REPORT OF THE 2010 BOWHEAD WHALE SURVEY AT BARROW WITH EMPHASIS ON METHODS FOR MATCHING SIGHTINGS FROM PAIRED INDEPENDENT OBSERVATIONS

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ABSTRACT

The 2010 ice-based survey of bowhead whales migrating past Barrow, Alaska, began on 31 March and ended on 28 May. Two observation locations were used (sequentially) in 2010, and each location had both a primary perch and a second independent observer (IO) perch. The 2010 survey season began with an unusual pulse of bowheads in late March which has not been recorded in any prior year. We speculate that early lead development (possibly associated with climate change) together with an increasing bowhead population are two explanatory factors. A total of 1,332 new (including 12 calves) and 242 conditional whales were seen in 397 hours of watch from the primary perches. The period when independent observations were made was from 30 April to 25 May. A total of about 1,200 new whales were seen in 304 hours of IO watch. Field methods for operating IO perches were developed, as were methods for real-time and post hoc matching of whale sightings between perches. Custom software, BHTracker, was developed to aid with matching. A total of 759 matches were made from 3,188 whale sightings, although many of the 3,188 sightings were known re-sightings of the same animal(s), so the effective matching rate is much higher than 759/3188. Substantial portions of the bowhead migration occurred during times when sighting was impossible due to ice and weather conditions. Therefore, no abundance estimate will be attempted from the 2010 data. However, the survey yielded a large amount of IO data, from which estimates of detection probabilities will be made.

INTRODUCTION

Ice-based surveys to estimate the abundance of the Bering-Chukchi-Beaufort Seas (BCBS) population of bowhead whales (*Balaena mysticetus*) have been conducted off Point Barrow since the late 1970s. The 2010 survey marks the 21th survey attempt since 1977 when rigorous efforts to estimate population size began. Whales are visually counted together with acoustic surveillance to determine the offshore distributions they migrate from the Bering to the Beaufort Sea (Krogman *et al*., 1989; George *et al*., 2004).

The survey requires maintaining a watch from the shorefast ice margin for about seven weeks during the migration. This paper describes the 2010 ice-based survey, field impressions, the IO methods, and matching work conducted in 2010.

In 2010, the survey effort began on 31 March and ended 28 May. Like other high-latitude cetacean surveys, the ice-based survey is sensitive to environmental conditions and has failed in about half the attempts since its inception. The primary objectives of the 2010 survey were to estimate the abundance of BCBS bowheads and detection probabilities using two independent observations sites (hereafter perches).

A critical component of the 2010 survey was the independent observer (hereafter IO) experiment to estimate detection probabilities from fully independent sightings from each of two perches. To analyze the IO data, we need to match sightings made independently from the two perches set close together operating throughout the season. Details of the IO methods are described below.

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METHODS

The methods used in the 2010 ice-based bowhead survey are consistent with past seasons dating back over 30 years (Krogman *et al*., 1989; Zeh *et al*., 1993; George *et al*., 2004). A major exception is that in 2010 we collected data from a fully independent two-perch design in order to estimate detection probabilities. Details of the survey methods follow.

Basic Survey methodology

Visual counts are made from a perch situated on top of a high ice ridge located on the shorefast ice as near to edge of the shear zone, or lead, as possible (Figure 1). It is safer and preferable, but not always possible, to establish perches on grounded pressure ridges. The 2010 survey was conducted near Point Barrow, in an area where ice conditions were stable. A 24-hour watch was planned but once it was clear that insufficient data would be obtained to produce a fully reliable abundance estimate (see below), a 16-hour watch was maintained by at least two but usually three observers. One observer operated a theodolite (used for obtaining positions of whales at the surface), another recorded the data, and all watched for whales. Observers worked two 4-hr shifts per day over a six-day workweek. An intensive safety and counting-method training session was conducted at the start of the survey.

Two observation locations were used in 2010 – Ahpuk Perch and Sila Perch - and both had a paired IO perch. “Ahpuk” perch (and its IO companion) was established first, but this primary perch was soon abandoned due to ice conditions (see below). A new primary perch, “Sila”, and its IO companion were then established. The primary perch (i.e., the one kept in operation even when IO effort was not conducted) was the north one in both cases. Sila Perch was west of Point Barrow in a location similar to past seasons (Figure 1).

One critical aspect of data collection involves linking multiple sightings of whale groups by the same perch. Observers used nautical-type plotting sheets and calculators to help them link whale sightings and evaluate whether a sighting was of a whale seen before (a “duplicate”) or of a whale not previously seen (termed a “new whale”).Whales that could not be assigned with certainty to one of these categories were recorded as ‘conditional’ (50% chance of being seen previously).Codes were assigned to linked whales depending on the observers’ confidence that the sighted whale(s) had been seen before (Table 1). Duplicate sighting were assigned the codes of X, Y or Z if observers were 100%, 90% or 50-90% confident, respectively, that the whale(s) had been previously seen (Table 1). Note that an R sighting is essentially a subset of an X sighting, applying when whales were sighted more than once in a single surfacing sequence.

Plotting sheets were used in the earliest survey years and then again in the most recent surveys (1993, 2001, 2010) to facilitate linking. Calculators have also been used since 1980 to calculate whale swim speeds and angles, which also improves the ability to link sightings (George et al., 1995).

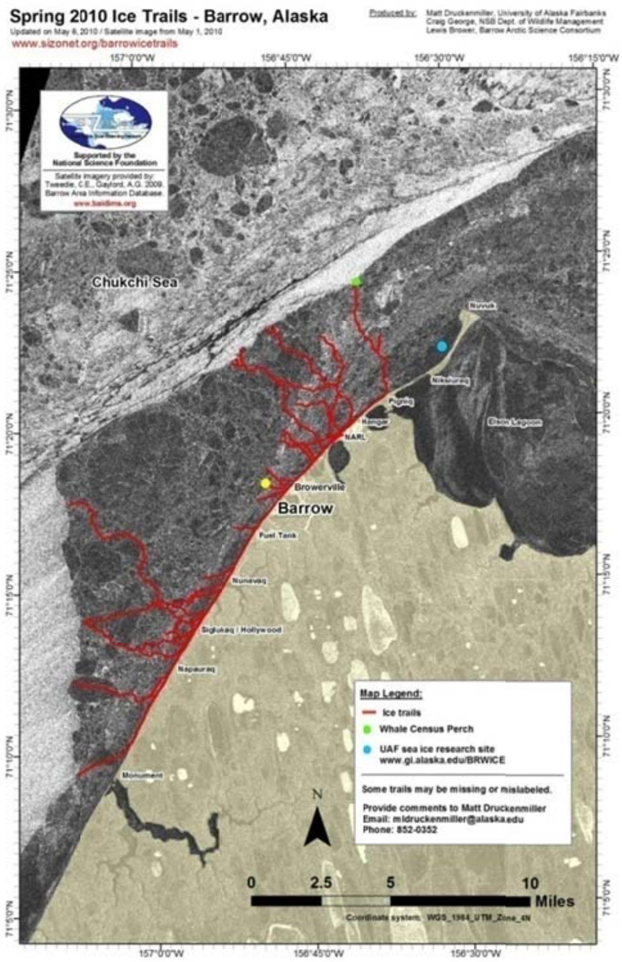

Figure 1. High resolution radar image showing the area near Point Barrow and trails used in the subsistence hunt of bowhead whales. The survey perches were located at the end of the northernmost trail (green dot). The [yellow] dot west of Barrow shows the location of Ahpuk Perch and the lead in late March and early April. The large ice attachment (Inupiat: *iiguak*) west of the perch (on 10 April) totally precluded any chance of seeing whales in the lead 10 km away. The ice also covered and obscured the entire 5-element acoustic array.

Acoustic array

Arrays of acoustic instruments to locate calling whales have been in use since 1984 on the ice-based census to estimate the proportion of whales beyond observer vision (P4) and as an indication of migrating during periods of ice cover. A 5-element acoustic array was deployed on 9 April with special permission from the Barrow Whaling Captain's Association. We used Marine Autonomous Recording Units (MARU) for our array due to their portability and our long-standing partnership with Dr. C. Clark, Cornell University.

There is no limit to the number of linked observations that can be made by an observer team, but typically only a few are made for any sighting because the main objective is to sight new whales. Hence in some cases observations of whales that were certain duplicates were ignored due to time constraints.

A large amount of additional data was collected while sightings and links were made. Observations on lead conditions (width and sea ice concentration) and visibility scores (ability to see a whale, rated as unacceptable, poor, fair, good, very good, or excellent) were made every two hours in a manner consistent with past methods (Krogman et al., 1989). Many additional covariates were also measured; see Table 2.

Field summaries were conducted daily and a 100% data check was conducted after the season comparing the database against the raw field data sheets. Additional data checking occurred as anomalies were detected during data analysis.

Independent Observer methods

Unlike the early years of the ice-based survey (1978-1985), we used a fully independent observer (IO) study design to enable the estimation of detection probabilities. Previously, we had used a single-blind survey strategy and estimated detection probabilities with the removal method (see Seber, 1982). In the old approach, observers from the primary (south) perch were required to radio their sightings data to the other perch, which attempted to re-detect those whales while also maintaining their own sighting effort. This approach was extremely difficult because at high whale passage rates, observers on the north perch simply could not with full reliability receive and record south perch data, record their own sightings, and make matching decisions all at the same time. Our 2010 IO methods were markedly different from the removal method approach; they were similar to those described by Rugh *et al.* (2008) for migrating gray whales that used two fully independent observation sites. The IO approach has several advantages: a) observers do not have to make matching decisions in real-time, b) observations are completely independent and, c) the perches remain functional at high (> 10 whales/hr) whale passage rates (Krogman *et al*., 1989).

Whale sightings made from independent perches in 2010 were matched in order to identify whales that were seen by both perches. Matching efforts were attempted both in “real time” during the survey (in a “Command Center” referred to as CC) for a limited number of days, and later in autumn during post hoc matching sessions. Matching was conducted by a group of matchers composed of very experienced past observers. As opposed to matching in real time at the CC, the matching team felt that having the time to thoroughly examine matches resulted in higher-quality data (and was far less disruptive to the survey).

Table 1: Linking codes for sightings of whale groups. Every sighting is classified using one of these codes.

Code	**Meaning**
N	New whale or group. Observer team is confident that it is seen for the first time.
R	Roll. The sighting is part of a sequence of surface dives or ‘roll series’ of a previously sighted whale or group. A link is assigned to indicate the associated previous sighting.
X	Duplicate. The observer team is 100% confident that the whale or group can be linked to a specific previous sighting. A link is assigned to indicate the associated previous sighting.
Y	Duplicate. The observer team is about 90% confident that the whale or group can be linked to a specific previous sighting. A link is assigned to indicate the associated previous sighting.
Z	Duplicate. The observer team is quite sure that the whale or group has been previously sighted but s/he cannot link it back to a specific previous sighting with 90% confidence. Rarely a link is assigned.
C	Conditional. The observer team cannot determine whether this whale or group is New or a Duplicate of some previous sighting. Links can begin with C sighting; but other sightings cannot link to a C.

Table 2. Listing of covariate data and codes used on the ice-based survey.

LINE #	LINK #
X = Observer **O** = Comment	Line # of original whale sighting that current whale is duplicate of

# / N,C,R,X,Y,Z	
N = New whale	Whale Seen for the first time.
C = Conditional whale	Can't determine if whale is new or duplicate (50% chance of being new)
R = Duplicate	Sighting part of surface "roll series"
X = Duplicate	100% certain whale is duplicate; marked whale or cow-calf pair. A deep dive (˜ 2 minutes) has occurred since last sighting.
Y = Duplicate	90% confident of re-sighting and must be linked, no clear markings.
Z = Duplicate	Less than 90% sure; can't link sighting but fairly certain it's been seen before. Generally do not give link #.

NSL	VISIBILITY CODE (VIS)	WEATHER CODE (WEA)
N North Traveling	**EX** Excellent	**CL** Clear
S South Traveling	**VG** Very Good	**PC** Partly Cloudy
L Lingering	**GO** Good	**OV** Overcast
? Don't Know	**FA** Fair	**LS** Light Snow
P Pushed south by current but headed north	**PO** Poor	**HS** Heavy Snow
	UN Unacceptable	**LF** Light Fog
W Whale headed SW, W, or NW		**HF** Heavy Fog
		HR Heavy Rain
		SR Snow/Rain mix
		LR Light Rain

THEODOLITE NUMBER

(0) No theodolite	**(3)** Wilde 1600	**(6)** Sokkisha (5B)
(1) K&E Electronic	**(4)** Nikon	**(7)** Bino Watch
(2) K&E Eagle	**(5)** Sokkisha (5A)	

BEHAVIOR CODES	SPECIES COLUMN CODES	LEAD CONDITION CODES
O Ordinary Surfacing Pattern	**BM** Bowhead Whale, Agviq	**1** Lead is closed
H Heard Only	**DL** Beluga, Sisuaq	**2** Some open water visible, polynyas
PH Pushing up ice hummock	**OR** Walrus, Aiviq	**3** Well defined lead or series of polynyas
SH Spy Hop	**ER** Gray Whle, Agvigluaq	
? Can't determine	**OO** Killer Whale, Aaglu	**4** Wide open lead, far edge of pack ice not visible
R Resting on surface	UM Polar Bear, Ursus maritimus	
TL Tail Lobbing	**PH** Ringed Seal, Natchiq	
B Breach	**EB** Bearded Seal, Ugruk	
F Flukes	**VL** Arctic Fox, Tigiganniaq	
I Interaction of 2 or more whales	**LE** Lead Edge	
U Under-Ice feeding	**IC** Ice, Siku	
T Trawl (Surface) feeding	**VM** Vertical Mark	
BX Breeding	**BT** Boat	
! Other – Explained in Comments	**CM** Calibration Mark	
	SI Simultaneous Ice Shot	

LEAD MAPPING	PERCENT OPEN WATER
Indicate near or far shore of lead as a comment use **Line #** of the first shot in the series to indicate near and far lead edge	Observers best estimate of the percent open water as viewed from the perch.

Perch Height

The initial main perch and its companion IO perch were established at the Ahpuk location west of the village of Barrow (71° 16.8 N; 156° 51.6 W). In late April, ice conditions rendered this location completely unusable. Therefore on 29 April we moved the survey operation north to Point Barrow (see Figure 1). The new perches (Sila main and its companion IO) were low and nearly identical height at 5.4m. Fundamentally, attainable perch height is determined by the vagrancies of ice formation and pressure ridges. In an unprecedented effort, by 4 May we had added 2 m of ice to the main Sila perch (north) to increase its height to that used in most past surveys (this amounted to moving approximately 18 metric tons of ice—obtained by pick and shovel—to the top of the 5m perch). Time and logistic constraints prevented us from adding 2 m to the IO perch (south). The perch height difference was a concern since 5.4 m is lower than most observation perches in past seasons. Nonetheless, the observers quickly noticed that the difference in whale detection was not nearly as pronounced as they expected. Daily tallies of sightings for each perch were usually quite similar and the lower (south, IO) perch often had higher counts. However, there were periods when south perch simply could not see far offshore whales and counted few whales (e.g., 7 May). The fact that the difference in perch height did not generally appear to us to affect detection probabilities was unexpected, but the detection probability estimates of Givens et al. (2011) confirmed this finding.

Calibration

Calibration of the instruments used for locating whales was essential for conducting the IO experiment. Prior to the season, we sent both theodolites to a certified surveying shop for calibration.

In the field, we used a both GPS (±5 m) differential GPS to position each instrument (±~1 cm) on the perch and to position a calibration stake used for “zeroing” the theodolite. Based on the positions, we calculated the correct angle from each perch to the zero-stake such that both instruments were calibrated to magnetic north. We also conducted periodic tests, such as simultaneous shots on ice floes in the lead, and on fixed objects to assure that the resulting estimated (x, y) positions were close in space. That is, the estimated positions and bearings to the object (or whale) needed to be sufficiently close that whale sightings from the two perches could be correctly matched during analysis. Mid-way and post season, we did bench tests at our laboratory to compare vertical angles to fixed targets. The theodolites were found to closely agree in bench tests (<1' of angle). However, in the field we noted differences in calculated ranges to objects (such as ice floes) that were greater than those that could be attributed to small differences in machine calibration. These range errors were inconsistent. They may be attributable to differences in how various observers aligned the theodolite reticles on targets or to observers shooting different objects.

BHTracker Software

To facilitate the identification of potential whale matches, a computer program named BHTracker was developed by modifying gray whale software provided by Robert Holland (SWFSC). The software, written in Visual Basic, was used to display sightings from the 2010 survey (R.A. DeLong, pers. comm., 2010).

BHTracker provides a visual display of observed whale locations, links between observed whales, and whale matches for both perches. The software allows efficient color coded plotting of whale observations and estimated whale swim speeds and directions as an aid for real time and post-hoc matching. An example of the BHTracker display is given in Figure 2.

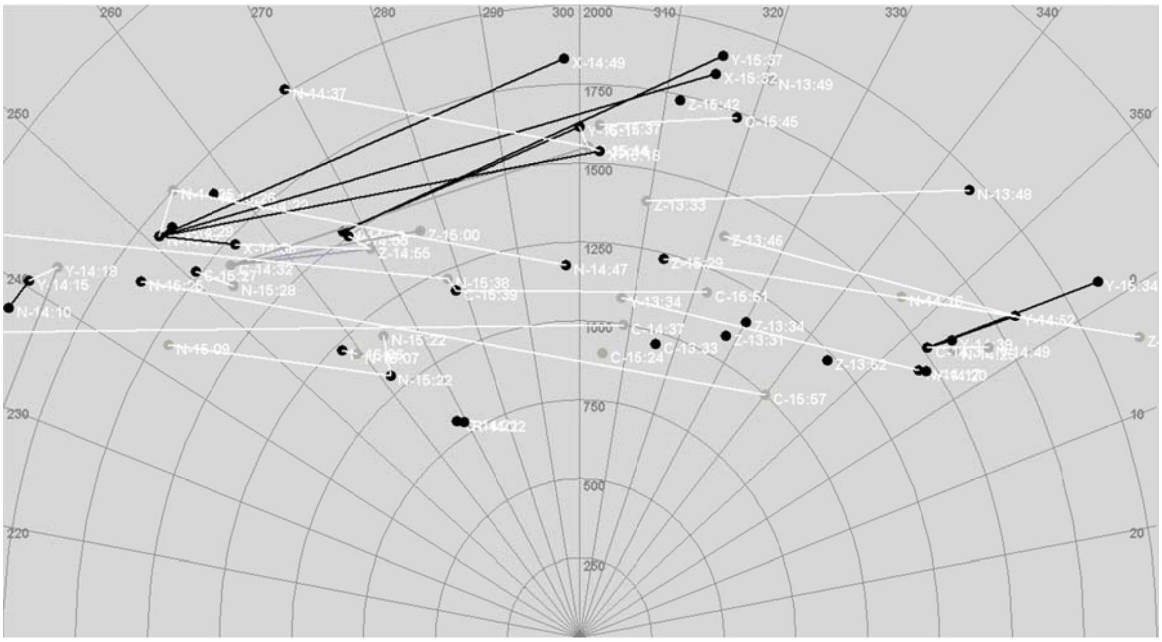

Figure 2. Plot of a BHTracker display for 8 May at 16:00 with a 2.5 hour look-back. Note whales sighted as early as 13:30 are displayed as part of the look-back feature. Black dots represent sightings made from north perch and gray from south perch. Black and gray lines represent *links* between sightings from the same perch. White lines represent *matches* between sightings from different perches.

The primary BHTracker display is oriented with both perches in the same location at the bottom center of the screen. The bottom edge of the display is aligned with the lead angle expressed as a magnetic bearing north along the edge of the lead. The radial lines are marked with magnetic bearings from the perches and the semicircles represent distances in meters from the perches. Observed whales are displayed on this grid labeled with the whale link code and the time of observation. When used in real-time, this display evolves as newly sighted whale observations, links, and matches are entered into a MS Access database file through BHTracker using an entry screen under the primary display, while older sightings eventually disappear.

BHTracker allows user control over a number of parameters. Look-back time controls how long after a whale is observed it remains on the display. Whale observations older than the look back time are not displayed. For example, if look-back time is set to 1.5 hours, any whale observed more than 1.5 hours prior to the current time will not be displayed.

BHTracker also provides the ability to display look-ahead “sighting trails”. These are projected possible locations of an observed whale based on the whale’s direction (N, S), a track uncertainty angle, and a minimum and maximum swimming speed. A trapezoidal zone where a previously sighted whale might be located at the current time can be plotted on the display using these parameters together with the amount of time that has elapsed since the whale was previously observed. We found this feature confusing and we did not want to use it as a semi-automated crutch. Therefore, the look-ahead feature was not used often, and never used to the exclusion of other pieces of evidence and expert judgment.

In addition to real time operation, BHTracker provides a simulation mode for use in post hoc matching. Simulation mode allows the user to specify a starting time and a time step. When the simulation is engaged, BHTracker uses the simulation starting time as the current time and allows the user to manually step through observations in increments equal to the time step. While in simulation mode, other functions of Bhtracker, including lookback time, operate based on the simulation's current time.

MatchingMethods

"Command Center". Rugh *et al*. (2008) made whale linkages post-season using a mathematical algorithm; however, we initially used a "command center" (hereafter CC) to make matches in real-time when whale passage rates allowed. In our approach, whale location data were independently radioed (on separate frequencies) from each perch to the CC where they were immediately entered into BHTracker and plotted onto a large screen. The lead angle was set to 36 degrees based on field observations and the lookback time was set to 1.5 hours. Matches were made using criteria similar to what an observer would use on the perch; see below for more details.

Real-time matching. Real-time matching in the command center worked reasonably well at low passage rates. Under high passage rates (~10-15 whales/hour) we simply could not communicate with the perch, record the data, and make match decisions without significantly disrupting the counting operations. At such time periods, the command center was shut down. The CC operated from 1 May to 14 May, after which time we decided to employ post-hoc matching because real-time operations were proving to be infeasible.

Post hoc matching. Matching was re-attempted two months after the field season during sessions in August and in September-October, using the full IO dataset after it had been carefully scrutinized for data entry errors. For post hoc matching, the data were loaded into BHTracker using simulation mode. The lead angle was set to 36 degrees based on field observations. For the simulation, a time step of 1 hour was used together with a look-back time of 1.5 hours. The simulation was started at the beginning of IO observations and proceeded through the entire IO data set. Technicians (hereafter "matchers") also had the raw IO data available for both perches during the match session for reference. This allowed them to examine other parameters that might affect observations such as environmental conditions, watch crews, current speed/direction, etc. Another useful component of the dataset is an open-ended "comment field" where observers could add any relevant remarks; these can contain information that facilitates matching. Each match session—during which the entire dataset was covered—required two weeks of effort by the matchers.

One may ask whether the matching sessions were independent. Would we remember earlier matches made in May when these data were re-examined by the matchers during the post hoc sessions? It was quickly evident that matching is like trying to remember moves in a chess game. In our matching sessions and in a chess game, there are many possible choices at each step and you cannot remember exactly what moves you made months earlier. On the other hand, although we could not remember previous decisions, we could (and did) use the same decision-making process. One thing that did vary, however, was our tolerance of match uncertainty; see below.

The first post hoc matching effort began in August. It involved two of the co-authors (JCG, BT) and two experienced observers from the field season. The IO periods that were not matched in real-time by the command center were completed, as well as a "re-matching" of the data examined during the CC period. The latter "re-matching" was completed without direct reference to the outcomes of the CC matching effort. Hence, two datasets were produced: one with unmatched periods filled in, and another that could be viewed as the first comprehensive match results for the entire dataset.

A second post hoc matching session, termed the September-October session, represented our attempt to make a final "gold-standard" match dataset. We used a longer look-back function of 2.5 hours in BHTracker.

Throughout the September-October session, the August match dataset was reviewed for possible "promotion" or "demotion". By this, we mean that we sought to identify previous matches that we felt we had made in error (demotion, or false positives), and to detect any missed matches (promotion, or false negatives). We also examined matches to assess whether their quality ratings (see below) warranted any change. The September-October match session was conducted with a slightly different mindset than during the August session. It was felt that in August the matchers had "cherry-picked" the easiest matches (Excellent and Good) and had been reluctant to declare less certain matches. In the September-

October session, matchers concentrated on less certain adequate matches. If they erred in this direction, it would introduce a positive bias in detection probabilities and a negative bias in abundance estimation.

At the end of the September-October match session, the May CC matches were also reviewed and entered into the master dataset if they did not conflict with a match made in August, September-October, or they were found to be the best match. Some matches from the May session did not have to be entered because identical matches had been found and entered during either the August or September-October sessions.

Match quality. The matchers scored match quality using a confidence rating (excellent, good, and adequate, or E/G/A). The definitions of these ratings are given in Table 2. Note that, some A-matches were only slightly more likely than not to be a match. Possible matches with less than 50% certainty were not declared.

Matches that were within a few seconds and 10s of meters are easy to declare and always scored as E. However, we gave many others lower match quality scores (i.e., G, A) when sightings were more separated by time and/or space. For example, we believed that some matches caught the beginning and end of a surfacing blow series, but since they were as much as 100 m and > 1 minute apart, they were not scored as E. Recall that on average, a whale will make 6-7 surfacings (blows) in a series, cover ~100 m, and total surface time is ~1.5 minutes (Carroll and Smithhisler, 1980; Zeh et al., 1993).

Types of matches

Matchers also specified the match criteria (reasons) for each match they identified (Table 3). Occasionally, more than one reason was given. The matchers often recorded comments about each match for further clarification. Below we review various match reasons.

Table 2. Match quality scores used in matching.

Excellent (E)	At least 90 % certainty
Good (G)	Less than 90% but at least 66 % certainty
Adequate (A)	Less than 66% but at least 50% certainty

Table 3. Match criteria entered the match reason field.

Code	**Reason**	**Description**
S	Simultaneous	A whale observed by both perches at nearly the same time and same location. Matchers considered range error and whether sightings were entered as Approximate by observers. Match time window could be up to 1.5 minutes to include an entire roll series. For approximate sightings, considerable range error, moderate bearing error, and time to ~1.5 minute was allowed.
TS	Time-space	Matchers considered whale speeds from roughly 2-5 kmh, direction of travel, location of sighting and environmental conditions (e.g. current speed, visibility).
GS	Group Size	Same number of individual whales in a group was observed by each perch.
B	Behavior	Same behavior documented by each perch.
M	Marked Whale	Obvious marking on whale documented by each perch.
CC	Cow/Calf	Cow/calf pair

- *Simultaneous matches*. During each time increment, matchers initially scanned the dataset for "simultaneous" (S) matches, which are whales seen by both perches in nearly the same location at nearly the same time. S matches were easily identified and were usually rated as Excellent (E) quality. We have most confidence in matching simultaneous sightings, even considering range error from approximate sightings (e.g., when a bino-compass bearing was used (see below).
- *Time-space matches*. The most difficult matches were those separated in time and space. Once the matchers completed the S matches, TS matches were considered. Matchers looked for reasonable time periods, distances and direction of travel between perch sightings and then looked at the speed at which the whale would have traveled between sightings. Sea current speed was considered, if available, to evaluate the travel speed of the whale. Visibility was also considered in some cases. The matchers also considered comments made by each perch about group size, cow/calf pairs, and marked whale when evaluating matches. The toughest match calls are those separated by ~1 km with swim speeds in the 2-3 and 5-6 km/h range (i.e., unusually slow or fast but not impossible) and not necessarily parallel to the lead edge. When considering swim speed, we tried to adjust for current speed and direction (if available), for example tolerating faster apparent swim speeds if the both the whale and the current were northbound. Such matches are agonizing: they are obviously quite possible but our confidence is much lower. They were often given the lowest match score (A). Some were initially flagged in the comments for reconsideration.
- *Other reasons.* Other evidence for matching whales included group size, behavior, markings, and calf presence. These reasons were usually noted in addition to a reason of S or TS.

Other matching issues

Over-the-horizon-whales. On some days there were a number of over-the-horizon (OTH) whales for which only the blow was seen. In such cases, the blow was seen quite clearly but the whale's body was not. All were labeled as "approximate" locations. The range to the animal could not be calculated but the bearing could be measured quite precisely with the theodolite. However if only binocular compasses were used (instead of the theodolite) then the bearings were less accurate (±5 deg). In many OTH cases, the observer simply shot the horizon (with the theodolite) beneath the blow so a minimum distance estimate was calculated by the computer.

This OTH situation obviously presents problems for matching. May 23 had mostly OTH whales as did some other days. We did our best to match sightings using S and TS matches with liberal speeds and direction allowances.

Range Error. From calibration tests we know that the theodolite vertical angles do not agree exactly, which resulted in some range error. Bearing error in these tests was very small, which means we can point at a whale with great precision. Potential range error was considered during matching.

Adjustments to Match-Links. During analysis of the matches, some logical inconsistencies in matches became apparent. An example would be a case where two New whales recorded by the same perch are connected to each other via a series of perch-links and inter-perch matches which would imply that the two sightings rated as New by the same perch must have been the same whale if all links and matches were to be believed. This is a logical inconsistency because the assignment of two New codes by the single perch is an explicit declaration by that perch that these two sightings are not the same whale. In these cases, we re-evaluated the matches. This review suggested that in some cases observers at a perch failed to link likely duplicate whales. However, just as often we noticed linked whales from a specific perch that were clearly different animals. For instance, a link implying a swim speed of 20 km/h is clearly unreasonable. In other cases, the review of logical inconsistencies caused the matchers to reconsider their previous match decision and decide that it was most appropriate to remove the match. These instances always corresponded to very ambiguous A links that could be argued either way.

Another inconsistency that can occur during the matching process is group size discrepancy as described by Givens et al. (2011).Apparent group size inconsistencies occur for some matches due to the loose affiliations between whales as they join and split from aggregations - particularly for breeding groups. Differences can also occur if one of the animals in a group is obscured by sea ice or if a surfacing was simply missed. (Note: during the 2011 season, we've confirmed that both situations definitely occur.) It is possible, therefore, that a chain of sightings connected by links and/or matches will be recorded by observers at either or both perches as having different group sizes at different positions along the chain. Because the reasons for group size discrepancy are numerous, such inconsistencies were not used as an automatic reason not to match sightings. Instead, flexibility was allowed to reflect the realities of whale behavior and detection.

RESULTS

Number of sightings

A total of 1332 new (including 12 calves) and 242 conditional whales were seen in 397 hours of watch from the primary perches (Table 4). Duplicate sightings from the primary perches totaled 49 X (includes 12 calves), 154 Y (includes 1 calf), and 156 Z (includes 1 calf) sightings.

As a sub-set of the seasonal whale count, the *independent observations* were made from 30 April to 25 May. A total of approximately 1,215 (includes 11 calves) and 1,074 (including 8 calves) new whales were seen in 304 hours of IO watch from North and South Perch respectively. Both Ahpuk Perch and Sila Perch had companion IO perches; IO operations only took place at Sila perch.

Acoustic array

The 5-element acoustic array of MARU's was deployed on 9 April; however it became completely "buried" underneath a very large ice shelf. All the MARU's were retrieved in mid-July and the data were recovered; however the acoustic data were not analyzed because: a) an abundance estimate was not possible and b) the acoustic data were considered almost useless since they were so distant from the lead edge.

Feasibility of Obtaining an Abundance Estimate

For a critical portion of the 2010 survey season, survey effort was impossible because heavy ice prevented any whale observations (Figure 3). Specifically, starting on 12 April the leads closed under westerly winds and did not reopen until 30 April. When leads finally did open a 10 km wide ice attachment (Inupiat term: *iiguaq*) remained in front of Ahpuk perch completely preventing any chance of seeing a whale. From past surveys, we know that whale passage is high during this period (George et al. 2004; Figure 3). Furthermore, during the same period 3 of 6 satellite-tagged bowhead whales migrated past Point Barrow under the ice. The lead was also closed during 4-6 May: a period that can include high passage rates. Moreover, the survey was shut down on 28 May, but previous surveys (e.g. 2001) have indicated that a substantial number of whales may pass after that date. Thus, we believe that we cannot calculate a suitably accurate and precise estimate of abundance using the 2010 data.

Because these limitations and realities became apparent to us as the survey went on, we decided to focus survey effort entirely on maintaining effort in order to improve estimates of detection probabilities, even when this meant fewer hours (16 hr/day) of watch overall. This partially explains why the counts (bars) for 2010 are lower than those for 2001 in Figure 3 during times when both surveys were operating. The 2001 survey had 1,130 hours of watch effort vs. only 397 hours during the 2010 survey.

Table 4. Totals of new and duplicates sightings by primary perches during the entire 2010 season. N=new whale, seen for first time; C= conditional whale, 50% probability of being new; see Table 1 for definitions for duplicate sightings: R, X, Y, and Z. Note the very low numbers of whales seen at Ahpuk Perch due to closed leads.

Perch	N	C	R	X	Y	Z
Ahpuk	31	4	5	1	4	0
Sila	1301	238	113	49	150	156

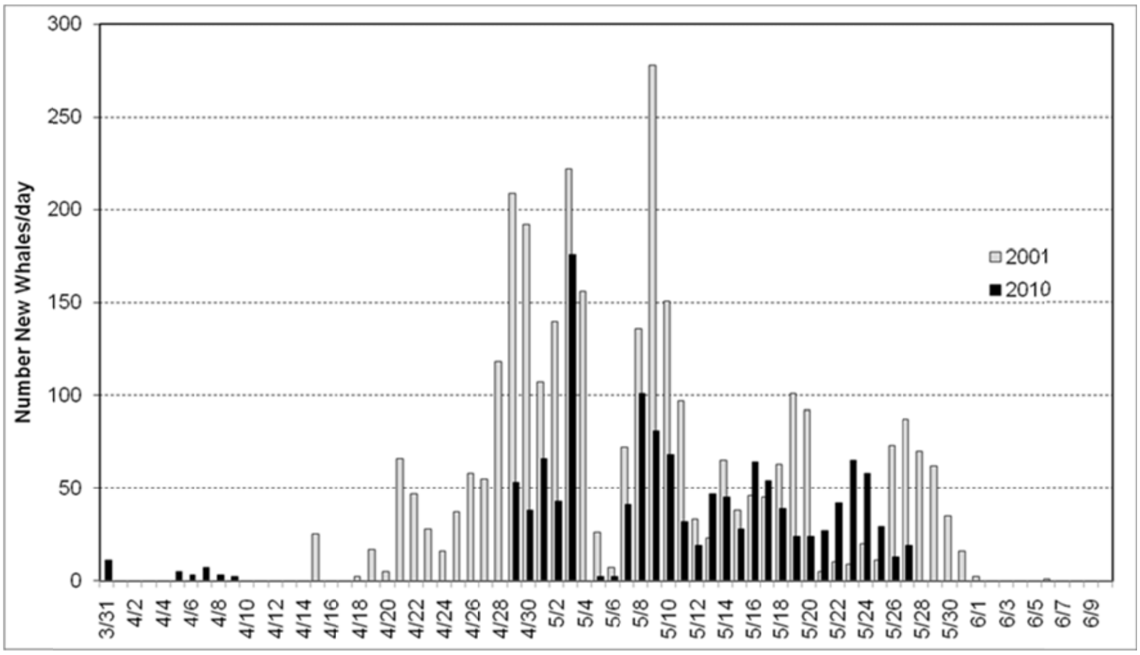

Figure 3. Plot of numbers of new whales seen by day for the 2010 and 2001 seasons. Numbers are unadjusted for watch effort. Thus, the lower bar heights for 2010 are partly attributable to the reduced watch effort (caused by increased focus on IO effort), not by whale passage rates. The lack of observations in mid-to-late April 2010 is due to closed leads

Early Migration Timing

An interesting and unusual feature of the 2010 survey was that a significant number of whales migrated past Point Barrow between 31 March and 10 April (Figure 3). Previous ice-based surveys (since 1978) have not recorded whales that early. Reasons for this timing are unknown, and it is difficult to assess whether this occurrence represented an aberration or a longer-term change in migratory behavior. On the one hand, the early development of shore leads in 2010 and a larger population size may have contributed to the early migration. On the other hand, it is also possible that the thinner first-year ice that has predominated the Chukchi and Beaufort Seas in recent years can be more readily navigated than the multi-year ice common decades ago, thereby enabling an earlier migration northward. It is worth noting that the 2011 survey has again exhibited very early starting date.

We ended the 2010 survey on 28 May when the ice became very unsafe. However, whales were still passing the perch on 27 May. There was no evidence of “resident” whales which are now commonly seen in low numbers during July and August (NMML, 2010).

Table 5: Comparison of match decisions for the August and September-October match sessions. Cell entries represent counts of each combination of match decisions for the two sessions.

		September-October				
		None	Adequate	Good	Excellent	Total
August	None	1713	265	45	7	2030
	Adequate	1	165	1	0	167
	Good	0	2	132	2	136
	Excellent	0	0	2	176	178
	Total	1714	432	180	185	2511

Matching and Linking Results

The August match session identified 481 matches. After the September-October session, a total of 797 matches had been identified. These counts are approximate because there are several sorts of matching anomalies that are ambiguous (about 21 cases). For example, in several instances a whale was matched to one sighting by the August session but matched to a different sighting in September-October.

The numbers of whales seen by each perch were similar despite the fact that about 50% of the whales seen were different animals based on findings in Givens et al. (2011). This suggests that observers count similar portions of the whales available to be seen.

As noted earlier, S matches are the easiest to identify. Essentially all (99%) of the E matches were 'simultaneous' whereas only 23% of the A matches were 'simultaneous'. Based on counts of matches of new whales unadjusted for links, we found that about 45% and 48% of the new whales seen during IO were matched at the North and South perches respectively.

Table 5 summarizes the outcomes of the August and September-October match sessions. The table cell entries are counts of sightings. The rows and columns correspond to match decisions in August and September-October, respectively. Row and column labels refer to E/G/A match qualities, and none indicates 'no' match. Thus, for example, there were 45 sightings unmatched in August but participating in a Good match in September.

Table 5 shows that the total number of matches increased from the August session to the September-October session. The increase was overwhelmingly due to the identification of additional A matches. This reflects the intention and mindset described previously. There are also a number of cases where matches were 'promoted' or 'demoted' during the final match session. Givens et al. (2011) provide a lot of detailed data about matches, links, and similar issues.

It is important to note that the variation in match decisions between the three match sessions does not primarily reflect untrustworthiness of the matches. Instead, it reflects an increasingly strong effort to identify matches even when they approached the 50% plausibility region for Adequate. This assertion is supported by the off-diagonal table entries excluding the first row and column, where we see that matches declared in August were nearly perfectly confirmed in September-October. The goal of the overall match process was to produce a 'gold standard' dataset after all 3 match sessions, where any bias could confidently be expected to be in the direction of excessive matching

SUMMARY

The 2010 survey season began with an unusual pulse of bowheads in late March which has never been recorded prior to this year. Leads closed soon afterwards preventing us from sighting *any* whales from 10-28 April and leading us to set aside efforts to make an abundance estimate. However, we were able to collect valuable and unprecedented IO data. Detection probabilities were estimated in a companion analysis (Givens et al., 2011) and found to be consistent with—but slightly lower than—those estimated in the early years of the ice-based census using a single-blind recapture approach (summarized in Zeh et al., 1993).

The IO data collection methods we developed in 2010 were applied to the 2011 season. Hence, a significant contribution of this project was the development and documentation of an approach for conducting an ice-based IO survey and matching methods to estimate detection probabilities. These methods can be applied to future surveys.

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