SC/67B/AWMP/16

Bering-Chukchi-Beaufort Bowhead Whale Abundance Estimation Survey Workshop Report

M.C. Ferguson, J.T. Clarke, R. Angliss, J. Bengtson, A. Brower, J. Citta, P.J. Clapham, P. Conn, K.A. Forney, J.C. George and G.H. Givens

INTERNATIONAL WHALING COMMISSION

Bering-Chukchi-Beaufort Bowhead Whale Abundance Estimation Survey Workshop Report

4-5 April 2018
Marine Mammal Laboratory, AFSC, NOAA

ATTENDEES

MEGAN FERGUSON[1*], JANET CLARKE[2], ROBYN ANGLISS[1], JOHN BENGTSON[1], AMELIA BROWER[1,3], JOHN CITTA[4], PHIL CLAPHAM[1], PAUL CONN[1], KARIN FORNEY[5], CRAIG GEORGE[6], GEOF GIVENS[7]

[1] Marine Mammal Laboratory, AFSC, NOAA
[2]Leidos
3Joint Institute for the Study of the Atmosphere and Ocean
[4]Alaska Department of Fish and Game
[5]Marine Mammal and Turtle Division, SWFSC, NOAA
[6]North Slope Borough Department of Wildlife Management
[7]Givens Statistical Solutions

**Contact email: megan.ferguson@noaa.gov*

BACKGROUND

The Bering-Chukchi-Beaufort (BCB) Sea stock of bowhead whales (*Balaena mysticetus*) is hunted for subsistence by Native whalers from Alaska, Russia, and Canada. The most recent population abundance estimate for this stock is 16,820 (95% CI 15,176 to 18,643), derived from a 2011 ice-based survey (Givens et al. 2016). The International Whaling Commission (IWC) sets the aboriginal subsistence quota for BCB bowhead whales, requiring a new population abundance estimate every 10 years. Based on IWC rules, a new abundance estimate is required by spring 2021.

From 1978 through 2011, ice-based surveys conducted during spring near Point Barrow, Alaska, reliably provided data needed to estimate the abundance of BCB bowhead whales (George et al. 2012). Deteriorating spring sea ice conditions in the Arctic have increased the risks, and lowered the chances of success, of conducting ice-based surveys. Predicted changes in Arctic climate are likely to exacerbate this trend, precluding the use of ice-based surveys for estimating BCB bowhead whale abundance in the near future. Photo-identification data also have been used successfully to estimate BCB bowhead whale abundance in a mark-recapture framework (daSilva et al. 2000; Schweder et al. 2009; Koski et al. 2010; Givens et al. 2016), but analyzing imagery for this type of analysis is time intensive, typically resulting in a 3-yr lag between when the imagery are collected and a new abundance estimate is finalized.

In response to the management need for a new BCB bowhead whale abundance estimate, NOAA and the North Slope Borough Department of Wildlife Management convened an expert workshop to discuss the use of aerial line-transect surveys in the Beaufort Sea during 2019 to collect data for estimating the abundance of this population. Workshop participants included experts in bowhead whale ecology, statistics, aerial line-transect surveys, IWC management, and satellite telemetry. The Aerial Surveys of Arctic Marine Mammals (ASAMM) project (funded by the Bureau of Ocean Energy Management [BOEM], conducted by NOAA, and co-managed by BOEM and NOAA) provided nearly four decades of information on bowhead whale relative density, behavior, and distribution in the eastern Chukchi and western Beaufort seas, and highlighted the challenges specific to conducting aerial line-transect surveys for this population.

Workshop objectives were to: 1) identify known gaps in information needed to estimate abundance of the BCB bowhead whale population from aerial line-transect surveys; 2) discuss research that could be conducted to address those information gaps; 3) provide recommendations on aerial line-transect survey design and protocols specific to BCB bowhead whales in the Beaufort Sea; 4) discuss analytical methods that could be used to produce the most precise, unbiased estimate of BCB bowhead whale abundance that can be achieved using aerial line-transect survey data; and 5) provide an estimate of how much it will cost to generate a new abundance estimate. Appendix A is the workshop agenda.

ASAMM represents a wealth of information on bowhead whales and conducting aerial surveys in the Arctic; therefore, the ASAMM survey design and protocols served as a starting point for framing the 2019 abundance survey.

INFORMATION GAPS AND HOW TO FILL THEM

Known gaps in critical information needed to estimate BCB bowhead whale abundance from ASAMM-like surveys are:

- Lack of correction factors for availability bias[1] and perception bias[2] on the transect specific to bowhead whale data collected during ASAMM surveys;
- Lack of uncertainty in bowhead whale group size estimates from ASAMM; and
- Uncertainty in the proportion of the BCB bowhead whale population present in the Beaufort Sea during any given period in the summer.

Availability bias

Although empirical methods can be used to estimate overall transect detection bias, which is comprised of unknown proportions of availability bias and perception bias (Laake et al. 1997), workshop participants thought that direct estimation of availability bias separate from perception bias during ASAMM surveys is likely possible and, therefore, preferred. Availability bias is a function of the length of time a whale is at the surface (surface interval, *s*), underwater (dive interval, *d*), and potentially visible to an observer (*t*) (Laake et al. 1997):

$$\hat{a} = \frac{E[s]}{E[s] + E[d]} + \frac{E[d](1 - e^{-t/E[d]})}{E[s] + E[d]}$$

Information about BCB bowhead whale surface and dive intervals in the Beaufort Sea exists in historical data from aerial focal follow surveys (e.g., Ljungblad et al. 1988; Würsig et al. 1984, 2002; Robertson et al. 2015) and recent satellite telemetry data (e.g., Citta et al. 2015). Focal animal follows incorporate specialized survey methods and consume a significant amount of time in order to generate even a relatively small sample size; however, they provide a direct and accurate estimate of the length of time that whales are available to be seen from the aircraft. Existing satellite telemetry data were collected in a way that optimizes information about dive intervals but not surface intervals, and therefore do not provide all of the necessary information for deriving an availability bias correction factor for ASAMM. Telemetry

[1] Availability bias refers to animals that are located on or near the transect but cannot be seen because they are underwater or they are too far fore or aft of the aircraft and, therefore, are not in the observers' field of view
[2] Perception bias refers to animals that are *available* to be seen, but the observers fail to detect them due to distance, high sea states, glare, sea ice, etc.

data provide considerable information about bowhead whale ecology at a relatively low cost and with relatively little labor. Therefore, the workshop ***recommended*** the following:

1. **For a given combination of month (or season), region (western Beaufort Sea, eastern Beaufort Sea), and depth zone (shallow, deep), compare the historical information on surface and dive intervals from the aerial focal follow surveys with that from the existing satellite tag data to determine whether the datasets could both be used to estimate availability bias for ASAMM.**
2. **Evaluate the costs and benefits of deploying SPLASH10 satellite tags on BCB bowhead whales during autumn 2018. These tags would ideally provide data on whale surface and dive intervals, and location, during the planned 2019 aerial line-transect abundance survey.**
3. **During summer and autumn 2018, collect focal follow surveys in various habitats (e.g., depths) and geographic areas on an opportunistic basis to obtain information on individual and group surfacing intervals.**

In order to estimate the length of time an observer has to potentially detect an object at the water's surface, ASAMM has conducted dedicated field trials to estimate the complete field of view (e.g., Hain et al. 1999; Robertson et al. 2015) from the bubble windows in the Turbo Commander aircraft used to conduct ASAMM surveys since 2009. Data collected to date confirm that the field of view is affected by numerous factors, including: observer position in the bubble window, eyesight, and familiarity with the target; sun position (direction and angle); precipitation, including rain, snow, haze, or fog; sea state; winds at the altitude of the survey aircraft, which affect the aircraft's angle relative to its direction of travel; and target color, reflectance, size, and shape. Under the assumptions of standard line-transect theory, the only aspect of the field of view that is relevant to estimating availability bias is the length of time an object located on or near the transect is potentially visible to an observer. Therefore, the workshop ***recommended*****:**

4. **ASAMM should collect data during upcoming surveys in 2018 and 2019 to estimate the time an object located on or near the transect is in view. Floating, inanimate objects opportunistically encountered while surveying, such as marine mammal carcasses or logs, would likely be good targets for collecting these time-in-view data. Draft protocols are provided in Appendix B.**

Perception bias

Data to estimate the magnitude of and variability in correction factors for transect perception bias in line-transect data are typically collected using protocols in which sighting data are simultaneously recorded for two independent observers, one of which might not be human, such as a camera. Mark-recapture methods are used to analyze the data in order to derive the correction factors. The aircraft used to conduct ASAMM surveys was chosen partly based on its ability to fly both at the relatively low speeds (115 kts, 213 km/hr) needed for conducting surveys and high speeds (180 kts, 333 km/hr) needed to effectively transit between distant points in a large study area. The ASAMM aircraft size and configuration does not allow line-transect surveys to be conducted with two teams of independent human observers onboard. The ASAMM aircraft does have a belly port with a camera mount, which was used to collect aerial imagery concurrent with ASAMM surveys in 2015. Only 36 cetaceans were detected in the imagery in 2015, too few to derive a reliable correction factor for perception bias. To derive a better estimate of the correction factor for perception bias, the workshop ***recommended*****:**

5. **ASAMM should collect imagery from the belly-mounted camera system during ASAMM surveys in the Beaufort Sea in 2018 in order to increase the sample size necessary to derive a correction factor for perception bias in the ASAMM bowhead whale data. Although manually processing the imagery is time intensive, ASAMM observers in the field can work on this task when they are not conducting surveys.**
6. **Information in the ASAMM historical database on initial and final bowhead whale group sizes should be evaluated to determine if these data can be used to derive correction factors for transect detection bias.**

Sea ice can affect perception bias because objects are more difficult to detect in a field of broken ice than in open water. Since the early 1990s, sea ice has largely been absent from the ASAMM study area during the ASAMM field season. Sea ice may be more of an issue during the abundance estimation surveys in 2019, although reliable predictions of sea ice distribution in the Beaufort Sea study area are not available months in advance. The belly-mounted camera will provide a continuous record of sea ice directly beneath the aircraft. In addition, standard ASAMM protocols are to take oblique photographs of sea ice opportunistically over the course of a survey to document the survey conditions and ground-truth remotely-sensed data, among other things. The "ASAMM Survey" software used to record line-transect data currently allows only a single value to be entered for the percent of sea ice in the viewing area. However, sea ice cover can differ considerably between the left (port) and right (starboard) sides of the aircraft if, for example, the aircraft is flying parallel to a large patch of sea ice, with open water on one side of the aircraft. To accurately and efficiently record the variability in sea ice cover on each side of the aircraft, the workshop ***recommended*:**

7. **The ASAMM Survey software should be modified to allow separate estimates of sea ice cover to be entered for each side of the aircraft.**

Uncertainty in group size estimates

Bowhead whales in the western Beaufort Sea may be distributed as single individuals separated from other whales by large distances, sparsely distributed groups of only a few animals, aggregations of feeding animals that are densely distributed and cover a large area (Figures 1 and 2), or any combination of these units. An aerial observer's ability to determine the number of whales present in a sighting depends on a number of factors, including distance from the aircraft, environmental conditions, animal activity and coloration, and observation time. In general, the number of whales in an aggregation is the most difficult group size to estimate accurately and precisely. Uncertainty in group size estimates affect the resulting uncertainty in the population abundance estimate. The workshop ***recommended* :**

8. **Analytical methods such as bootstrapping or Bayesian hierarchical modeling should be evaluated to determine whether they can produce an accurate and precise abundance estimate that also captures group size uncertainty.**

Uncertainty in the proportion of the population in the survey area

Bowhead whales are migratory animals. The vast majority of BCB bowhead whales appear to migrate to the eastern Beaufort Sea; however, some are thought to be resident near Point Barrow, and some are thought to summer near Chukotka, Russia (Citta et al. 2012). Multiple lines of evidence (e.g., traditional ecological knowledge, aerial surveys, telemetry, passive acoustic monitoring) suggest that interannual variability exists in the timing and location of their westward autumn migration across the Beaufort Sea. The timing of bowhead whales' departure from the eastern Beaufort Sea during late summer or early fall is related to upwelling strength and the timing of copepods entering their diapause phase in that area

(Walkusz et al. 2012). The rate at which bowhead whales travel westward across the Beaufort Sea is related to the existence of foraging opportunities, which are ephemeral and spatially variable over the course of weeks, months, and years. Because the goal for the 2019 Beaufort-wide survey is to estimate the total abundance of the BCB population, and because it is known that not all bowheads will be in the study area during the survey period, it is important to be able to estimate the proportion of the population that is outside the survey bounds. Recommendation #2 above is designed to provide information to address this issue. In addition, the workshop ***recommended*:**

9. **Analyze existing satellite telemetry data for BCB bowhead whales to estimate the proportion of whales in the survey area during the period corresponding to the 2019 survey, and examine inter-annual variability therein.**
10. **Consider whether a quantitative model can be created to relate the timing of bowhead whale departure from the eastern Beaufort Sea to wind patterns or other environmental covariates. If a reliable model could be created, it may be used retrospectively to estimate the state of the migration at the time of the 2019 survey.**
11. **During ASAMM surveys in 2018, fly longitudinal transects between 72º-73ºN, 157º-160ºW during summer to collect information on bowhead whale use of this area.**

2019 LINE-TRANSECT SURVEY DESIGN AND PROTOCOLS

Fundamental questions about the 2019 survey design concerned the boundaries of the study area, survey timing and duration, aircraft type and number, bases of operations, and survey type. Because bowhead whales are migratory animals, the question of study area and survey timing are inherently linked. Based on available information about the spatiotemporal distribution of BCB bowhead whales throughout their range (Figure 3; e.g., Citta et al., 2015; Clarke et al. 2018; Harwood et al. 2010, 2017), workshop participants agreed that conducting a line-transect survey across the Beaufort Sea in summer has the highest probability of capturing a snapshot of the population when the majority of the whales are located in an area that can be surveyed by aircraft in a relatively short period. Experience from ASAMM indicates that weather will allow aerial surveys to be conducted in the Alaskan Arctic on 35-50% of the days in summer and autumn. The only airports in the study area east of Utqiaġvik with critical infrastructure needed for conducting aerial surveys (aviation fuel and lodging) are located at Deadhorse, Alaska (USA) and Inuvik, Northwest Territory (Canada).

Although existing satellite telemetry data suggest that the majority of the population is likely confined within the eastern Beaufort Sea in June (Citta et al. 2015), satellite imagery from 2009-2016 suggests that considerable portions of the Beaufort Sea may be covered by at least 30% sea ice concentrations as late as early August during some years (Figure 4; National Ice Center 2018). Marine mammals are extremely difficult to detect in broken floe sea ice habitat during visual line-transect surveys (Figure 5). Correction factors for perception bias resulting from sea ice can be estimated. The accuracy and precision of those correction factors depends on sample size (among other factors), and workshop participants did not reach a consensus regarding whether a reliable correction factor for perception bias due to sea ice could be derived. By late August in recent years, sea ice has mostly receded from the Beaufort Sea (Figure 4) and satellite telemetry data suggest that the majority of the BCB bowhead whale population remains east of Point Barrow (Druckenmiller et al. 2017). Satellite tags have tracked BCB bowhead whales as far north as Viscount Melville Sound during August and September (Harwood et al. 2017), but those appear to be relatively rare excursions and recent data suggest that bowhead whales from the Baffin Bay and Davis Strait stock might be expanding into that area (Heide-Jørgensen et al. 2012). Based on the distribution of sea ice and bowhead whales, the workshop ***recommended*** the following survey design features**:**

12. **The 2019 BCB bowhead whale abundance estimation line-transect survey should begin in early August and fly every day, weather-permitting, for three to four weeks in order to cover the entire study area. A three-week survey is considered minimally acceptable for completing the entire survey due to the extent of the study area, long transit times to reach certain portions of the study area due to the lack of airports with infrastructure (aviation fuel and lodging), and expected number of days that will not be conducive to surveying due to poor weather (e.g., strong winds, precipitation, or both). This estimate of field season duration is based on the assumption that each aircraft can survey for up to 5 hrs (with 1 hr of fuel in reserve) and can conduct two flights on some days.**
13. **The study area should range from just west of Point Barrow to eastern Amundsen Gulf, along the western side of Banks Island, and exclude Viscount Melville Sound (Figure 6).**
14. **Three aircraft should be used to increase the probability of completing the survey within the survey period.**
15. **One aircraft should be based in Deadhorse and should focus surveying west of ~138ºW. Two aircraft, based in Inuvik, should concentrate their survey effort in the eastern Beaufort Sea.**
16. **The Turbo Commanders, such as those used to conduct ASAMM since 2009, are a good platform for this survey due to their ability to transit quickly to distant reaches of the study area.**
17. **Ideally, the three aircraft will spread out and cover different portions of the study area on a given day to capture a snapshot of the population over a large extent in a short period of time, minimizing bias due to animal movement.**
18. **Priority should be given to surveying shoreward of the 200-m isobath. Coverage of Barrow Canyon and the portion of the study area west of Point Barrow should also be prioritized in order to determine the number of whales exiting the northwestern corner of the study area.**
19. **Lower priority should be given to transects west and east of Banks Island and waters > 200 m in the western Beaufort Sea (west of ~138ºW).**
20. **A systematic survey design should be used, with transects equally spaced and oriented to cut perpendicularly across isobaths, which will also tend to cut across the bowhead whale distribution in the study area.**
21. **Power analyses should be used to determine optimal transect spacing based on expected whale densities. The survey design should be stratified to allow larger spacing between transects in low density areas. Given the relative lack of information about bowhead whale distribution in the eastern Beaufort Sea, it is better to err on placing transects too close in that area because that survey design can easily be modified in the field by omitting transects in low density areas.**
22. **If time and weather permit, transects may be repeated over the course of the survey period to allow examination of spatiotemporal variability in bowhead whale distribution and density.**

The overall goal for the survey protocols is to collect data that can be analyzed using design-based distance sampling methods (Thomas et al. 2010), although model-based methods also can be used if they result in a more accurate and precise population abundance estimate. Workshop participants agreed that the existing ASAMM survey protocols (Clarke et al. 2017) should be used, with a survey altitude of 305-366 m (1000-1200 ft) and slight modification to protocols for surveying large aggregations of high densities of cetaceans. The workshop's ***recommendations*** for the Cetacean Aggregation Protocols (CAPs) are as follows:

23. **Data collection on bowhead whales should take precedence over any other species for the duration of the abundance estimation surveys. Data should not be recorded on non-bowhead whale sightings if it compromises the ability to record accurate and complete data for bowhead whale sightings.**
24. **The definition of a "group" needs to be strictly defined prior to the surveys and applied during every line-transect survey flight. The existing ASAMM definition of a group is sufficient: a group comprises all surfaced whales located within 5 body lengths of each other[3].**
25. **All surveys should be flown with the belly-mounted, downward-pointing digital single lens reflex camera recording imagery. Metadata for each image should include time, latitude, longitude, and altitude. The imagery can be used to estimate the number of whales located within the left-truncation distance of the transect. This is necessary to produce an unbiased abundance estimate.**
26. **Appendix C provides further details on the draft Cetacean Aggregation Protocols. Although the appendix refers generically to "cetaceans," bowhead whales will take precedence during the 2019 BCB bowhead whale abundance survey (see Recommendation #23).**
27. **CAPs should be implemented for high-density aggregations of all cetacean species encountered during standard ASAMM surveys.**
28. **During the 2018 ASAMM field season, every opportunity should be used to test CAPs and revise, as necessary, to collect reliable data using standardized, repeatable methods. Cetacean aggregations are relatively rarely encountered over the course of an ASAMM field season. When a cetacean aggregation is encountered, the field team is encouraged to spend time testing, tweaking (if necessary), and re-testing CAPs, even if this means repeatedly surveying the same stretch of transect on the same day, assuming weather and fuel allow. If CAPs is tweaked during flight, it is important for the data to clearly identify when, how, and why protocols were altered.**

Workshop participants discussed whether additional or alternative survey methods should be used. One idea was to conduct a "gateway" aerial survey, repeatedly flying in a location where bowhead whales could be found migrating in a narrow band on the continental shelf, analogous to the scenario near Point Barrow during spring that the ice-based survey has capitalized on in the past. A spring aerial or vessel-based survey was not considered to be an option due to the potential disturbance it might cause to spring whaling activities. Experts determined that the gateway survey design would not be reliable for surveying bowhead whales after spring for several reasons. First, a well-defined stream of bowhead whales migrating westward does not exist. Not all whales migrate to the eastern Beaufort Sea each year. Bowhead whales will linger (for an unknown length of time) to forage on ephemeral and spatially dynamic feeding grounds during their return trip westward across the Beaufort Sea. For BCB bowhead whales that travel to the eastern Beaufort Sea, the timing of their departure exhibits large interannual variability, likely due to variability of winds and resultant upwelling in the southeastern Beaufort Sea, Amundsen Gulf, and elsewhere; this timing cannot be predicted in advance. For logistical reasons (e.g., aircraft and observer contracts, lodging), the survey period must be set many months in advance.

Workshop participants also discussed using unmanned aircraft systems (UAS), such as hexacopters, to conduct focal follows of bowhead whales. Although the hexacopter is a stable, quiet, portable, and relatively inexpensive platform for collecting high-resolution imagery data, their endurance (total flight

[3] Aerial Surveys of Arctic Marine Mammals (ASAMM) Observer Manual – 2017. Version 7. 28 August 2017. This is an unpublished document that is regularly updated.

time before needing to recharge) is a limiting factor. Currently, the hexacopters with the longest endurance must recharge every ~40 minutes. Due to the harsh Arctic environment and the dynamic distribution of bowhead whales, it was determined that existing UAS technology would likely not be successful for conducting focal follows.

Close-kin mark-recapture methods (e.g., using genetic samples from the BCB bowhead whale harvest) might be useful for reconstructing historical population abundance or providing short-term management advice, but results likely could not be obtained by the IWC's deadline for a new BCB bowhead whale population abundance estimate.

No other methods were considered to be valuable for collecting data that could increase the accuracy and precision of a new BCB bowhead whale abundance estimate in 2019.

ANALYTICAL METHODS FOR ESTIMATING POPULATION ABUNDANCE

Workshop participants discussed analytical techniques for estimating the abundance of BCB bowhead whales, but were not prescriptive. Emphasis was placed on designing the survey and implementing protocols that would produce data that met the assumptions for a standard, design-based distance sampling analysis (Buckland et al. 2001). Because the variability in encounter rate typically contributes the most uncertainty to the resulting abundance estimate (e.g., Fewster et al. 2009), analytical methods should be used that can take advantage of the theoretical variance-reducing aspects of a systematic line-transect survey design (Fewster 2011). Incorporation of the CAPs protocols for surveying large bowhead whale aggregations will facilitate separate analyses of small and large groups, which should decrease the CV of the mean group size estimate for each type; this will ultimately improve the overall abundance CV, given adequate sample size of large groups. Hierarchical methods should be considered as a way to account for the uncertainty in the proportion of the BCB bowhead whale population in the study area during the survey period. There was some discussion about Horvitz-Thompson-like estimators producing biased results under certain circumstances, such as when sighting densities are rare and the detection process is heterogeneous. This issue can be examined in detail using the ASAMM historical database.

COST ESTIMATES

Cost estimates for the BCB bowhead whale abundance aerial surveys range from $777K to $902K (US dollars). Several variables affect the cost of the surveys, including extending some transects to the 2,000-m depth contour in the western Beaufort Sea, incorporating transects west or east of Banks Island, and the capability to refuel at small airports in the eastern Beaufort Sea. If fuel can be safely and reliably obtained at locations in the eastern Beaufort Sea in addition to Inuvik, estimated costs should decrease substantially.

Each cost estimate assumes the following:

- One aerial survey team based in Deadhorse for two weeks. The shorter length of time for the Deadhorse team is possible because that team will likely be responsible for far less transect coverage and, therefore, fewer survey hours. Estimated survey hours for the Deadhorse team are 29-34 hrs, depending on extension of transects to 2,000-m depth contour. Overall costs are lower for the Deadhorse team because the team will already be on site for ASAMM surveys.
- Two aerial survey teams based in Inuvik for three weeks each. Estimated survey hours for the Inuvik teams (combined) are 91-144 hrs, depending on the inclusion of Banks Island transects. Overall costs are higher for the Inuvik teams because the aircraft and personnel will be traveling to that base from either Utqiaġvik or Anchorage, AK (estimate includes 23 hrs transiting).

- Several transects will need to be flown singly due to their distance from Inuvik.
- Transects are spaced 17-18 km apart.
- Circling was estimated at a rate of 0.3 hours per hour of transect.
- All transits (to and from transects, between transects, and to and from bases at the start and end of the abundance survey) were assumed to occur at 180 kts.

	Estimate A	Estimate B	Estimate C	Estimate D
1 SCC aircraft - 2 weeks	x	x	x	x
2 Inuvik aircraft, 3 weeks each	x	x	x	x
Deeper water transects in western Beaufort			x	x
Fuel limited to Utqiaġvik, Deadhorse, and Inuvik	x	x	x	x
Some transects flown singly	x	x	x	x
Transects off Banks Island	x		x	
Estimated cost	$891K	$777K	$902K	$788K

ACKNOWLEDGMENTS

The ASAMM study was funded and co-managed by the U.S. Department of the Interior (USDOI), Bureau of Ocean Energy Management (BOEM, formerly MMS), Alaska Outer Continental Shelf Region, Anchorage, Alaska, through Interagency Agreement No. M17PG00031, as part of the Alaska Environmental Studies Program. We are thankful to the AFSC IT group for the fancy whiteboard and ensuring that the workshop ran smoothly.

LITERATURE CITED

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L, Borchers, D.L., and Thomas, L. 2001. Introduction to Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press. 432 pp.

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

Citta, J.J., Quakenbush, L.T., Okkonen, S.R., Druckenmiller, M.L., Maslowski, W., Clement-Kinney, J., George, J.C., Brower, H., Small, R.J., Ashjian, C.J., Harwood, L.A., and Heide-Jørgensen, M.P. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006-2012. *Progress in Oceanography* 136:201-222.

Clarke, J.T., Brower, A.A., Ferguson, M.C., and Willoughby, A.L. 2017. Distribution and relative abundance of marine mammals in the eastern Chukchi and western Beaufort Seas, 2016. Annual Report, OCS Study BOEM 2017-78. Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349. Available from: https://www.afsc.noaa.gov/nmml/cetacean/bwasp/

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

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

Druckenmiller, M.L., Citta, J.J., Ferguson, M.C., Clarke, J.T., George, J.C., and Quakenbush, L. 2017. Trends in sea-ice cover within bowhead whales habitats in the Pacific Arctic. *Deep Sea Research Part II* doi.org/10.1016/j.dsr2.2017.10.017.

Fewster, R.M., Buckland, S.T., Burnham, K.P., Borchers, D.L., Jupp, P.E., Laake, J.L., and Thomas, L. 2009. Estimating the encounter rate variance in distance sampling. *Biometrics* 65: 225-236.

Fewster, R.M. 2011. Variance estimation for systematic designs in spatial surveys. *Biometrics* 67: 1518-1531.

George, J.C., Herreman, J., Givens, G.H., Suydam, R., Mocklin, J., Clark, C., Tudor, B., and DeLong, R. 2012. Brief overview of the 2010 and 2011 bowhead whale abundance surveys near Point Barrow, Alaska. Paper SC-64-AWMP7 presented to the IWC Scientific Committee, May 2012 (unpublished). 9pp.

Givens, G.H., Edmondson, S.L., George, J.C., Suydam, R., Charif, R.A., Rahaman, A., Hawthorne, D., Tudor, B., DeLong R.A., and Clark, C.W. 2016. Horvitz-Thompson whale abundance estimation adjusting for uncertain recapture, temporal availability variation, and intermittent effort. *Environmetrics* 26:1-16.

Hain, J.H.W., Ellis, S.L., Kenney, R.D., and Slay, C.K. 1999. Sightability of right whales in coastal waters of the southeastern United States with implications for the aerial monitoring program. Pp. 191-208 *In* G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald, and D.G. Robertson (eds.). Marine Mammal Survey and Assessment Methods. Proceedings of the Symposium on Surveys, Status, and Trends of Marine Mammal Populations, Seattle, WA, USA, 25-27 February 1998.

Harwood, L.A., Auld, J., Joynt, A., and Moore, S.E.. 2010. Distribution of bowhead whales in the SE Beaufort Sea during late summer, 2007-2009. DFO Canadian Science Advisory Secretariat Research Document 2009/111. iv + 22 p.

Harwood, L.A., Quakenbush, L.T., Small, R.J., George, J.C., Pokiak, J., Pokiak, C., Heide-Jørgensen, M.P., Lea, E.V., and Brower, H. 2017. Movements and inferred foraging by bowhead whales in the Canadian Beaufort Sea during August and September, 2006-12. *Arctic* 70(2):161-176.

Heide-Jørgensen, M.P., Laidre, K.L., Quakenbush, L.T., and Citta, J.J. 2012. The Northwest Passage opens for bowhead whales. *Biology Letters* 8:270-273. doi: 10.1098/rsbl.2011.0731.

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

Laake, J.L., Calambokidis, J.C., Osmek, S.D., and Rugh, D.J. 1997. Probability of detecting harbor porpoise from aerial surveys: estimating g(0). *Journal of Wildlife Management* 61:63-75.

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

National Ice Center. 2018. http://www.natice.noaa.gov/products/weekly_products.html

Robertson, F.C., Koski, W.R., Brandon, J.R., Thomas, T.A., and Trites, A.W. 2015. Correction factors account for the availability of bowhead whales exposed to seismic operations in the Beaufort Sea. *Journal of Cetacean Research and Management* 15:35-44.

Schweder, T., Sadykova, D., Rugh, D., and Koski, W. 2009. Population estimates from aerial photographic surveys of naturally and variably marked bowhead whales. Journal of Agricultural and Biological Environmental Statistics 15(1):1-19.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A., and Burnham, K.P. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology* 47:5-14.

Walkusz, W., Williams, W.J., Harwood, L.A., Moore, S.E., Stewart, B.E., and Kwasniewski, S. 2012. Composition, biomass and energetic content of biota in the vicinity of feeding bowhead whales (*Balaena mysticetus*) in the Cape Bathurst upwelling region (south eastern Beaufort Sea). *Deep Sea Research Part 1: Oceanographic Research Papers* 69:25-35.

Würsig, W., Koski, W.R., Thomas, T.A., and Richardson, W.R. 2002. Activities and behavior of bowhead whales in the eastern Alaskan Beaufort Sea during late summer and autumn. p. 12-1 to 12-38 *In:* W.J. Richardson and D.H. Thomson (eds.), Bowhead whale feeding in the eastern Alaskan Beaufort Sea: update of scientific and traditional information, vol. 1. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Anchorage, AK, and Herndon, VA.

Wursig, B., Dorsey, E.M., Fraker, M.A., Payne, R.S., Richardson, W.J., and Wells, R.S. 1984. Behavior of bowhead whales, *Balaena mysticetus*, summering in the Beaufort Sea: surfacing, respiration and dive characteristics. *Canadian Journal of Zoology* 62:1910-1921.

ADDITIONAL BACKGROUND INFORMATION

Boyd, C., J. Barlow, E.A. Becker, K.A. Forney, T. Gerrodette, J.E. Moore, and A.E. Punt. 2018. Estimation of population size and trends for highly mobile species with dynamic spatial distributions. Diversity and Distribution 24: 1-12.

Bradford, A.L., Forney, K.A., Oleson, E.M., and Barlow, J. 2014. Accounting for subgroup structure in line-transect abundance estimates of false killer whales (*Pseudorca crassidens*) in Hawaiian waters. PLoSONE 9(2): e90464 doi: 10.1371/journal.pone.0090464.

Ferguson, M.C., Givens, G.H., Clarke, J.T., Willoughby, A., Brower, A. and George, J.C. 2017. A minimum abundance estimate of BCB bowhead whales in the western Beaufort Sea in late August, 2016. IWC SC/67A/AWMP/08.

Hamilton, O.N.P., Kincaid, S.E., Constantine, R., Kozmian-Ledward, L., Walker, C.G., and Fewster, R.M. 2017. Accounting for uncertainty in duplicate identification and group size judgments in mark-recapture distance sampling. *Methods in Ecology and Evolution* DOI 10.1111/2041-210X.12895.

Heide-Jørgensen, M.P., Laidre, K.L., Hansen, R.G., Burt, M.L., Simon, M., Borchers, D.L., Harding, H.K., Rasmussen, M., Dietz, R., and Termann, J. 2012. Rate of increase and current abundance of humpback whales in West Greenland. *Journal of Cetacean Research and Management* 12(1):1-14.

Johnson, D.S., Laake, J.L., and Ver Hoef, J.M. 2010. A model-based approach for making ecological inference from distance sampling data. *Biometrics* 66: 310-318.

Koski, W.R. and Johnson, S.R. 1987. Responses of Bowhead Whales to an Offshore Drilling Operation in the Alaskan Beaufort Sea, Autumn 1986: Behavioural Studies and Aerial Photogrammetry. LGL Ltd., King City Ont, for Shell Western E&P Inc., 601 West Fifth Avenue, Anchorage, Alaska. 131pp.

Richardson, W.J. and Thomson, D.H. (eds). 2002. Bowhead Whale Feeding in the Eastern Beaufort Sea: Update of Scientific and Traditional Information. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. From LGL Ltd., King City, Ontario, Canada for US Minerals Management Service, Anchorage, Alaska and Herndon, Virginia, USA. Vol. 1, xliv+420pp; Vol. 2, 277pp.

Richardson, W.J., Würsig, B., and Greene, C.R., Jr. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. *Journal of the Acoustical Society of America* 79: 1117-28.

Thompson, S.K. 1991. Adaptive cluster sampling: designs with primary and secondary units. *Biometrics* 47(3):1103-1115.

Figure 1. Aerial photograph of a bowhead whale feeding aggregation taken during ASAMM surveys in 2009.

Figure 2. Aerial photograph of a bowhead whale feeding aggregation taken during ASAMM surveys in 2015

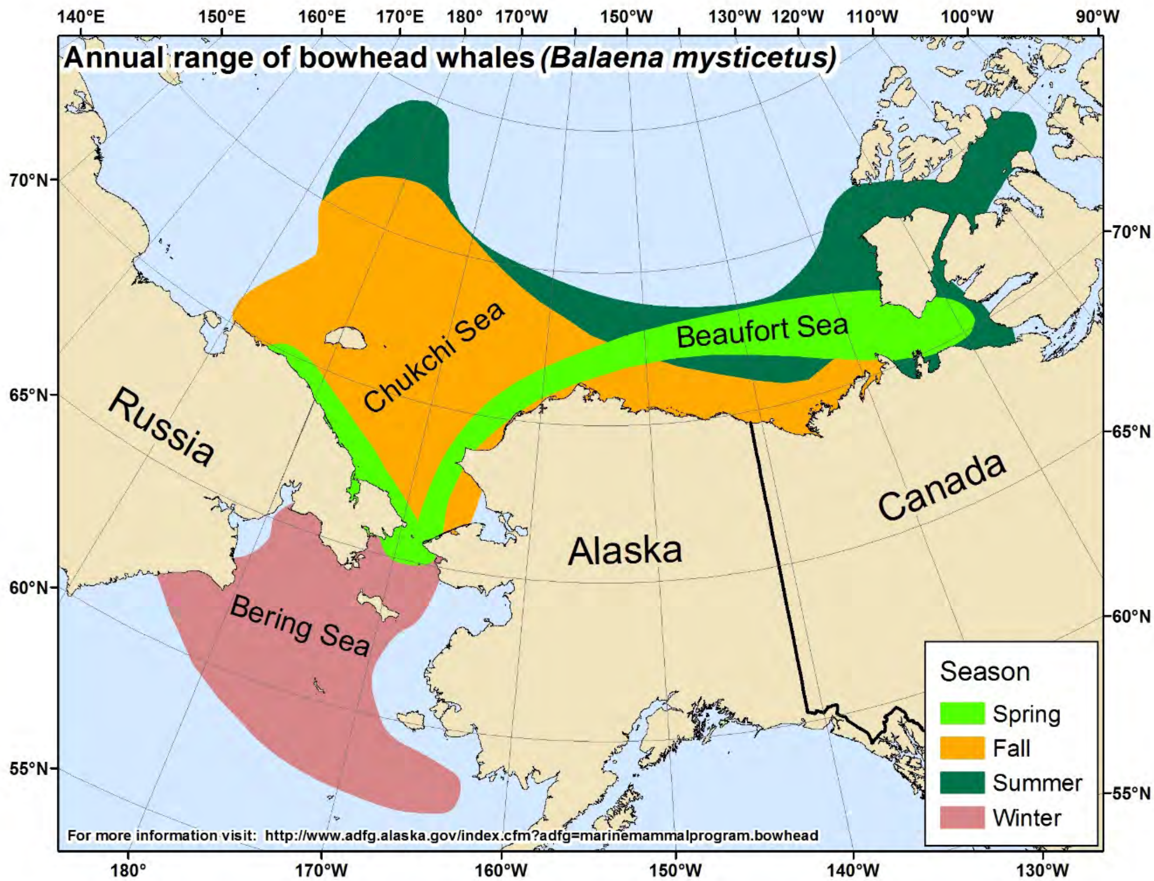


Figure 3. Seasonal distribution of bowhead whales from the Bering-Chukchi-Beaufort Seas stock (map courtesy of Alaska Department of Fish and Game).

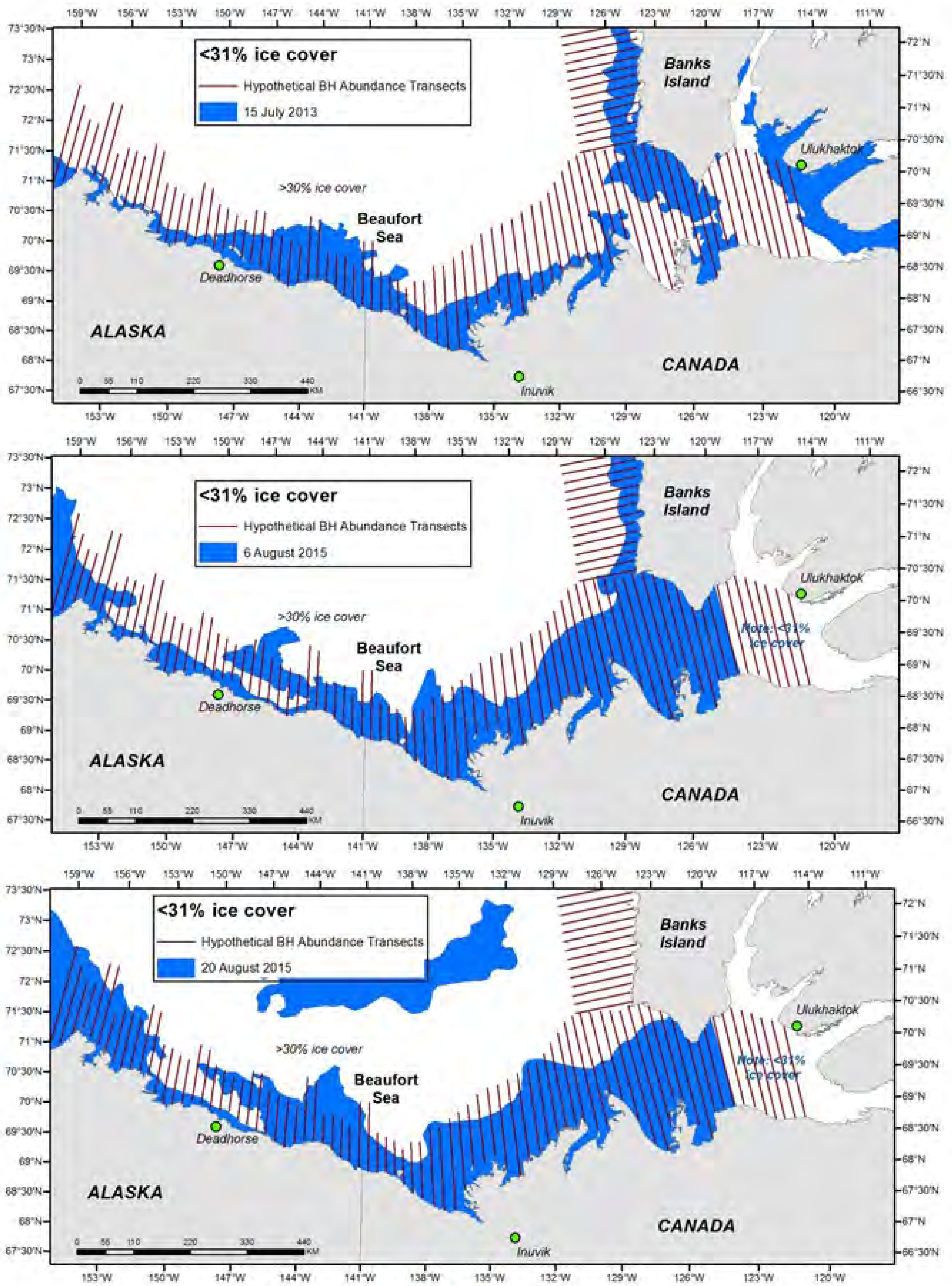


Figure 4. Highest ice concentrations in the Beaufort Sea per fortnightly period from mid-July to late August, 2009-2016.

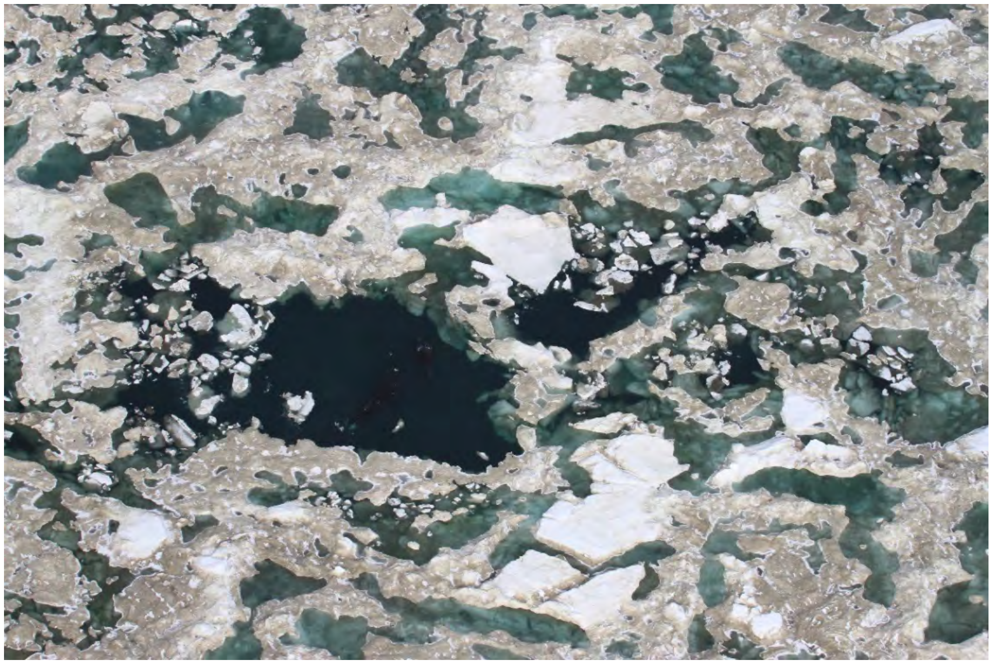


Figure 5. Find the bowhead whale in sea ice!

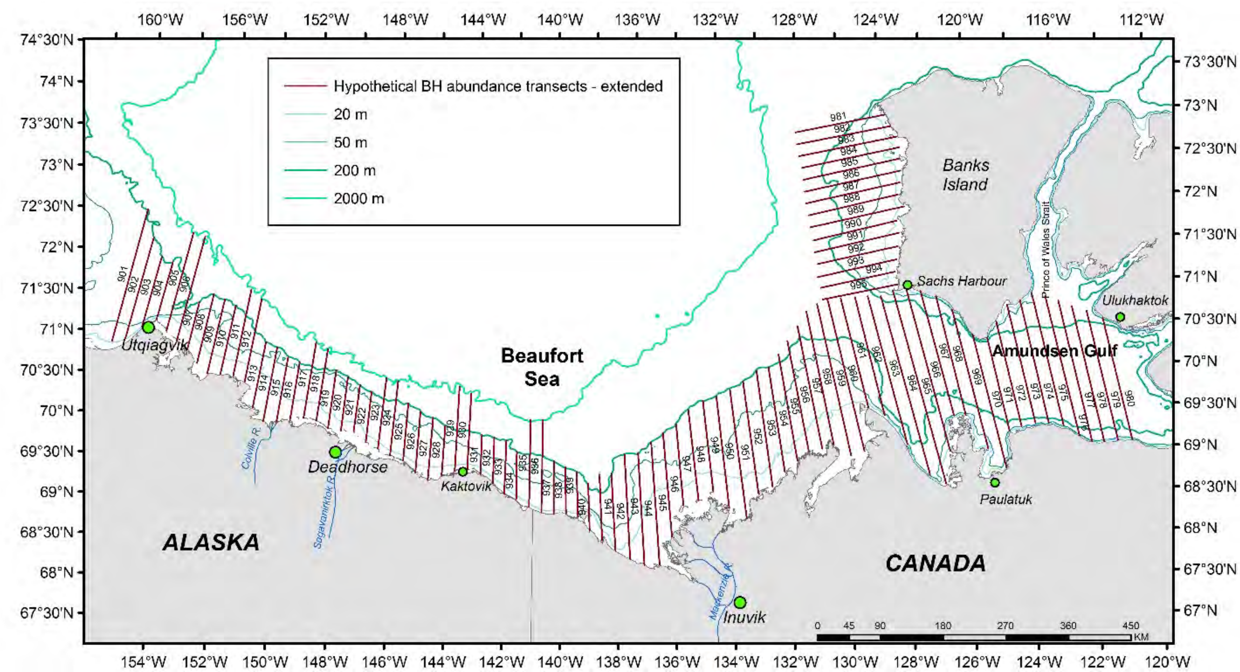


Figure 6. Proposed BCB bowhead whale abundance survey area. Transects are oriented as they will be flown, but transect spacing will be determined for spatial strata depending on expected differences in bowhead whale density. In the western Beaufort Sea (west of ~138ºW), occasional transects will extend beyond the 200-m isobath; the spacing between these offshoots will be determined analytically based on expected bowhead whale density beyond the continental shelf. Fuel and lodging are available in Utqiaġvik, Deadhorse, and Inuvik. Alternate landing strips (without fuel and lodging) are located at various locations in the study area, but are not shown on this map.

Appendix A

Estimating Abundance of Bering-Chukchi-Beaufort Bowhead Whales from Aerial Line Transect Surveys

Agenda v11

4-5 April 2018
NOAA AFSC Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115

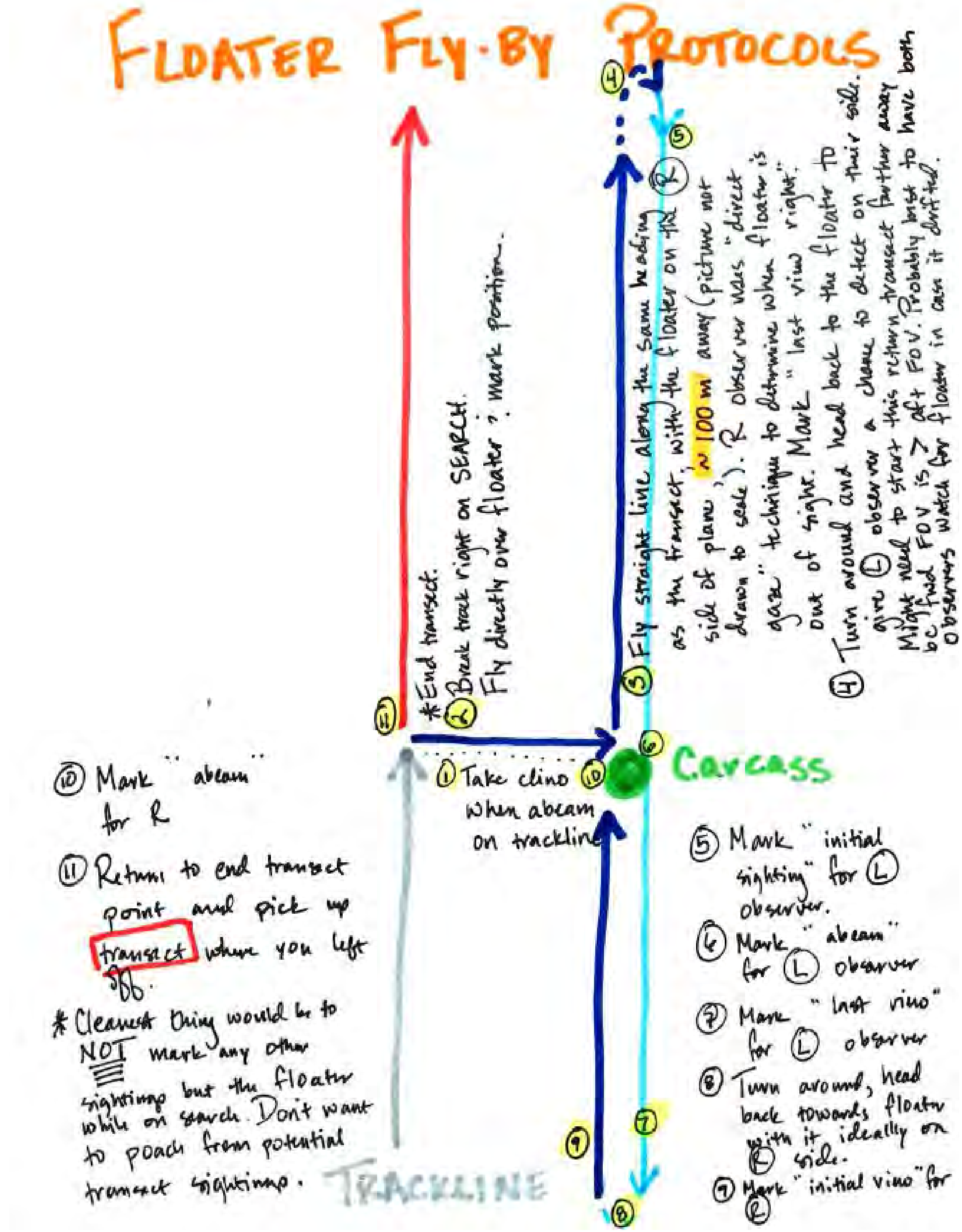
April 4: 09:00-17:00 hrs
April 5: 08:30-13:00 hrs

MML Large Conference Room (room # 2039)

1. Background on the need for a revised abundance estimate for BCB bowhead whales
2. Overview of BCB bowhead whales in the Chukchi and Beaufort Seas
    a. Aerial Surveys of Arctic Marine Mammals (ASAMM) project: Study area, objectives, history, and field protocols (e.g., Clarke et al. 2017)
    b. Eastern Beaufort Sea (Harwood et al. 2010 and 2017)
    c. Core Use Areas and Timing: Citta et al. (2015)
3. Bowheads in the western Beaufort Sea in August 2016
    a. What happened and why was this unique?
    b. Initial attempt to estimate *Nmin* (Ferguson et al. 2017; Ferguson 2017)
    c. Status update on revising this *Nmin* (Ferguson and Clarke 2018)
4. Elaboration on known information gaps or analytical weaknesses identified in Ferguson and Clarke (2018)
    a. Field of view from the ASAMM survey aircraft bubble windows (Hain et al. 1999; Robertson et al. 2015)
    b. Bowhead whale surface and dive behavior (Richardson et al. 1986; Koski et al. 1987; Ljungblad et al. 1988; Richardson and Thomson 2002; Heide--Jørgensen et al. 2012; Citta et al. 2015; Citta's "More correction factor stuff" notes)
    c. Uncertainty in group size estimates (Hamilton et al. 2017)
    d. Uncertainty in encounter rate (Fewster et al. 2009; Fewster 2011; Johnson et al. 2010)
    e. Perception bias
5. Group discussion on recommendations moving forward
    a. Changes to ASAMM protocols
        i. Geometer
    b. Existing sources of data
    c. Other research to address information gaps
        i. Field work for summer 2018
        ii. Field work for 2019
    d. Analytical methods (Boyd et al. 2018)

Appendix B

Extremely Draft ASAMM Floater Fly-By Protocols



Appendix C

ASAMM
Cetacean Aggregation Protocols
CAPs

Version 6
17 April 2018

Data collection on cetacean aggregations should take precedence over any other species during all ASAMM surveys. Data should not be recorded on non-cetacean sightings if it compromises the ability to record accurate and complete data for cetacean sightings.

The definition of a "group" needs to be strictly applied during every ASAMM flight. ASAMM defines a group to be all surfaced animals of the same species located within 5 body lengths of each other. This is important when we divert from transect to circling to verify species and determine calf presence because any whale sighted during circling that is >5 body lengths from the transect sighting will trigger CAPs mode. A "metagroup" is defined as all cetacean groups (regardless of species) observed on one side of the transect in a single CAPs segment, within 3 km (1.6 nmi) of the transect, that are part of a larger high-density patch of cetaceans. An aggregation comprises all CAPs metagroups plus any whales located >3 km from any transect in the same high-density patch of cetaceans. An aggregation may span several transects (Figure 1).

Ideally, all surveys should be flown with the belly-mounted, downward-pointing single-lens reflex camera recording imagery. Metadata for each image should include time, latitude, longitude, and altitude. The imagery can be used to estimate the number of whales located within the left-truncation distance of a transect. This is necessary to produce an unbiased abundance estimate. If the camera system is not available, it is o.k. to fly without it, but notify program management upon landing so that a solution can be found.

The "trigger" for commencing CAPs is the point when the density of groups of large cetaceans exceeds the team's ability to mark, record an accurate declination angle for, and circle every cetacean group detected (Figure 2). In ASAMM terminology, the entire CAPs portion of the survey will be flown in "CAPs" (FltType 7) and "circling-from-CAPs" (FltType 9) modes. At the trigger point, "end transect" (FltType 4, enttag 1) and "start CAPs" (FltType7, enttag 1). If necessary, the team can backtrack along a transect and return to a logical trigger point to implement CAPs (Figure 3).

During CAPs, the first step (FltType 7, enttag 1) is to continue to fly directly on the transect without breaking track to circle (i.e., "passing mode" in distance sampling terminology), compiling an initial estimate of the number of cetaceans located on the left (port) and right (starboard) sides of the aircraft, each side separately. During this part of CAPs, observers should monitor the declination angle corresponding to the distant boundary of the aggregation on each side of the aircraft. When the aircraft reaches the point where cetacean density has obviously diminished to background levels, record (for left and right sides separately): initial group size (all individuals in sight, regardless of species), number of calves, species observed, and minimum declination angle of the distant boundary of the aggregation (i.e., farthest from the transect because the horizon is located at 0^{o}). ASAMM code for these sightings will be FltType 7, enttag 3. If more than one species was observed on one side, select "multi" from the species dropdown list and manually enter a note that lists each species observed on that side. A CAPs sighting event should be entered for each side of the transect, even if no cetaceans were seen on one side. In the latter case, species should be entered as "multi" and initial group size entered as "0". Environmental updates (FltType 7, enttag 2) can be entered during this part of the survey.

Divert to circling-from-CAPs (FltType 9, enttag 1) towards right or left (choose one) and record sighting data (species, min/max/final group size, number of calves, calf detection certainty, reactions, behavior) for each group that is located ≤3 km (1.6 nmi) of the transect. It is o.k. to cross back and forth over the transect to thoroughly survey groups during circling-from-CAPs. All circling-from-CAPs sightings will be Flt Type 9, enttag 3. While circling-from-CAPs, all sightings on the right side of the transect should be attributed to the Right Observer and all groups on the left side of the transect attributed to the Left Observer, regardless of who sighted the group[4]. **WHILE CIRCLING DURING CAPs, DO NOT RECORD DATA FOR CETACEANS LOCATED > 3 km FROM THE TRANSECT.** If it is not feasible to collect data on each individual group in the metagroup that is within 3 km of the transect, it is o.k. to combine data for multiple groups of one species into a single sighting, but note this in the data, if possible. Unique species should be entered separately from each other. There is no time limit for collecting data on groups during this point of the protocol, assuming weather and fuel allow. The "width" limit for surveying aggregations is ≤3 km on either side of the transect. There is no limit to the "length" of a CAPs segment (along the transect); however circling-from-CAPs should never extend beyond the bounds of the initial CAPs segment (see Figure 2). Environmental updates (FltType 9, enttag 2) should continue to be entered as time allows during circling-from-CAPs sessions.

When metagroups on both sides of a transect have been surveyed out to a maximum of 3 km from the transect, return to the point on the transect downstream of the aggregation where only unsurveyed transect lies ahead. "Start transect" (FltType 2, enttag 1), and proceed to survey using standard ASAMM protocols. If the aggregation extends farther than the initial CAPs segment, start a new CAPs session (FltType7, enttag 1).

If the team backtracked along a transect to return to a logical trigger point to implement CAPs after circling-from-transect commenced, all of the original sightings on transect located perpendicular to the CAPs segment should be identified and deleted (see example in Figure 3). The data recorder can make a list of duplicate sightings-on-transect that need to be deleted and give that list to the data editor to make the necessary edits (saved=0) during post-flight processing.

[4] This includes pilot sightings, data recorder sightings, and fourth observer sightings.

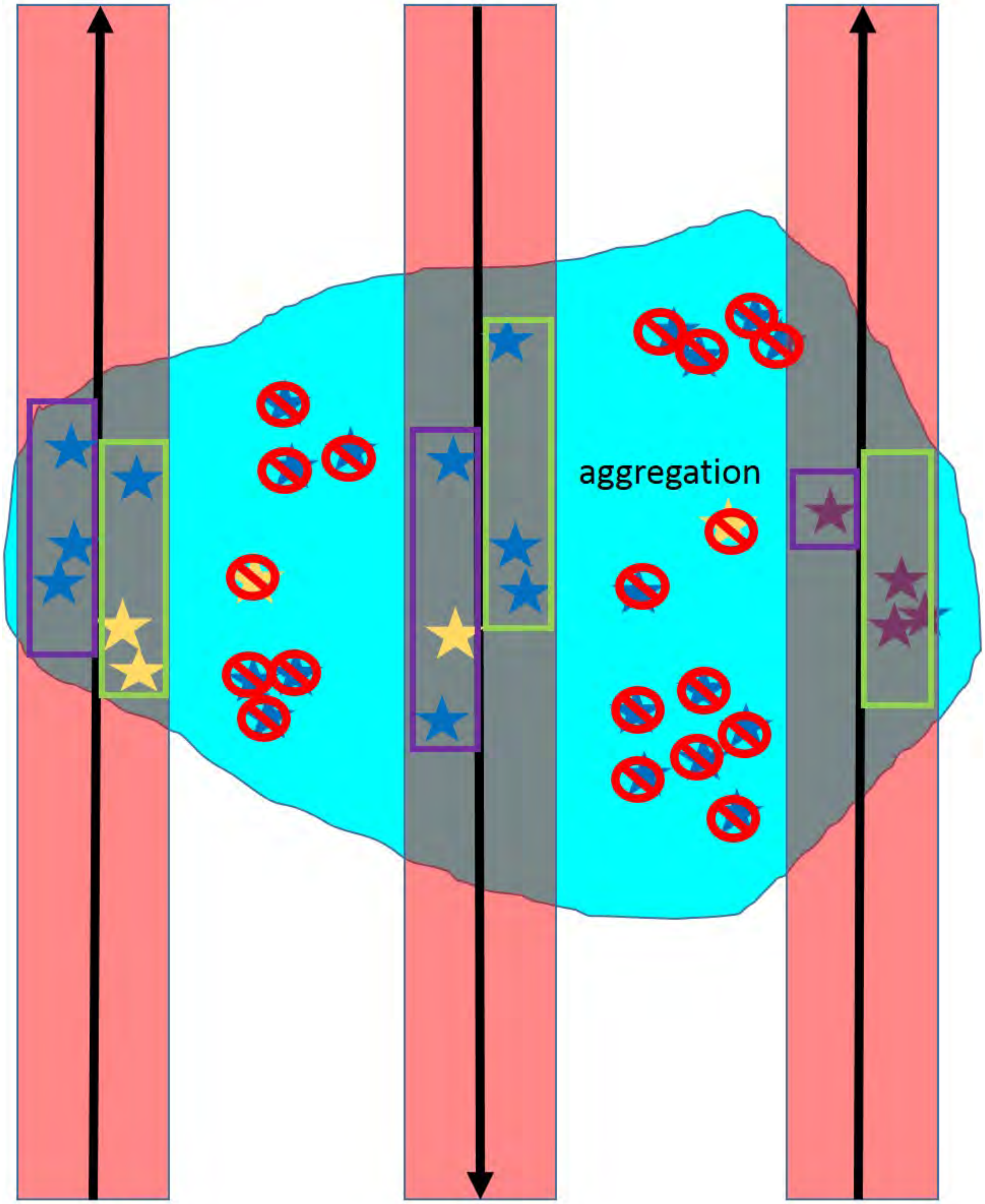


Figure 1. A cetacean group comprises surfaced cetaceans of the same species within five body lengths of each other. A metagroup comprises all cetacean groups, regardless of species, observed on one side and within 3 km (1.6 nm) of a transect during a CAPs session, outlined in purple and lime green. An aggregation comprises all cetaceans in a high-density patch of cetaceans, including those beyond 3 km from a transect, depicted within the turquoise blob. An aggregation may span more than one transect. Black arrows: transects. Salmon shading: 3-km strip on each side of a transect. Colored stars: individual species. Ghostbusters symbols: cetaceans that are part of the aggregation but not part of any metagroup because they are >3 km from a transect.

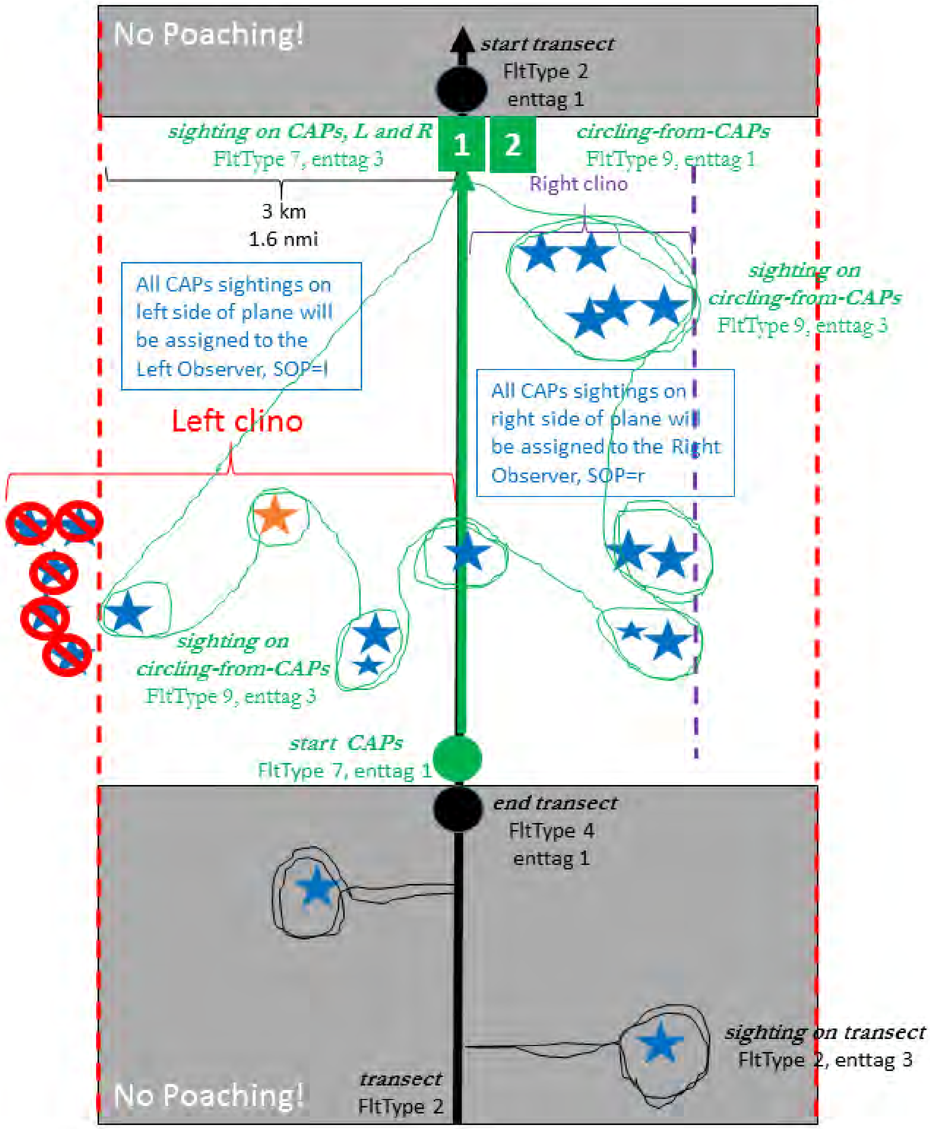


Figure 2. Black: transect (thick line; FltType 2) and circling-from-transect (thin line; FltType 5), surveyed using standard ASAMM protocols, from bottom to top of figure. Green: CAPs protocols. Green box “1”: record, for left and right sides separately: a) initial group size, including all cetaceans seen regardless of species and not limited to cetaceans within 3 km of transect; b) number of calves; c) species observed; and d) minimum declination angle (clino) of the distant boundary of the aggregation (i.e., farthest from the trackline because the horizon is located at 0°). If >1 cetacean species is observed on one side of the plane, select “multi” from the species dropdown list and manually type the list of cetacean species observed in notes. Green box “2”: change the flight type to “divert to circling.” Red dashed line is 3 km (1.6 nmi) from transect. Red Ghostbusters symbols: do not count these cetaceans during circling because they are >3 km from transect. Stars: cetaceans; species denoted by color and calves denoted by small stars. While on CAPs, do not record sightings that are located before start CAPs or after the green “1” that designates the initial divert to circling during CAPs; these off-limit areas are identified in gray.

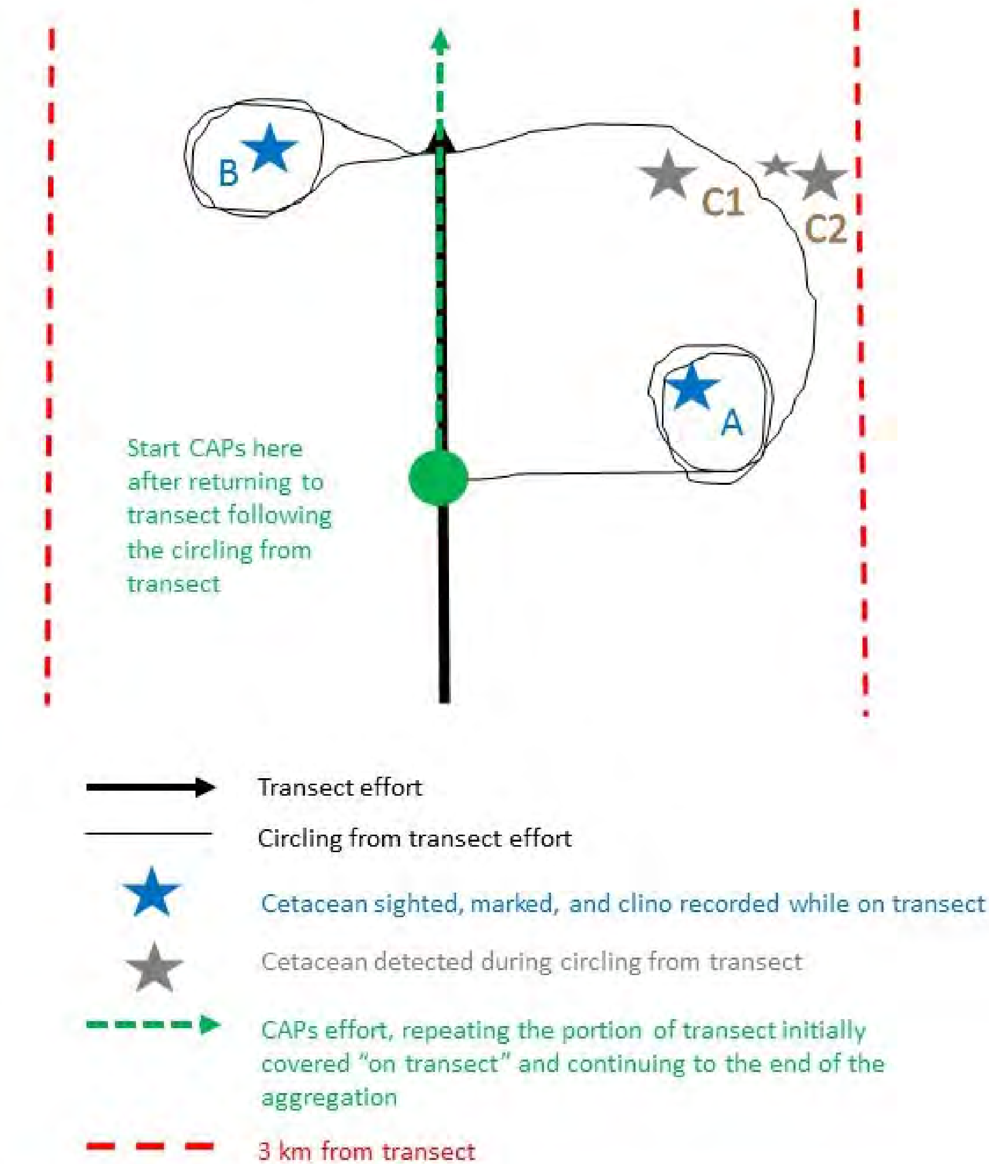


Figure 3. Cetaceans A and B were detected from the transect at approximately the same time. Cetacean A was marked with a clino; the aircraft continued on the transect to mark and record the clino for B before diverting to circle from transect. The aircraft circled B first, then crossed the transect to circle A. While flying towards A, cetacean groups C1 and C2 were detected for the first time. Because C1 and C2 were not detected (or marked) from the transect and are located ≤3 km of the transect and >5 body lengths from either A or B, they are entered as "sighting on circling – transect." Because C1 and C2 are located >5 body lengths from each other, they could be entered as separate sightings or, for expediency, they can be lumped into a single sighting. Lumping groups is permissible only for sightings on circling-from-transect, circling-from-search, or circling-from-CAPs. No effort should be made to circle C1 or C2. It is o.k. to circle A (and B) to collect the full suite of sighting data before returning to the transect. Upon returning to the transect at the point perpendicular to A, do the following in quick succession: 1) "resume" transect; 2) "end transect"; and 3) "start CAPs." Continue surveying the aggregation using standard CAPs protocols (not shown in diagram; refer to Figure 2). Note the event numbers of sightings A and B because they will need to be deleted (saved=0) during post-flight processing.