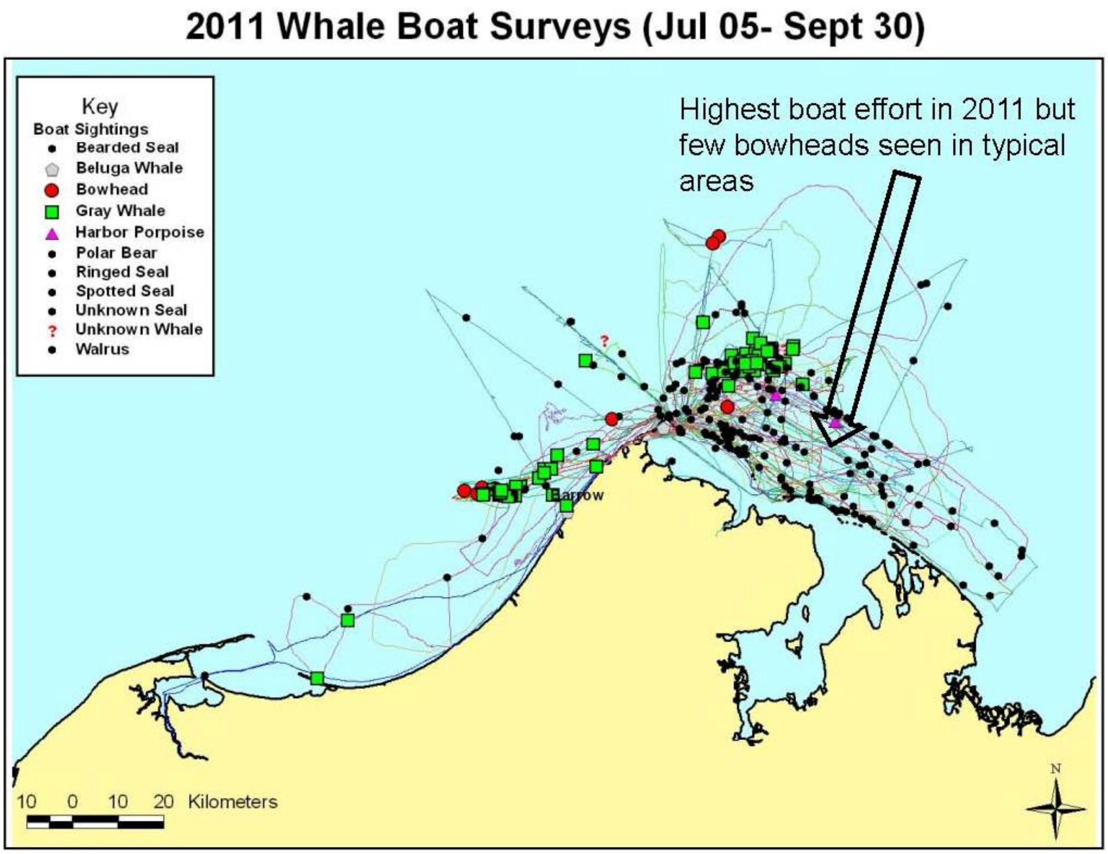

Figure V-4. *Survey effort and sightings obtained during small boat surveys in 2011.*

Table V-1. *Total whale sightings by day for boat-based surveys in 2011.*

Date	Bowhead	Gray Whale
6/28/2011	2	
7/5/2011	0	2
7/6/2011	0	2
7/9/2011	1	
7/14/2011	0	
7/15/2011	0	
7/18/2011	11	10
7/19/2011	0	
7/20/2011	0	
7/21/2011	0	
7/22/2011	0	1
7/23/2011	0	1
7/24/2011	0	
7/26/2011	0	
7/27/2011	0	5
7/28/2011	0	
7/31/2011	0	1
8/1/2011	11	29
8/5/2011	0	2
8/8/2011	0	
8/10/2011	0	
8/15/2011	0	4
8/17/2011	0	3
8/18/2011	0	10
8/19/2011	0	
8/22/2011	0	3
8/23/2011	0	
8/25/2011	0	7
8/28/2011	0	
8/29/2011	0	
Totals	**25**	**80**

Table V-2. *Effort by season for the NSB boat-based surveys.*

Year	Total effort (hr)
2008	82
2009	194
2010	322
2011	623
Total	**1220**

3. Digestive Efficiency

Samples of digestive 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, duodenum, and colon (Table V-3).

As in past seasons, 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), 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).

The digestive efficiency studies at UAF (Dr. Horstmann) are progressing well. Below are the milestones achieved through 2011:

- Intestinal tracts of 2 whales were sampled in detail during Fall 2011 and partial sets were obtained from 9 additional fall whales. Preliminary findings from both 2010 and 2011 are listed in Table V-3
- Detailed sampling included: forestomach, fundic and pyloric chamber, duodenal ampulla, duodenum, jejunum, ileum, ileoceacal junction, upper and lower colon
- Blood chemistry parameters (ALB, ALP, AST, ALT, AMY, Ca, GGT, BUN, TP, Glob, CK, Phos, Mg, TBil, GLU, Na, K, CRE) were analyzed for 9 fall whales
- All fall 2011 stomach content and fecal samples have been lypholized and await analysis for bomb-calorimetry, lipids, ash, protein, and stable isotopes
- Preliminary results were presented at the 19th Biennial Conference on the Biology of Marine Mammals, Tampa, Florida in 2011 and at the Alaska Marine Science Symposium, Anchorage, Alaska in 2012
- Contributed to BOWFEST calendar and added the Energetics section for month of "November")

Table V-3. *Preliminary findings from Digestive Efficiency Analyses (Horstmann Lab).*

Location	Season	Compartment	Sample	%Water	%Lipid	%N	%Ash	Crude Protein	Cal. content [kJ/g]	Extraction 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	54.0±5.3
		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	Forestomach	0	-	-	-	-	-	-	-
		Duodenum	0	-	-	-	-	-	-	
		Colon	14	86.1±4.4	TBD	5.0±2.2	TBD	TBD	19.4±5.3	
St. Lawrence I.	Spring 2010	Forestomach	0	-	-	-	-	-	-	-
		Duodenum	2	87.7±0.3	TBD	10.2±2.7	TBD	TBD	23.3±3.0	
		Colon	4	79.0±7.2	34.8±7.6	6.2±1.3	TBD	TBD	22.5±3.0	
Wainwright	Spring 2010	Forestomach	1	93.2	TBD	6.4	TBD	TBD	23.0	-
		Duodenum	0	-	-	-	-	-	-	
		Colon	0	-	-	-	-	-	-	
Barrow	Fall 2010	Forestomach	4	90.3±2.7	TBD	TBD	TBD	TBD	25.4±2.9	45.3±12.9
		Duodenum	4	88.3±6.1	TBD	TBD	TBD	TBD	21.7±3.1	
		Colon	5	81.0±4.1	TBD	TBD	TBD	TBD	15.7±4.4	
Kaktovik	Fall 2010	Forestomach	0	-	-	-	-	-	-	-
		Duodenum	0	-	-	-	-	-	-	
		Colon	2	82.6±1.6	TBD	6.7±0.6	TBD	TBD	18.4±1.0	
St. Lawrence I.	Spring 2011	Forestomach	0	-	-	-	-	-	-	-
		Duodenum	0	-	-	-	-	-	-	
		Colon	2	73.0±0.8	10.6±6.1	4.5±0.5	TBD	TBD	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

Location	Season	Compartment	Sample	%Water	%Lipid	%N	%Ash	Crude Protein	Cal. content [kJ/g]	Extraction Efficiency
		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	
H_0: no difference in extraction efficiency among years										*P*=0.32

Acknowledgements--We thank the Barrow, Kaktovik, and Saint Lawrence whaling communities and local Whaling Captains Associations for supporting and participating in this study. We thank BOEM for the vision and the funding of BOWFEST and the NSB DWM staff for their assistance. We appreciate the dedication, patience, and careful handling of the boat survey data by Barbara Tudor and Cyd Hans during the project. Rob Delong did a fine job helping analyze boat survey data and produced the maps in this report. The Barrow Arctic Science Consortium provided valuable assistance with boat logistics for the surveys. Barrow boat captains who were particularly helpful include: Fred Brower, Billy Adams, Harry Brower, Billy Okpeaha, and others.

BOWFEST PRESENTATIONS AND MEETINGS SINCE 2011

Note: This listing does not include telecons or informal meetings, nor does it include daily discussions of scientific and logistic protocol held within each research party.

*Posters on the Alaska Fisheries Science Center website.

2011 Jan 17-21: Alaska Marine Science Symposium, Anchorage. The following presentations were based, at least in part, on BOWFEST research:

Ashjian, C.J., Campbell, R.G., Okkonen, S.R., Sherr, B.F., Sherr, E. B. Year-to-year variability of ocean conditions across Barrow Canyon and the western Beaufort Shelf: 2005-2010. Oral presentation.

Berchok, C. L., K. M. Stafford, S. L. Grassia, J. L. Crance, D. K. Mellinger, S. Heimlich, S. E. Moore, J. C. George, F. Brower. Passive Acoustic Monitoring. Oral Presentation.

*Mocklin, J, L. Vate Brattström, K. Goetz, and D. Rugh. Advanced techniques for improving aerial photography of whales. Poster.

*Mocklin, J, K. Goetz , D. Rugh, and L. Vate Brattström. BOWFEST aerial survey 2010. Poster.

Okkonen, S.R., Ashjian, C.J., Campbell, R.G. Does the Alaska Coastal Current carry krill to the Arctic? Poster.

*Vate Brattström, L., K. Goetz, D. Rugh, C. Ashjian, S. Okkonen, and R. Campbell. Bowhead whales feeding in echelon formation. Poster.

2011 Jan 18: BOWFEST Workshop, Anchorage. Logistics and results of the 2010 field season were discussed, plans for 2011 were formulated, and discussions about wrap up and papers resulting from this research were held; 40 attendees.

2011 Aug 1: Hollings Scholar Final Presentation

Wright, D. L. Short term interannual comparison of bowhead whale (Balaena mysticetus) calls off Barrow, AK in the Western Alaskan Beaufort Sea during fall; 2008-2010. Oral Presentation

2011 Oct 31-Nov 4: Acoustic Society of America Conference, San Diego, CA

Grassia, S. L., C. L. Berchok, D. L. Wright, M. O. Lammers. Interannual temporal and spatial distribution of bowhead whales in the Western Alaskan Beaufort Sea; 2007-2010. Oral Presentation.

2011 Aug 26: BOWFEST PIs meet in Barrow to discuss field season logistics.

2011 Sept 15: BOWFEST dinner meeting in Barrow with researchers and support crew.

2011 Nov 28-2 Dec: Biennial Marine Mammal Conference in Tampa, Florida:

*Grassia, S., C. Berchok, D. Wright, and P. Clapham. 2011. Interannual temporal and spatial distribution of bowhead whales in the western Alaskan Beaufort Sea; 2007-2010. Poster.

Horstmann-Dehn, L., C. George, G. Sheffield, and M. Baumgartner. 2011. Bowhead whale feeding efficiency – making a living in the Arctic. Poster.

Lysiak, N., M. Baumgartner, and J.C. George. 2011. Correlating shifting baselines in the Arctic to long-term bowhead whale isotope records. Poster.

*Mocklin, J., L. Vate Brattström, K. Shelden, K. Goetz, and D. Rugh. 2011. Barrow, Alaska: Pit stop on the bowhead highway? Results from aerial surveys during the Bowhead Whale Feeding Ecology Study (BOWFEST). Poster.

*Vate Brattström, L., K. Goetz, D. Rugh, C. Ashjian, S. Okkonen, and R. Campbell. Bowhead whales feeding in echelon formation. Poster.

2012 Jan 16-20: Alaska Marine Science Symposium, Anchorage. The following presentations were based, at least in part, on BOWFEST research:

*Grassia, S., C. Berchok, D. Wright, and P. Clapham. 2012. Interannual temporal and spatial distribution of bowhead whales in the western Alaskan Beaufort Sea; 2007-2010. Poster.

Horstmann-Dehn, L., C. George, G. Sheffield, and M. Baumgartner. 2012. Bowhead whale feeding efficiency – making a living in the Arctic. Poster.

Lysiak, N., M. Baumgartner, and J.C. George. 2012. Correlating shifting baselines in the Arctic to long-term bowhead whale isotope records. Poster.

McEachen, H.J., S.R. Okkonen, and R.R. Hopcroft. 2012. Measuring Arctic zooplankton advection in the Bering and Chukchi Seas. Poster.

*Mocklin, J., L. Vate Brattström, K. Shelden, K. Goetz, and D. Rugh. 2012. Results from five years of aerial surveys during the Bowhead Whale Feeding Ecology Study (BOWFEST) off Barrow, Alaska. Poster.

Okkonen, S.R., D. Jones, C. Ashjian, M. Baumgartner, R.G. Campbell, J. Citta, J.C. George, K. Goetz, W. Maslowski, J. Mocklin, D. Rugh, L. Quakenbush, K. Stafford, and L. Vate Brattström. 2012. A year in the life of the bowhead whale: an educational outreach product in calendar format. Poster.

Stafford, K., S. Moore, and C. Berchok. 2012. Acoustic detections of bowhead and beluga whales in the Beaufort Sea and the Chukchi Plateau 2008-2009. Poster.

2012 March 12-13: BOWFEST workshop, Seattle. Principle Investigators gave oral presentations summarizing all 5 years of BOWFEST research. Logistics and expectations for producing the final report were discussed.

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