Seasonal distribution and foraging behavior of Cook Inlet belugas based on acoustic monitoring

Final Report

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Manuel Castellote[1], Robert J. Small[2], Jeffrey Mondragon[2], Justin Jenniges[2], and John Skinner[3]

[1]National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E. Seattle, WA 98115, and North Gulf Oceanic Society, 3430 Main Street. Homer, AK 99603.

[2]Alaska Department of Fish and Game, 1255 West 8th Street, Juneau, AK 99811.

[3]Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK 99518.

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1. SUMMARY

Information on the seasonal distribution and foraging behavior of beluga whales in Cook Inlet, Alaska, was obtained through passive acoustic monitoring during 2008-2013, at the following 13 locations: North Eagle Bay, Eagle River Mouth, South Eagle Bay, Six Mile, Point MacKenzie, Cairn Point, Fire Island, Little Susitna, Beluga River, Trading Bay, Kenai River, Tuxedni Bay, and Homer Spit. At each location, custom designed low-profile acoustic moorings were deployed, each with an Ecological Acoustic Recorder (EAR), which monitored for the low frequency (0-12.5 kHz) beluga social signals, and a Cetacean and Porpoise Detector (C-POD) that monitored higher frequency (20-160 kHz) beluga echolocation signals. Monitoring both social and echolocation signals maximized beluga detections, which we summarized within two seasons based on the ice phenology in Cook Inlet: 'summer', the ice-free period of May to October; and 'winter', the freezing to melting period of November to April.

Acoustic monitoring effort varied substantially by location and across months during the study period, primarily because one of the two instruments in each mooring often stopped recording before the other for several reasons. We accounted for this variation by defining an acoustic effort hour (AEH) as any hour for which either (or both) instrument recorded properly for at least 1 minute; recordings less than an hour typically occurred only at the start and end of a deployment, recognizing that the EAR recorded 6 minutes each hour because of the 10% duty cycle. Beluga detections were also summarized on an hour basis, by categorizing any hour in which a beluga echolocation, call, or whistle was detected (by either instrument) as a detection positive hour (DPH). On a monthly and seasonal basis, DPH estimates the overall beluga presence and absence. To account for variation in acoustic effort, we calculated normalized beluga presence (% DPH) as the percentage of DPH within the AEH (% DPH = (DPH∗100)/AEH) at each mooring location, on a monthly and seasonal basis.

Based on published documentation of how odontocetes echolocate on their prey, we defined beluga foraging behavior as echolocation click trains with a very short interval (2 ms) between consecutive clicks. We then classified each minute when at least one foraging click train was detected as a foraging positive minute (FPM). We then normalized the occurrence of foraging behavior by dividing FPM by Detection Positive Hours (DPH) to calculate a foraging index (Foraging index = FPM*100/DPH) at each mooring location, on a monthly and seasonal basis. Because the duration of foraging behavior is extremely short, we used a subjective multiplying factor of 100 to graphically compare the index across locations, months, and seasons.

A total of 282,441 AEHs (~11,769 days) were obtained across all 13 mooring locations during the study period. At six of seven locations outside of Knik Arm, acoustic recordings were collected year-round, yet effort was lower for the months prior to mooring recovering and redeployment with new batteries (i.e., November, April, and May). At the Little Susitna (the seventh location), data collection was not attempted in winter because we did not expect belugas to be in the river due to ice and shallow waters. The amount of recordings we obtained overwinter in Knik Arm was relatively small, because the large tidal influence caused the extensive ice coverage to shift continuously and resulted in the loss of several

moorings. Thus, we pooled data from the six mooring locations in Knik Arm into the Eagle Bay (North Eagle Bay, Eagle River Mouth, South Eagle Bay) and Lower Knik Arm (Six Mile, Point MacKenzie, Cairn Point) regions; the only break in recordings was in Eagle Bay, from January to April.

Belugas were detected at 12 of 13 locations, with no detections at Homer Spit, the location furthest south in Cook Inlet. Annually, the maximum weekly mean of daily beluga detection positive hours (DPH) was highest, ranging from 5-20, at five locations: the three locations in Eagle Bay, Little Susitna, and Beluga River. Maximum weekly mean DPH occurred near river mouths in summer; i.e., Little Susitna, Eagle River and Beluga River. The four locations south of Beluga River (Trading Bay, Kenai River, Tuxedni Bay, and Homer Spit) had the lowest weekly mean DPH, and the large majority of beluga detections were in winter.

At locations where recordings were obtained for two or more years, and maximum weekly mean DPH was relatively high (>5), there was a relatively consistent annual pattern in beluga detections, within and between seasons. In particular, beluga detections peaked during August-September at North Eagle Bay (Fig. 3A) and Eagle River (Fig. 3B), and during June-July, November-December, and February-March at Beluga River (Fig. 3E).

Normalized beluga detections (i.e., % DPH) were substantially different between seasons; overall, %DPH in summer was more than twice that of winter; 26.0% vs. 11.6%. The highest summer %DPH was at Eagle Bay (12.4%), followed by Little Susitna River (7.6%), and Beluga River (4.8%). The six other locations had %DPH values below 1%; i.e., less than one detection per 100 hours of effort. During winter the highest beluga presence was at Beluga River, with a %DPH of 6.0%; there was ~10-fold decrease in %DPH at Eagle Bay (1.3%), and Little Susitna was not monitored in winter. Trading Bay had the second highest winter DPH at 2.1%; similar to summer, the winter %DPH at all other locations was less than 1%.

In general, the observed seasonal distribution is in accordance with descriptions based on aerial surveys and satellite telemetry: beluga detections are higher in the upper inlet during summer, peaking at Little Susitna, Beluga River, and Eagle Bay, followed by fewer detections at those locations during winter. Higher detections in winter at Trading Bay, Kenai River, and Tuxedni Bay suggest a broader beluga distribution in the lower inlet during winter. Overall %DPH in summer was much higher than in winter, suggesting belugas did not concentrate at any of the mooring locations in winter.

Echolocation data allowed us to successfully document beluga foraging behavior in Cook Inlet. Only 0.3 % of all DPH contained foraging click trains, which were detected at 8 of the 13 locations we monitored: North Eagle Bay, Eagle River, Point MacKenzie, Cairn Point, Little Susitna River, Beluga River, Trading Bay, and Tuxedni Bay. Beluga foraging behavior was detected in all months except October, yet was substantially lower in winter compared to summer. Although monthly FPMs were highest in June, July, and August, because summer monthly DPH was substantially lower in May compared to June-September, the May foraging index was ~three times greater than all other summer months, and represented the peak month for foraging inlet-wide.

Seasonally, foraging behavior was more prevalent during summer (FPM = 707; 92.8%), particularly at upper inlet rivers, than during winter (FPM = 55; 7.2%). Foraging index was highest at Little Susitna, with a peak in July-August and a secondary peak in May, followed by Beluga River and then Eagle Bay; monthly variation in the foraging index indicates belugas shift their foraging behavior among these three locations from April through September. Overall foraging index values for winter were much lower than summer (4.7 vs. 19.8), confirming that for the 13 locations we monitored there is no evidence of concentrated foraging in winter at levels observed during spring and summer in upper inlet rivers. Our monitoring effort was restricted to nearshore areas, and thus our results do not allow an assessment of offshore foraging during winter, when belugas may forage on more dispersed prey (Moore et al. 2000).

Annually, based on the 13 locations monitored, foraging behavior appears to be extremely limited in winter, then increases in April followed by a major increase to a peak in May, stays elevated in June-August, decreases in September and reaches a minimum in October. On a broad spatial scale, across the two seasons, foraging behavior was most prevalent in Knik Arm compared to the upper and lower inlet, yet the highest foraging index was in the upper inlet during summer; detection of foraging in the lower inlet was extremely rare. Belugas were not present in the lower Inlet during summer, and although they were present in winter, at Kenai River and Tuxedni Bay, their presence was low when compared to the upper inlet and Knik Arm. These results suggest that winter foraging behavior is widespread, yet rarely detected or occurs infrequently; the probability of detecting foraging behavior is very low, because echolocation signals are highly directional, and thus foraging buzzes will only be detected by C-PODs when belugas are echolocating towards prey in the direction of the mooring.

2. BACKGROUND

In 2008 with funding from the NOAA Fisheries, the Cook Inlet Beluga Acoustics (CIBA) project began with the primary goal of using passive acoustic monitoring to detect the presence of beluga whales throughout Cook Inlet. The team of scientists involved with CIBA successfully developed moorings with two acoustic instruments that effectively monitored beluga presence year-round in Cook Inlet. In 2009, funding was received from the Department of Defense to continue the CIBA project, with a focus on the waters used by belugas on and adjacent to Joint Base Elmendorf Richardson (JBER), including Eagle Bay and Eagle River, for feeding, socializing and transiting.

3. OBJECTIVES

During 2011-2014, seven research objectives were pursued, with 12 associated deliverables. This report represents three deliverables, based on three objectives, as follows:

<u>Objective 1:</u> Record/log both social vocalizations and echolocation activity of beluga whales, and other odontocete species, to detect their presence and seasonal shifts in distribution.

> *<u>Deliverable #1:</u> Description of the seasonal distribution of CIB throughout the year.*

<u>Objective 1A:</u> Determine seasonal presence of belugas in Knik Arm with an emphasis on spring and winter usage of the waters adjacent to JBER.

> *<u>Deliverable #2A:</u> Seasonal presence of CIB at selected sites in Knik Arm. A report that describes the seasonal use of CIB at selected sites in Knik Arm, based on acoustic detections.*

<u>Objective 3:</u> Catalog the acoustic behavior of CIB as they forage for prey through the deployment of a D-tag

> *<u>Deliverable #5:</u> Description of the spatial and temporal occurrence of foraging at all study sites.*

4. MATERIAL AND METHODS

4.1 Locations Monitored

Acoustic moorings were deployed at 13 locations across lower Cook Inlet (Homer, Tuxedni Bay, and Kenai River), upper Cook Inlet (Trading Bay, Beluga River, Little Susitna River, and Fire Island) and Knik Arm (Point Mackenzie, Cairn Point, Six Mile, South Eagle Bay, Eagle River Mouth, and North Eagle Bay) during 2008-2013 (Figure 1). At locations where moorings were recovered and re-deployed on several occasions during the study, all moorings were within a ~1.0 km diameter; the different fine-scale locations were a result of strong currents during deployment and the location of moorings shifting between deployment and recovery.

We defined two seasons, based on the ice phenology in Cook Inlet: 'summer' being the ice-free period of May to October and 'winter' being the freezing to melting period of November to April. Eight locations were monitored continuously during both 'summer' and 'winter', four locations were monitored only during summer because of difficulties maintaining the moorings in the relatively shallow (0 to ~7 meters at low tide) areas with shifting ice in Knik Arm, and one location was monitored only during winter (Table 1).

Moorings deployed overwinter were not recovered at four locations, all within Knik Arm: North Eagle Bay, Six Mile, Point MacKenzie, and Cairn Point. Following failed recoveries, we deployed moorings in the same general area (within 100s of meters), yet at sites where we presumed bathymetric features would decrease the chances of losing the mooring by the following spring.

Table 1. The locations where acoustic moorings were deployed to monitor beluga whales, July 2008 to May 2013, in Cook Inlet, Alaska. Moorings not recovered during the initial recovery attempt were considered 'lost'; yet, some lost moorings were found later (months or years), either at the deployment location or elsewhere; see Mooring Status.

Location	Season Monitored	Mooring Status
North Eagle Bay	Summer & Winter	Lost 1 in winter & 2 in summer, all 3 found later
Eagle River Mouth	Summer	Lost 1 in winter; Lost 1 in summer, found later
South Eagle Bay	Summer	No winter attempted; Lost 1 in summer, found later
Six Mile	Winter	No summer attempts; Lost 3 in winter, found 1 later
Point MacKenzie	Summer & Winter	Lost 2 in winter; Lost 1 in summer, found later
Cairn Point	Summer & Winter	Lost 1 in winter, found later; Lost 2 in summer
Fire Island	Summer & Winter	Lost 1 in winter and 1 in summer, both found later
Little Susitna	Summer	No winter attempted; Lost 1 in summer, found later
Beluga River	Summer & Winter	All recovered
Trading Bay	Summer & Winter	All recovered
	Summer & Winter	All recovered
Tuxedni Bay	Summer & Winter	All recovered
Homer Spit	Summer & Winter	All recovered

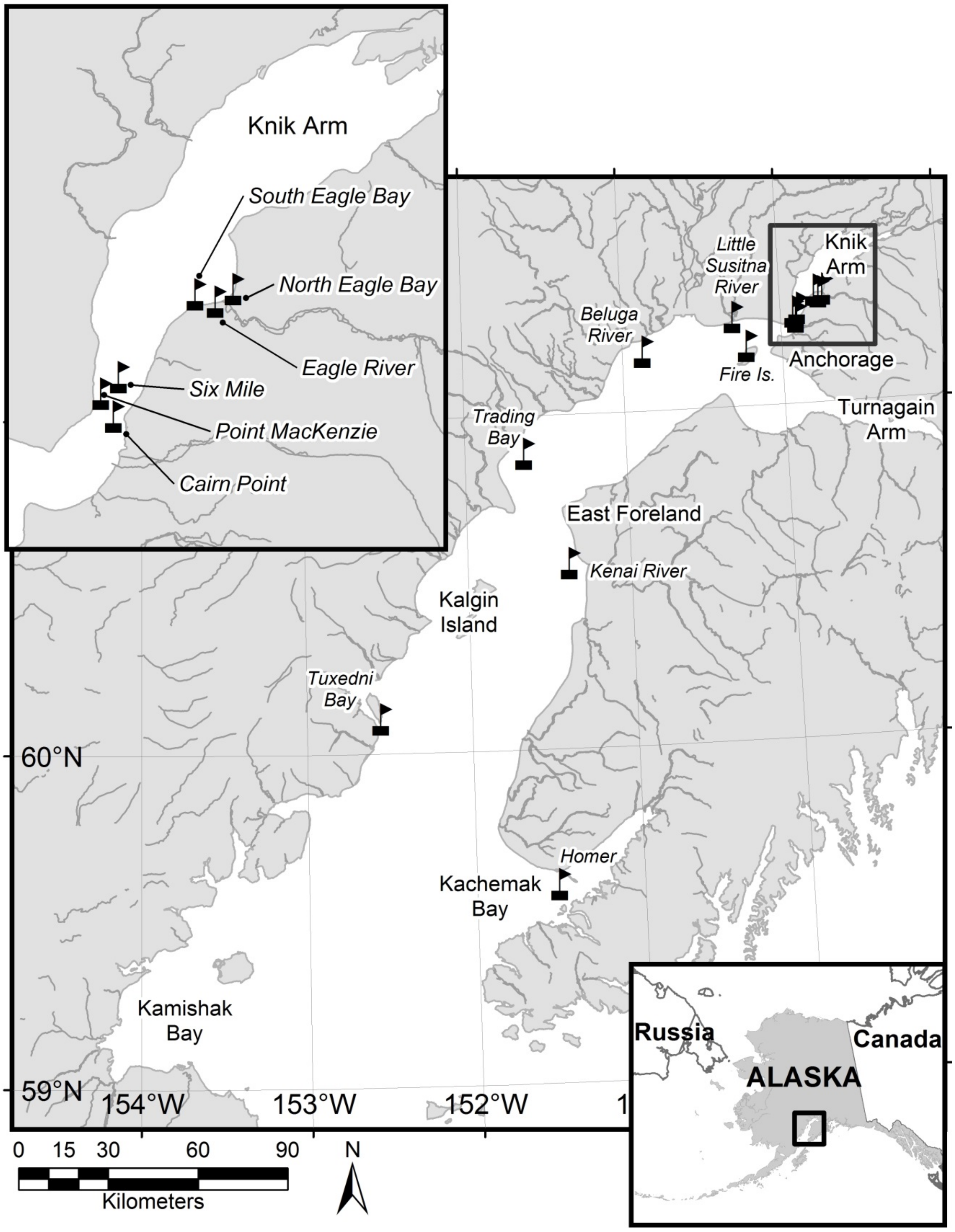

Figure 1. Locations where acoustic moorings were deployed to monitor for beluga whales from July 2008 to May 2013, in Cook Inlet, Alaska. The Knik Arm insert shows the six overwinter deployment sites for that area.

4.2 Acoustic Recordings

Custom designed low-profile moorings were used to resist the harsh environmental conditions of Cook Inlet (Lammers et al. 2013). Moorings contained two instruments, Ecological Acoustic Recorders (EARs) that monitored the 0-12.5 kHz frequency range to detect beluga social signals, and Cetacean and Porpoise Detectors (C-PODs) that monitored the 20-160 kHz frequency range to detect beluga echolocation. Monitoring both social signals and echolocation maximized beluga detections (Castellote et al., *In Press*). EARs were programmed on a 10% duty cycle to prolong battery life, which resulted in recordings of 30-seconds in duration obtained every five minutes (i.e., 300 seconds); C-PODs monitored continuously.

4.3 Quantifying Beluga Presence and Absence

Using SQL database management software, any hour in which a beluga echolocation, call, or whistle was detected, by either an EAR or C-POD, was categorized as a detection positive hour (DPH) to estimate overall beluga presence and absence. As such, a DPH may include one single type of beluga signal, or, up to all three types (echolocation, calls, and whistles) and at different rates (e.g., one single call or many calls). This DPH approach reduces behavioral effects when quantifying beluga presence and absence.

For an initial assessment of beluga presence, independent of acoustic effort, we first summed DPH for each day, and then calculated DPH weekly means, annually, for each of the 13 locations over the entire monitoring period. The graphical display of these DPH weekly means provided an overview of how beluga presence varied throughout a year, and whether such variation was consistent across years.

Acoustic monitoring effort varied substantially by location and throughout the overall monitoring period across months, primarily because one of the two instruments in each mooring (i.e., EAR and C-POD) often stopped recording before the other for several reasons (e.g., different battery life or memory limitations, one instrument leaked or electronics failed, etc.). We accounted for these differences by defining an acoustic effort hour (AEH) as any hour for which either (or both) the EAR or C-POD recorded properly for at least 1 minute; recordings less than an hour typically occurred only at the start and end of a deployment, recognizing that the EAR recorded 6 minutes each hour because of the 10% duty cycle. Effort hours were not replicated (i.e., when both instruments were sampling in one hour, only one hour was counted) and we assumed that acoustic effort was equal when only the EAR, only the C-POD or both instruments were sampling.

Beluga presence, accounting for variation in acoustic effort, was then normalized by location as the percentage of DPH within the AEH:

$$\% \text{ DPH} = (\text{DPH} * 100)/\text{AEH}$$

We calculated normalized beluga presence (% DPH) for each mooring location, except for Knik Arm, where we pooled the six moorings into the ‘Eagle Bay’ and ‘Lower Knik Arm’ sampling areas; moorings were deployed at the six different locations to try and increase the chances of them being recovered after extensive ice shifting and gouging during the overwinter period resulted in the loss of several moorings (see Table 1). Specifically, the North Eagle Bay, South Eagle Bay and Eagle River Mouth locations were pooled into 'Eagle Bay', and Six Mile, Point MacKenzie, and Cairn Point were pooled into 'Lower Knik Arm.' We calculated normalized beluga presence (% DPH) in these two areas by dividing the sum of DPH from the moorings in each area by the number of non-overlapping AEH to avoid replicated effort hours between merged data-sets.

Mean % DPH and standard deviation was calculated for summer and winter, based on monthly % DPH, for the two areas we defined for Knik Arm, and the seven other individual mooring locations; except for Little Su in winter, because the only deployment occurred during summer.

4.4 Quantifying Occurrence of Beluga Foraging Behavior

Echolocation data provides an opportunity to assess the presence of foraging behavior. Odontocetes emit a sequence of impulsive signals, termed clicks, and receive the echo from the target prey to interpret its distance and location. Each sequence of clicks is termed a click train (Au, 1993). When odontocetes echolocate on prey, their acoustic beam is locked on the prey target during the chase and capture phases (Verfus et al. 2009), which represent foraging behavior. During the capture phase, the inter-click interval (ICI) between consecutive clicks in a click train is reduced and often ends with a burst of clicks known as a terminal buzz. Previous studies on belugas have proposed a minimum ICI of 2 ms for click trains related to prey pursuit and capture (Roy et al. 2010, Castellote et al. 2013). Thus, in our study, we identified all click trains with a minimum ICI of 2 ms or lower; click trains were obtained only from C-PODs, not EARS. Subsequently, we deleted click trains with minimum ICI below 1 ms, because multipath propagation of sound waves may result in double clicks due to different delays arriving at the C-POD along different paths, e.g., by reflections from the water surface (Koschinski et al. 2008; Roy et al. 2010).

Similar to our treatment of DPH to minimize behavioral effects, rather than using the absolute number of foraging click trains to estimate foraging occurrence, we classified each minute when at least one foraging click train was detected as a foraging positive minute (FPM). We then normalized the occurrence of foraging behavior by dividing FPM by DPH:

Foraging index = FPM*100/DPH

This normalization allows foraging behavior to be compared among the different monitoring locations, at which DPH varied substantially. Because the duration of foraging behavior is extremely short, we used a subjective multiplying factor of 100 to graphically compare the index across sites or periods; otherwise, the index value would be too small when presented next to normalized beluga presence (% DPH) results.

5. RESULTS

5.1 Acoustic Effort

A total of 11,768 days (282,441 AEHs) were monitored acoustically when accounting for all the data collected at each of the 13 mooring locations. When data from the 6 locations in Knik Arm were combined into the regions Eagle Bay and Lower Knik Arm, only non-overlapped AEH were considered among the 6 locations, and the total number of sampled days decreased to 9,858 (236,590 AEHs), see Table 2; the 12 months of the calendar year are listed from May through April, to more readily interpret the data for summer (May through October) and winter (November through April).

Effort was lower for the months when the mooring were recovered and redeployed with new batteries (Fig. 2). Specifically, after an overwinter deployment instruments were typically serviced in April or May, and recording usually stopped weeks earlier due to low power or full memory. Because of the presence of ice, spring recoveries were not feasible sooner, and fall deployments later. Instruments deployed in spring were programmed to be recovered by October or early November; for some deployments recording stopped a few weeks prior to recovery.

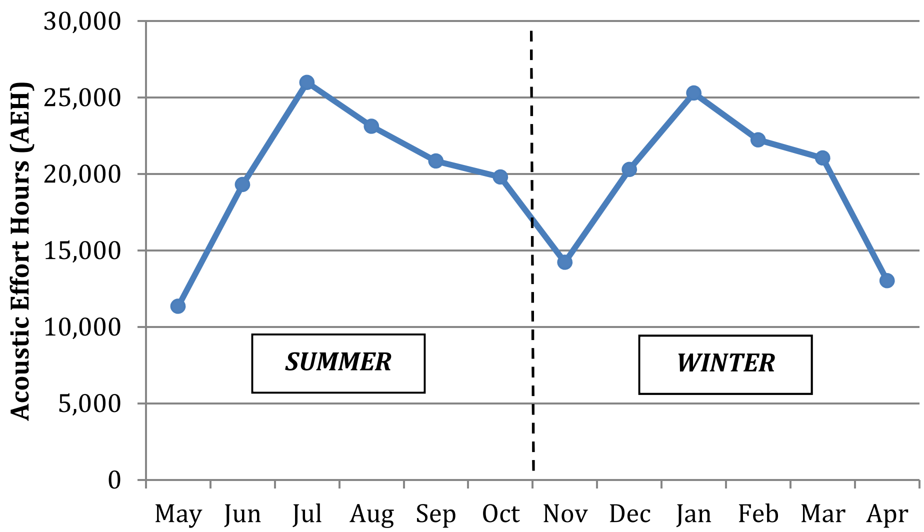

Figure 2: Total number of days sampled per month in the 13 locations where acoustic moorings were deployed as part of the CIBA research program to detect beluga whales in Cook Inlet, Alaska, July 2008 to May 2013.

Table 2: Total number of acoustic effort hours (AEH), by month and season, collected with acoustic moorings deployed in Cook Inlet, Alaska, during the CIBA research program, for the period July 2008 to May 2013. Lower Knik Arm and Eagle Bay include 3 different mooring deployment sites each, and only non-overlapped AEHs are included in this table.

	Beluga River	Fire Island	Homer	Kenai River	Little Susitna	Trading Bay	Tuxedni Bay	Lower Knik Arm	Eagle Bay	Total AEH
May	484	98	2,781	2,507	410	1,674	2,233	1,007	158	11,352
Jun	3,514	997	2,880	2,160	1,440	1,442	2,160	2,229	2,494	19,316
Jul	4,322	1,285	3,744	3,718	1,488	2,237	3,179	3,108	2,914	25,995
Aug	3,711	1,099	3,720	3,276	1,488	1,488	2,976	2,450	2,919	23,127
Sep	3,144	2,004	3,600	2,497	1,296	1,440	2,880	1,454	2,535	20,850
Oct	4,464	2,642	3,383	1,828	0	1,453	2,307	2,576	1,159	19,812
SUMMER	***19,639***	***8,125***	***20,108***	***15,986***	***6,122***	***9,734***	***15,735***	***12,824***	***12,179***	***120,452***
Nov	4,320	2,448	998	772	0	163	1,711	2,880	941	14,233
Dec	4,464	2,232	2,798	2,679	0	1,948	3,166	2,976	37	20,300
Jan	4,464	2,232	4,464	3,720	0	2,976	4,464	2,976	0	25,296
Feb	3,681	2,016	4,080	2,931	0	2,736	4,080	2,712	0	22,236
Mar	2,859	1,933	3,915	2,976	0	2,554	4,016	2,795	0	21,048
Apr	278	1,440	2,952	2,469	0	1,232	3,151	1,503	0	13,025
WINTER	***20,066***	***12,301***	***19,207***	***15,547***	***0***	***11,609***	***20,588***	***15,842***	***978***	***116,138***
Total AEH	***39,705***	***20,426***	***39,315***	***31,533***	***6,122***	***21,343***	***36,323***	***28,666***	***13,157***	***236,590***

Acoustic recordings were collected year-round, other than for short periods (~weeks) prior to recovery (when batteries died or memory was full), at six of seven locations outside of Knik Arm. At Little Susitna, the seventh location, data collection in winter was not attempted because belugas were not expected to be in the river due to ice in shallow waters. Obtaining recordings overwinter in Knik Arm was very difficult, because the large tidal influence caused the extensive ice coverage to shift continuously, resulting in the loss of several moorings. However, when data from the six mooring locations in Knik Arm were pooled into the Eagle Bay and Lower Knik Arm regions, the only break in recordings was in Eagle Bay, from January to April (Table 2).

5.2 Seasonal Beluga Presence

Belugas were detected at 12 of 13 locations, with no detections at Homer, our southernmost location in Cook Inlet. Annually, the maximum weekly mean of daily beluga detection positive hours (DPH) was highest, ranging from 5-20, at Beluga River and Little Susitna, and the three locations in Eagle Bay; see Figure 3 (A-E), noting the y-axis scale is 0 to 20. Maximum weekly mean DPH was less than five at the eight other locations; see Figure 4 (A-H), noting the y-axis scale is 0 to 5. For both Figures 3 and 4, %DPH is zero on the y-axis when there was acoustic effort but no belugas were detected; whereas the absence of %DPH indicates when there was no acoustic effort (and thus no detections were possible); additionally, lines that cross from December to January begin in the year noted by the color of the line.

Maximum weekly mean DPH occurred near river mouths in summer; i.e., Little Susitna (Fig. 3D), Eagle River (Fig. 3B), and Beluga River (Fig. 3E). The four locations south of Beluga River (Trading Bay, Kenai River, Tuxedni Bay, and Homer Spit) had the lowest weekly mean DPH, and all beluga detections were in winter, other than just a few detections in summer (September and October) at Trading Bay, the furthest north of the four locations.

At locations where recordings were obtained for two or more years, there was a relatively consistent annual pattern, within and between seasons, at most locations; patterns were more apparent at locations with maximum weekly mean DPH greater than five (Fig. 3). In particular, beluga detections peaked during August-September at North Eagle Bay (Fig. 3A) and Eagle River (Fig. 3B), and during June-July, November-December, and February-March at Beluga River (Fig. 3E). At locations with maximum weekly mean DPH less than five (Fig. 4), the most apparent patterns were a peak at Tuxedni Bay (Fig. 4G) in March 2010-2011 (but not 2009), and a slight pattern of August-September and November-December at Cairn Point (Fig. 4C). Otherwise, patterns in beluga detection were not evident at Point MacKenzie (Fig. 4B), Fire Island (Fig. 4D), Trading Bay (Fig. 4E), and Kenai River (Fig. 4F), though detections were much more common in winter at the latter two locations.

When acoustic sampling effort (AEH) is used to normalize beluga detections (i.e., % DPH = (DPH*100)/AEH), differences among locations in beluga presence between summer and winter are highlighted (Fig. 5). Overall, %DPH in summer was more than twice that of winter; 26.0% vs. 11.6%, respectively. The highest summer %DPH was at Eagle Bay (12.4%), followed by Little Susitna River (7.6%), and Beluga River (4.8%). The six other locations had %DPH values below 1%; i.e., less than one detection per 100 hours of effort.

During winter the highest beluga presence was at Beluga River, with a %DPH of 6.0%, which was slightly greater than the 4.8% during summer. There was ~10-fold decrease in %DPH at Eagle Bay, down from 12.4% to 1.3%. Both Eagle Bay and Beluga River were among the three locations with highest %DPH in both summer and winter; Little Susitna was not monitored in winter, and Trading Bay had the second highest winter DPH at 2.1%. Similar to summer, the winter %DPH at all other locations was less than 1%. During summer, belugas were not detected at either Kenai River or Tuxedni Bay, and DPH% was only 0.1% at Trading Bay, yet during winter %DPH increased at each of these three locations; 0.6%, 0.4%, and 2.1% respectively. Belugas were never detected at the Homer Spit, during either summer or winter, despite having 39,315 AEH (Table 2) during year-round monitoring over 3 years, except for a few weeks during late November-early December (Fig. 4H).

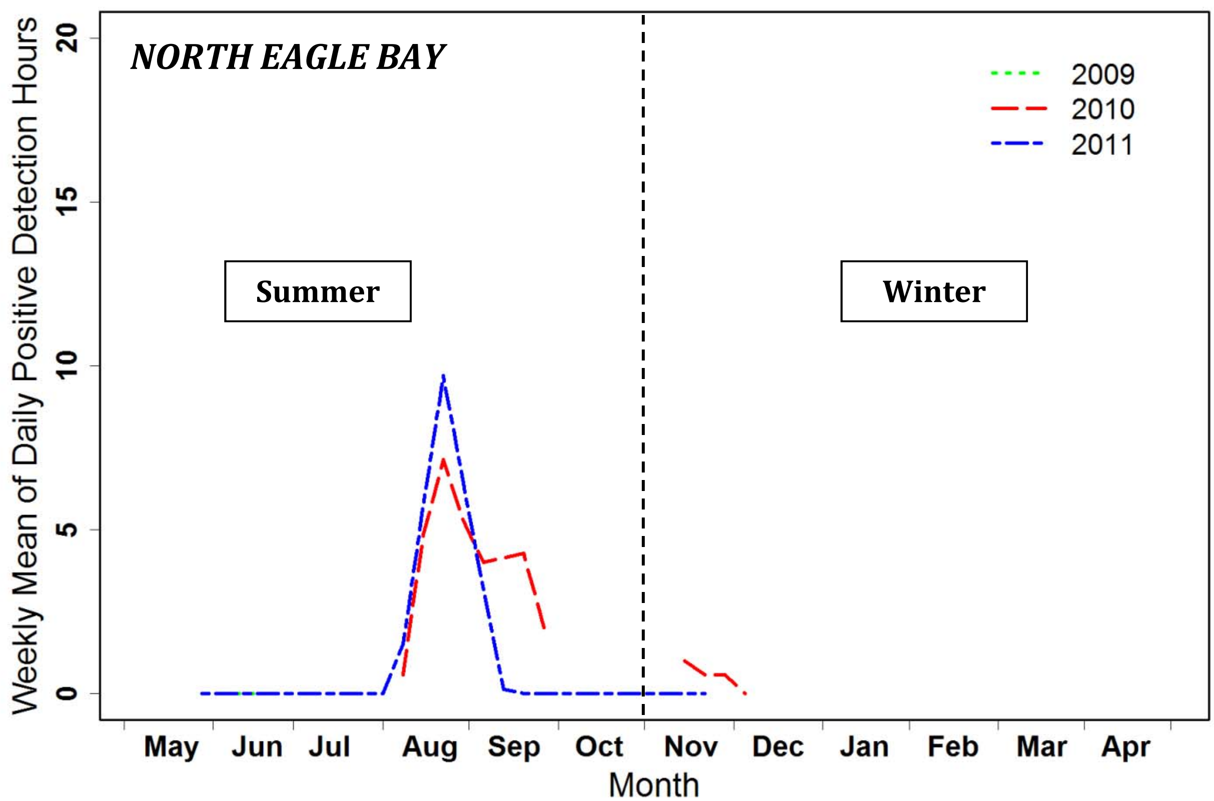

Figure 3A. Weekly mean of daily beluga detection positive hours (DPH) by month at North Eagle Bay, Cook Inlet, Alaska, 2009-2011.

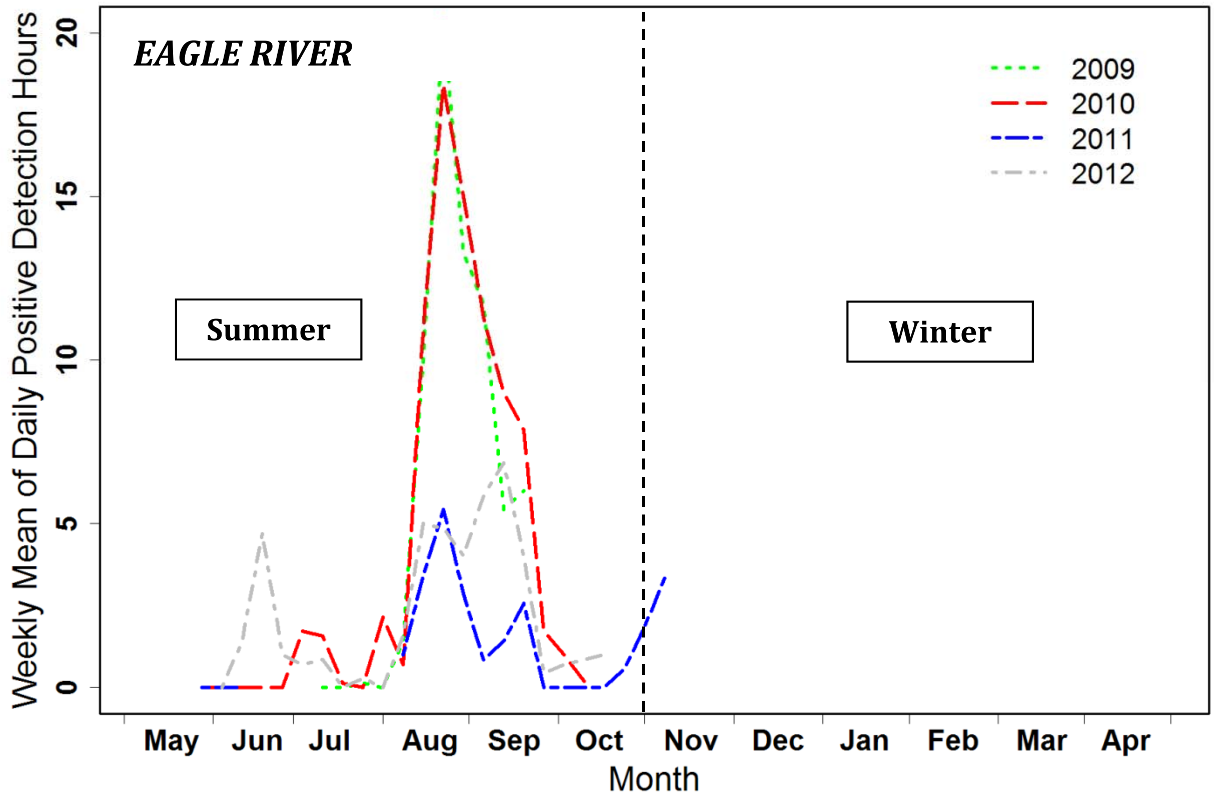

Figure 3B. Weekly mean of daily beluga detection positive hours (DPH) by month at Eagle River, Cook Inlet, Alaska, 2009-2012.

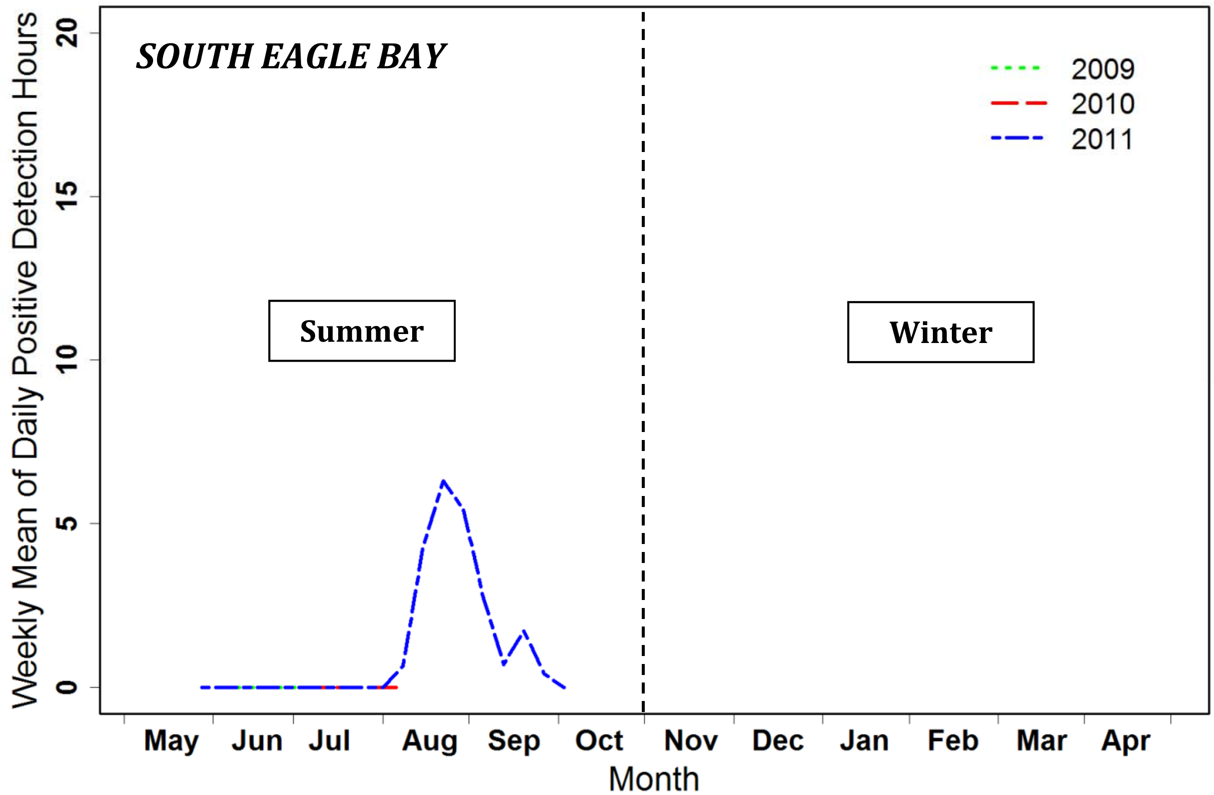

Figure 3C. Weekly mean of daily beluga detection positive hours (DPH) by month at South Eagle Bay, Cook Inlet, Alaska, 2009-2011.

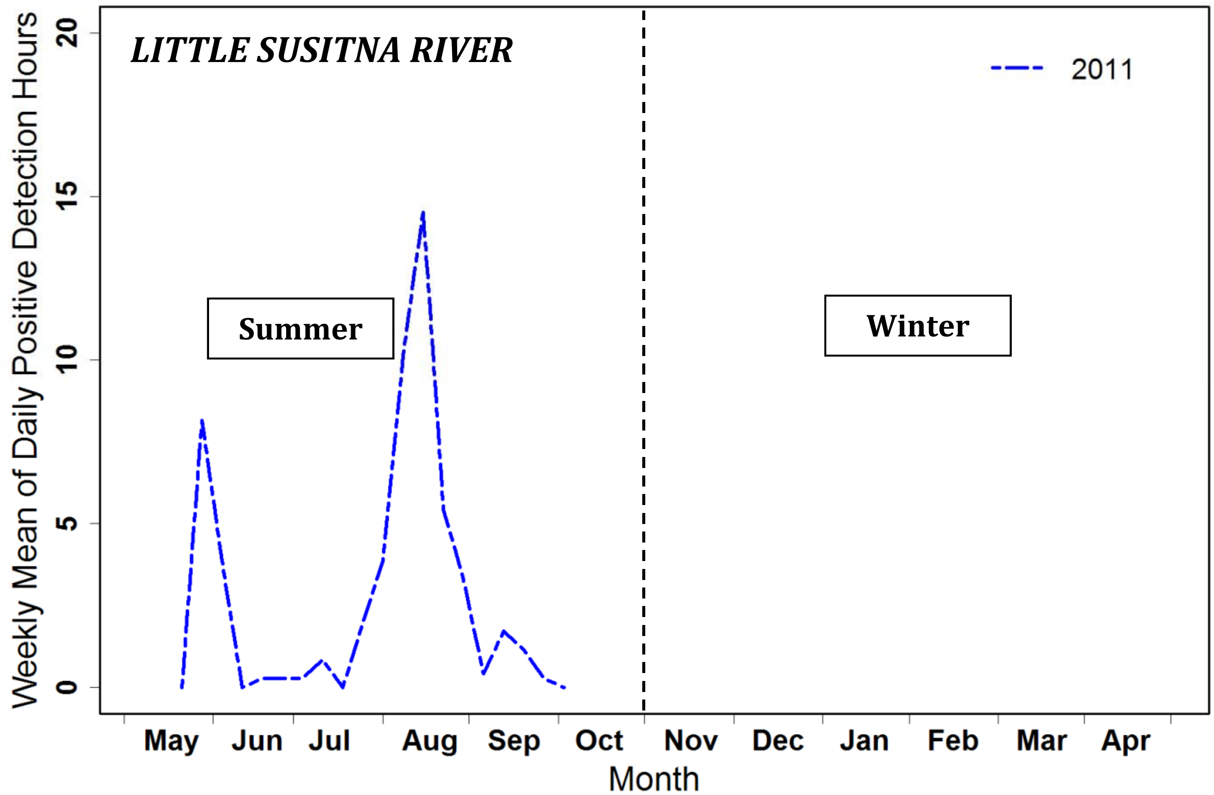

Figure 3D. Weekly mean of daily beluga detection positive hours (DPH) by month at Little Susitna River, Cook Inlet, Alaska, 2001.

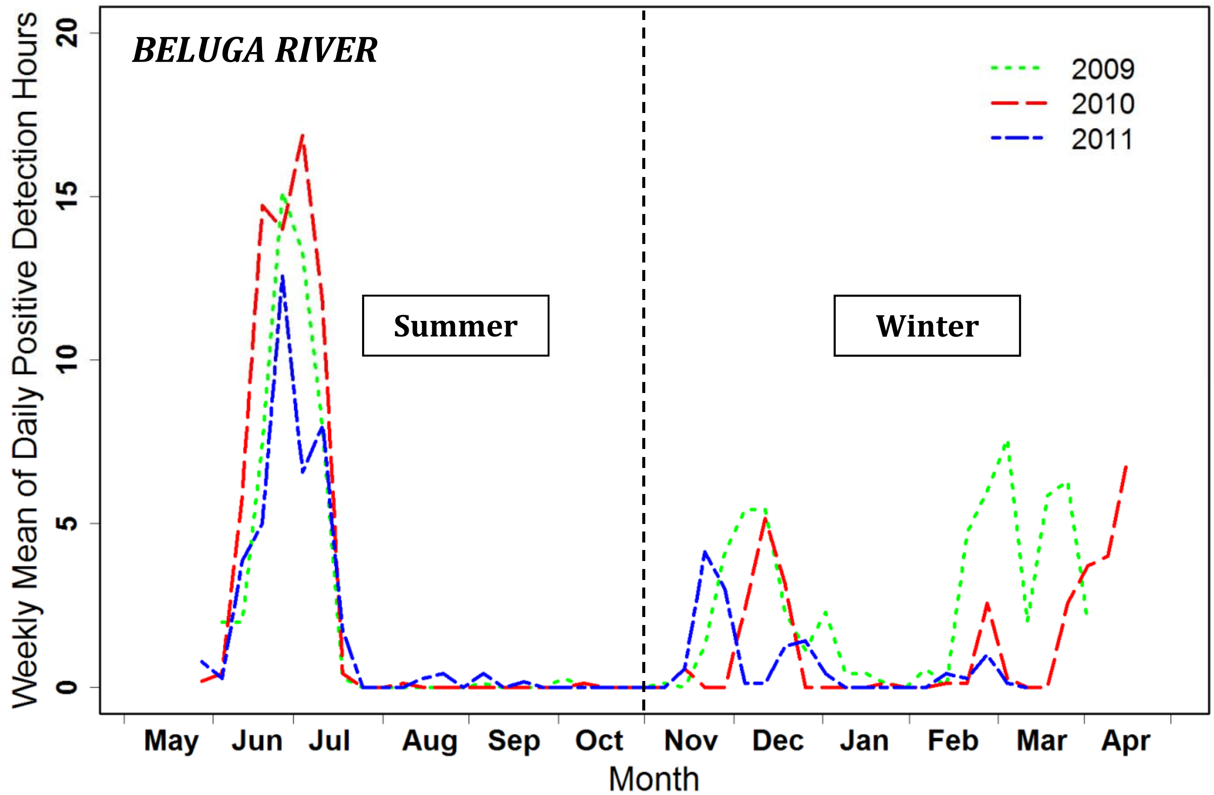

Figure 3E. Weekly mean of daily beluga detection positive hours (DPH) by month at Beluga River, Cook Inlet, Alaska, 2009-2011.

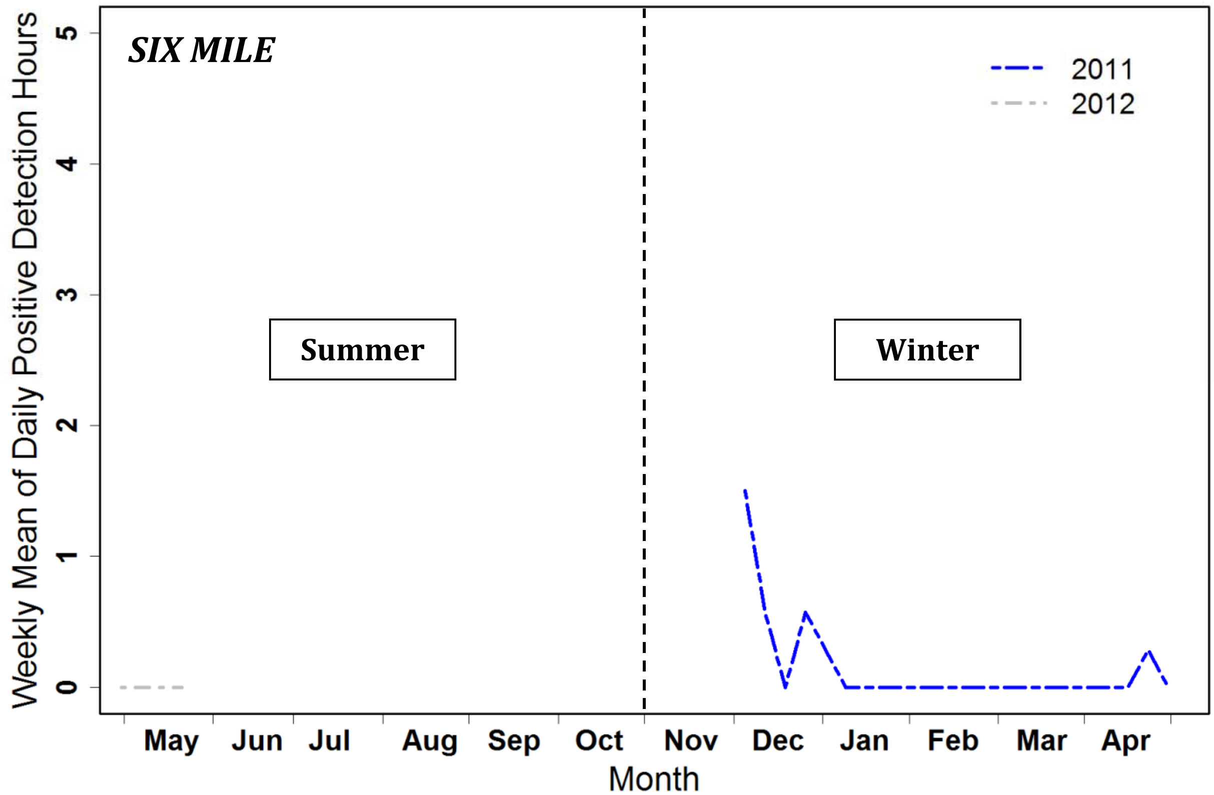

Figure 4A. Weekly mean of daily beluga detection positive hours (DPH) by month at Six Mile, Cook Inlet, Alaska, 2011-2012.

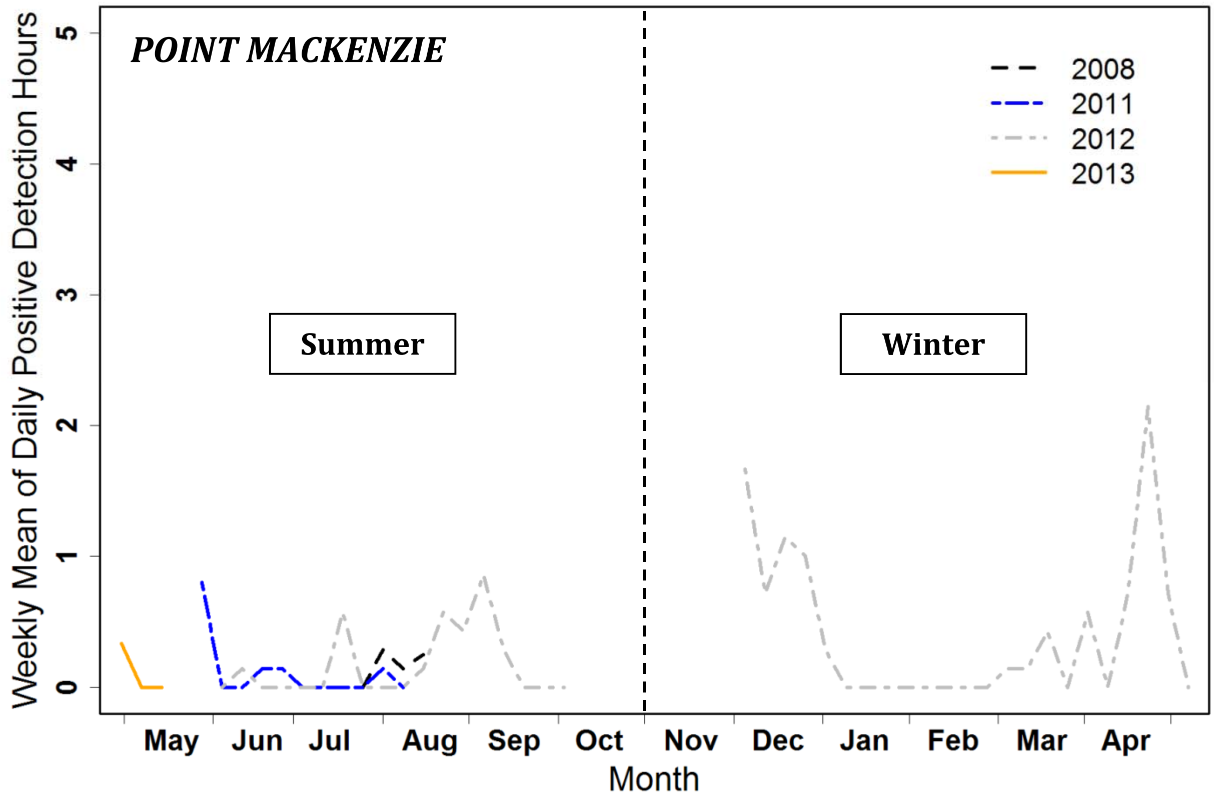

Figure 4B: Weekly mean of daily beluga detection positive hours (DPH) by month at Point MacKenzie, Cook Inlet, Alaska, 2008-2013.

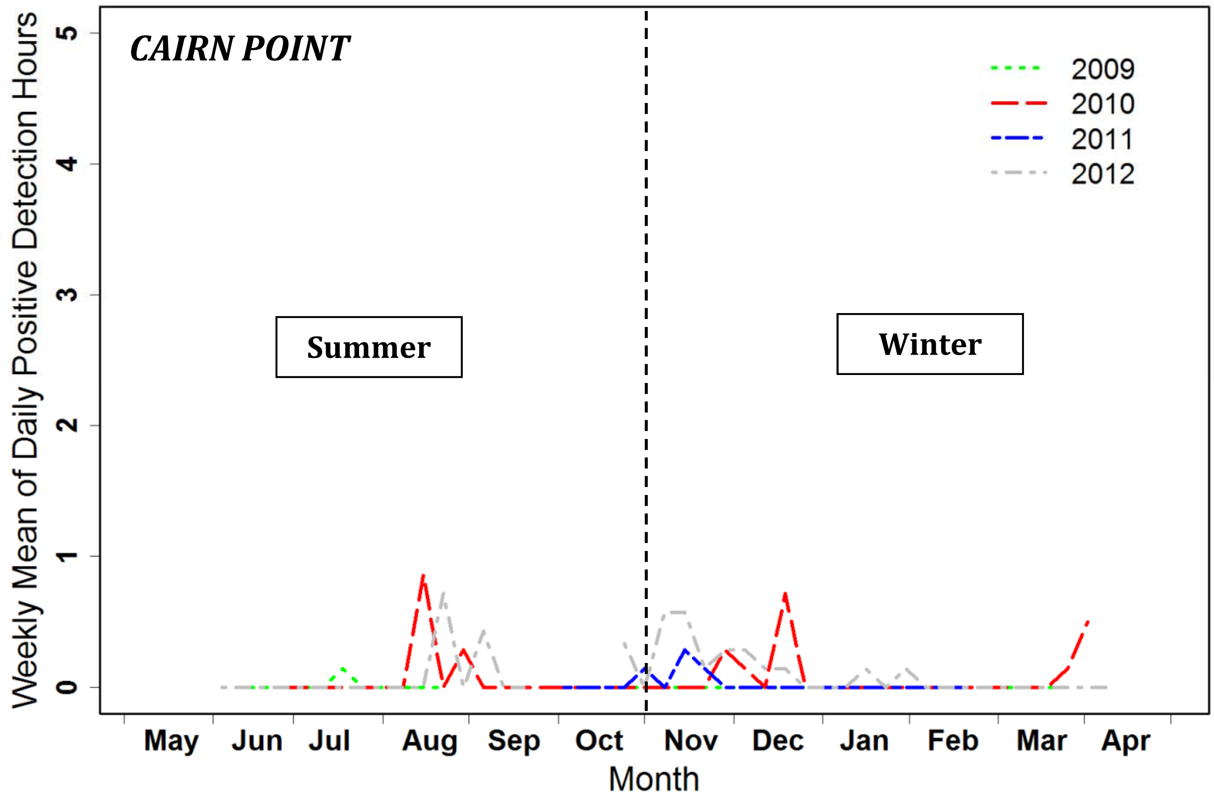

Figure 4C. Weekly mean of daily beluga detection positive hours (DPH) by month at Cairn Point, Cook Inlet, Alaska, 2009-2012.

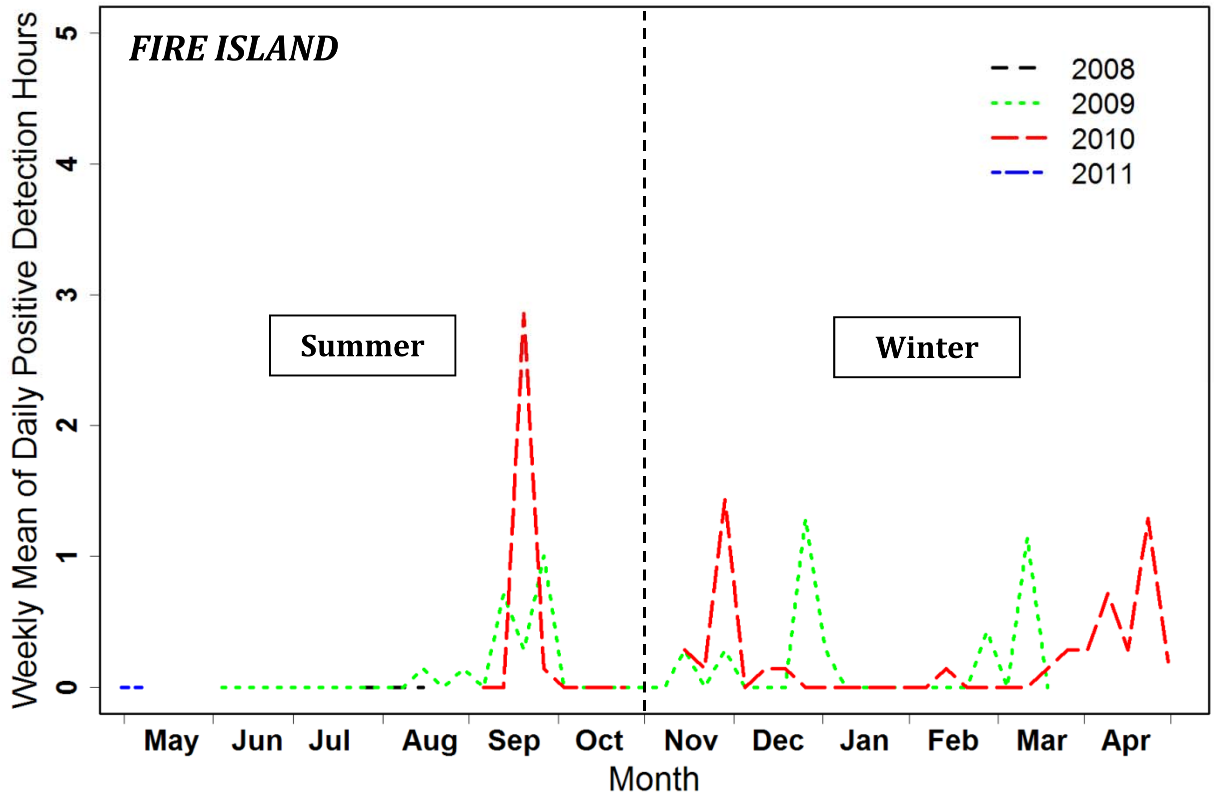

Figure 4D. Weekly mean of daily beluga detection positive hours (DPH) by month at Fire Island, Cook Inlet, Alaska, 2008-2011.

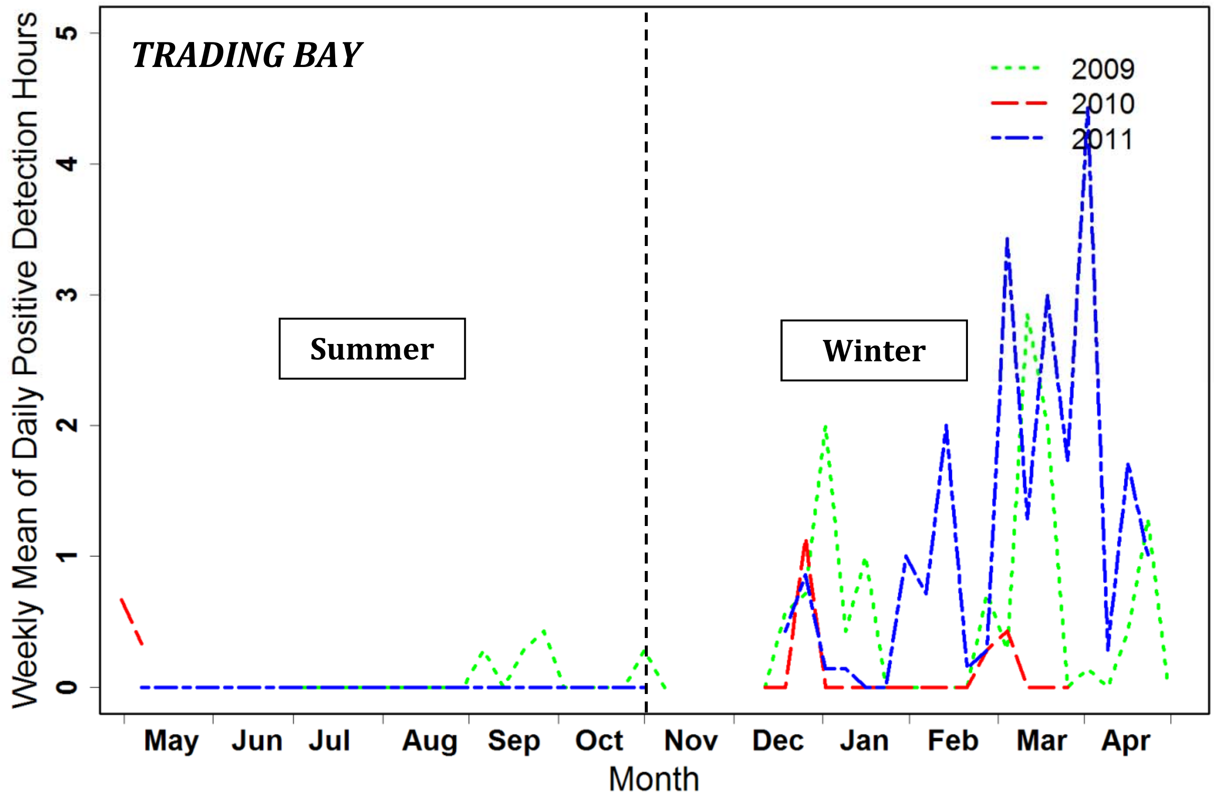

Figure 4E. Weekly mean of daily beluga detection positive hours (DPH) by month at Trading Bay, Cook Inlet, Alaska, 2009-2011

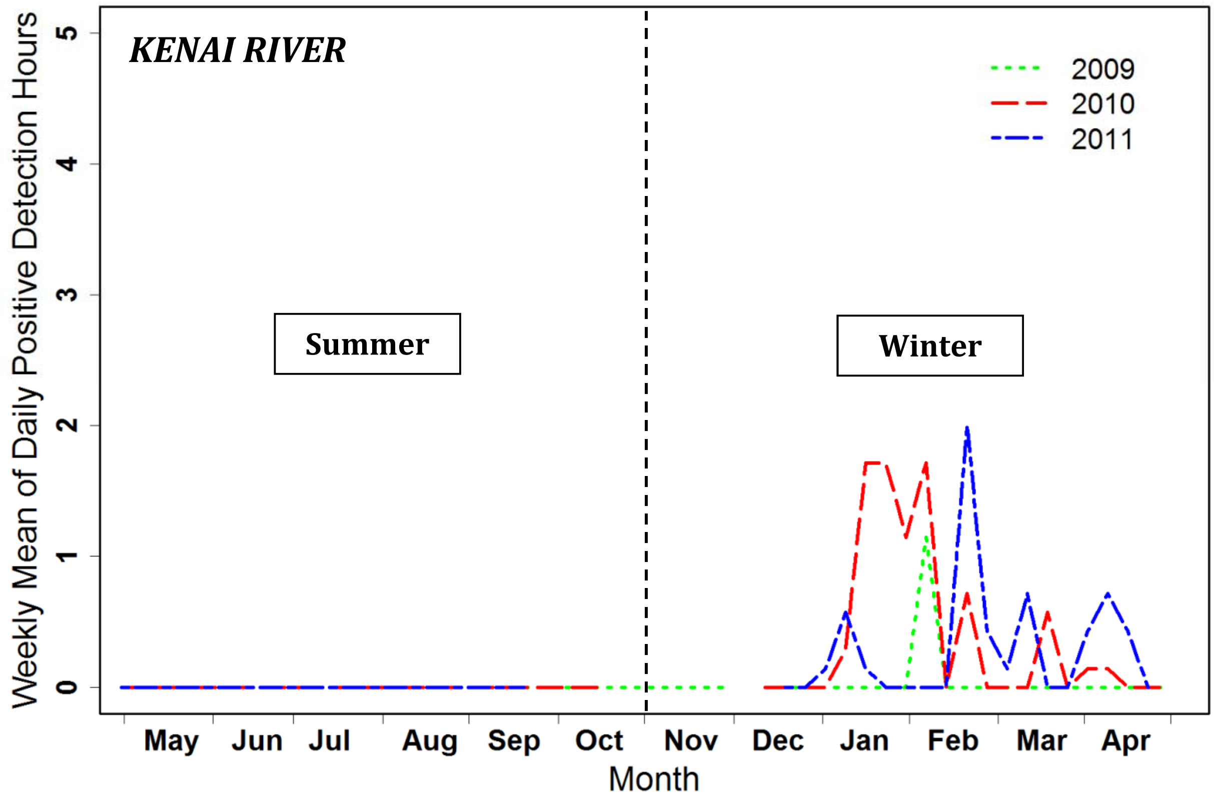

Figure 4F. Weekly mean of daily beluga detection positive hours (DPH) by month at Kenai River, Cook Inlet, Alaska, 2009-2011.

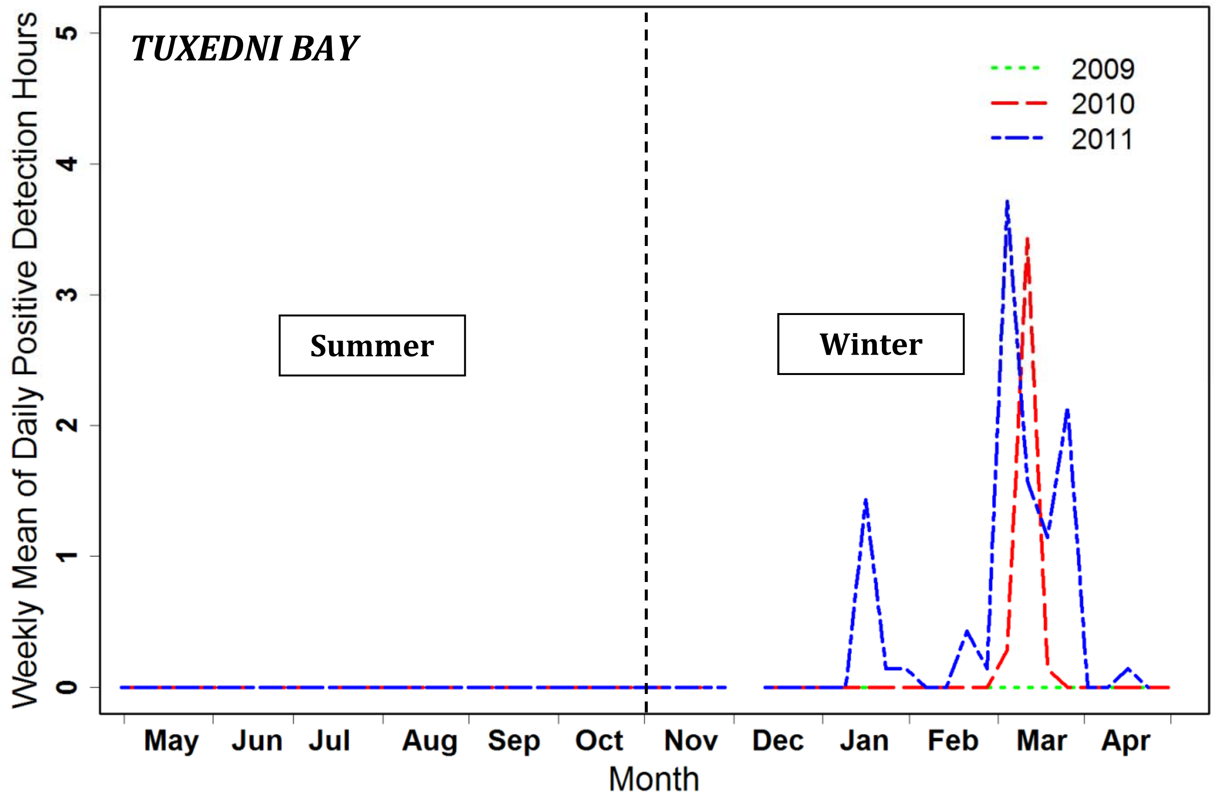

Figure 4G. Weekly mean of daily beluga detection positive hours (DPH) by month at Tuxedni Bay, Cook Inlet, Alaska, 2009-2011.

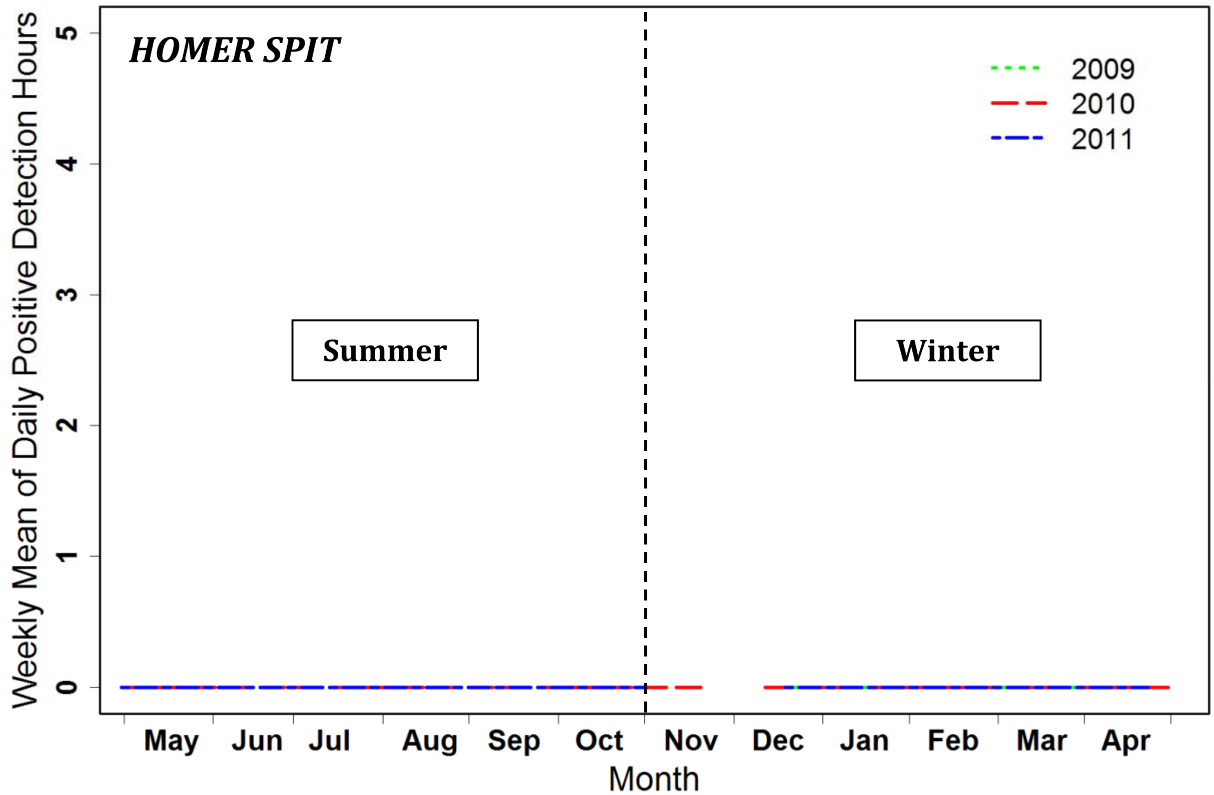

Figure 4H. Weekly mean of daily beluga detection positive hours (DPH) by month at Homer Spit, Cook Inlet, Alaska, 2009-2011.

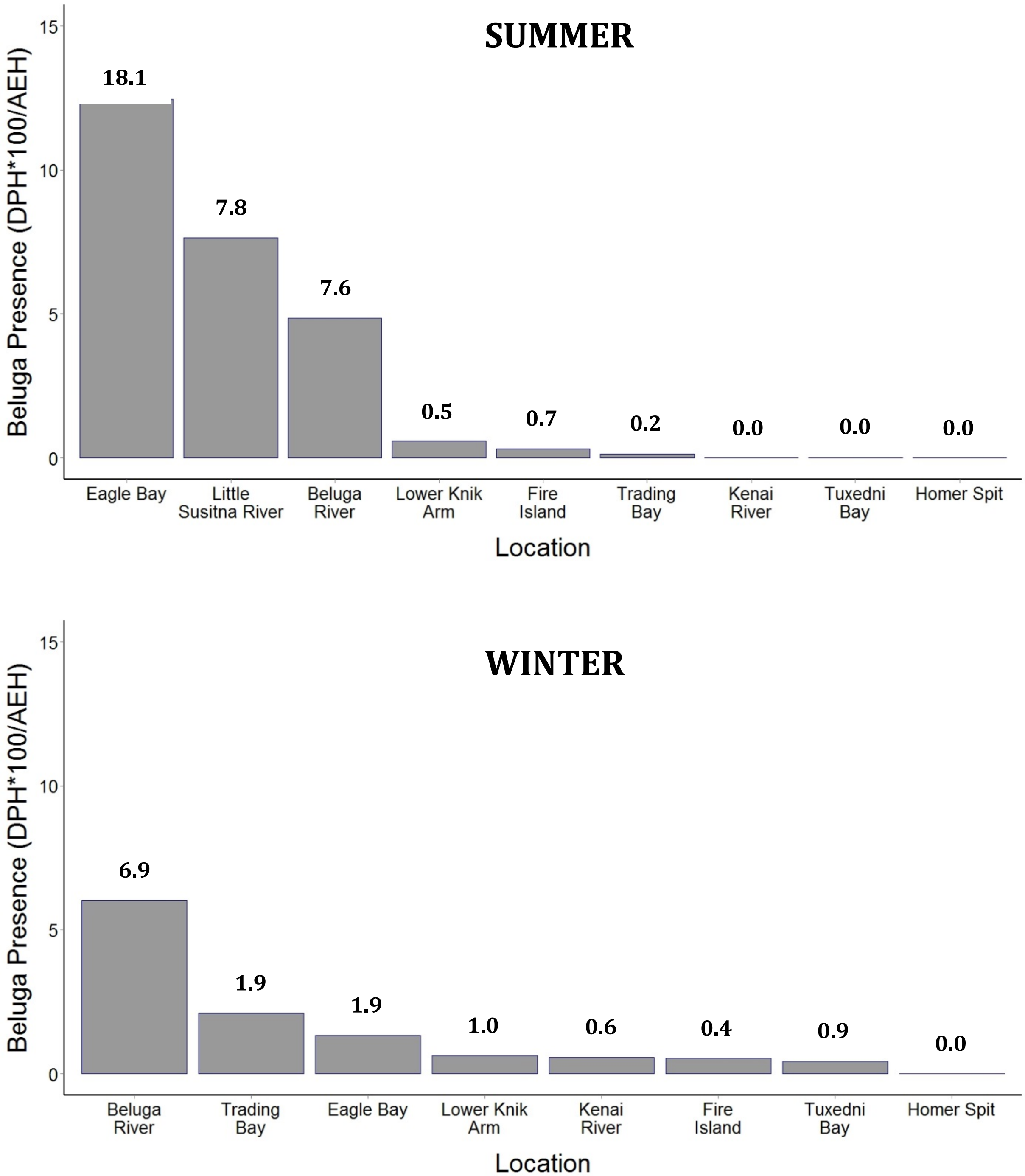

Figure 5. Beluga acoustic presence (%DPH), calculated as percent detection positive hours (DPH) over total acoustic effort hours (AEH), during summer (May to October) and winter (November to April) for all locations sampled during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013. Locations are ordered by decreasing %DPH in both seasons, and the standard deviation is shown above the %DPH.

5.3 Foraging Occurrence

Based on all recordings obtained, foraging behavior was detected in all months except October. However, foraging positive minutes (FPM) was below 23 in all six winter months and substantially higher, ranging from 48 to 337, during the 5 summer months (Table 3). The highest summer monthly FPMs were June, July, and August (164, 115, and 337), with FPM much smaller in the month before and after; i.e., May (48) and September (43). Summer monthly DPH was substantially higher during June-September (range of 466-1,590) compared to May (79), which resulted in a May foraging index of 60.8, ~three times greater than all other summer months, and thus the peak month for foraging inlet-wide. Annually, based on the 13 locations monitored, foraging behavior appears to be extremely limited in winter, then increases in April followed by a major increase to a peak in May, stays elevated in June-August, decreases in September and reaches a minimum in October (Fig. 6).

Table 3. Total number of beluga foraging positive minutes (FPM), detection positive hours (DPH) and foraging index for each month from all the beluga detections in all the locations sampled during the CIBA research program in Cook Inlet, Alaska, for the period July 2008 to May 2013.

	Month	FPM	DPH	Foraging index
Summer	May	48	79	60.8
	Jun	164	755	21.7
	Jul	115	466	24.7
	Aug	337	1590	21.2
	Sep	43	679	6.3
	Oct	0	46	0.0
Winter	Nov	5	184	2.7
	Jan	1	94	1.1
	Dec	13	263	4.9
	Feb	2	186	1.1
	Mar	14	417	3.4
	Apr	22	175	12.6

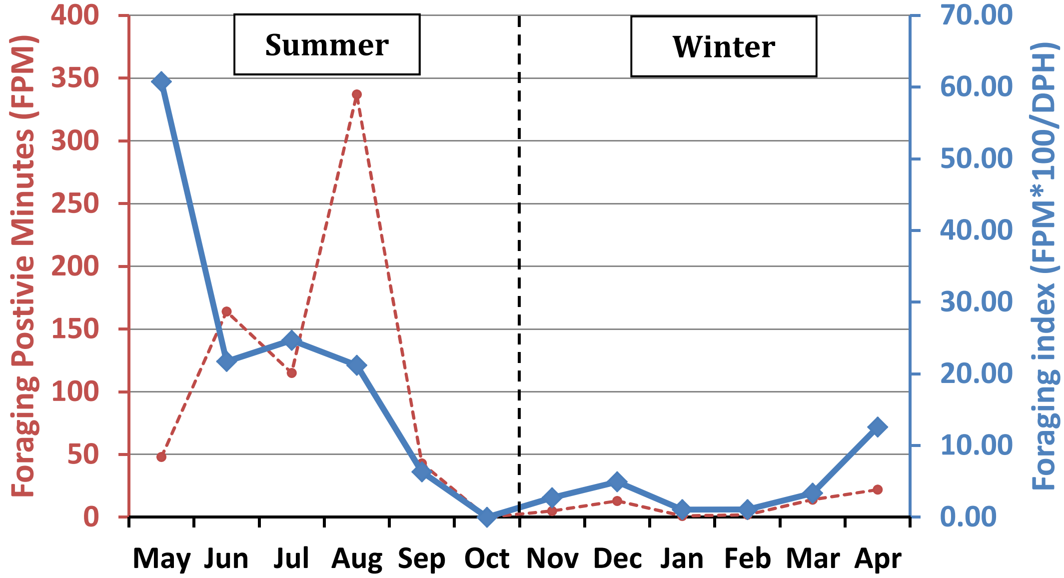

Figure 6. Beluga foraging positive minutes (FPM) and foraging index by month, based on acoustic detections (DPH) from all the locations sampled during the CIBA research program in Cook Inlet, Alaska, for the period July 2008 to May 2013.

Monthly FPM varied substantially by location, during both summer and winter (Table 4). During summer, not considering the three months with less than five FPMs, foraging was detected in May only at the Little Susitna; in June only at Beluga River; in July at both the Little Susitna and Beluga River; in August at both the Little Susitna and Eagle Bay; and in September only at Eagle Bay. For the three locations within Eagle Bay, FPMs were detected at North Eagle Bay and Eagle River, August 24.8% vs. 75.2% and September 24.8% vs. 5.2%; no FPMs were detected at South Eagle Bay, even though belugas were detected (Fig. 3C).

Based on FPMs, the difference in beluga foraging behavior between seasons was striking: 92.8% (707 FPM) in summer compared with 7.2% (55 FPM) in winter; an order of magnitude difference (Fig. 7). During summer, 100% of FPMs (707) were detected at locations in upper Cook Inlet; Little Susitna River (42.4%), Beluga River (35.4%), Eagle Bay (22.1%), and Lower Knik Arm (0.1%). During winter, more than 9 of 10 (94.5%) of the 55 FPMs were again detected in the upper inlet, at Beluga River (61.8%), Lower Knik Arm (16.4%), Eagle Bay (1.8%), and Trading Bay (14.5%). The only foraging behavior detected in the lower inlet during winter was 3 FPMs at Tuxedni Bay.

Table 4. Beluga foraging positive minutes (FPM), detection positive hours (DPH) by month obtained during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013. Not shown are 3 FPM in Tuxedni Bay in March.

		Beluga River			Lower Knik Arm			Eagle Bay			Little Susitna River			Trading Bay		
		FPM	DPH	Foraging Index	FPM	DPH	Foraging Index	FPM	DPH	Foraging Index	FPM	DPH	Foraging Index	FPM	DPH	Foraging Index
Summer	May	0	5	0.0	0	6	0.0	0	0	0.0	48	64	75.0	0	4	0.0
	Jun	163	656	24.8	0	19	0.0	0	54	0.0	1	26	3.8	0	0	0.0
	Jul	87	390	22.3	0	6	0.0	0	36	0.0	28	34	82.4	0	0	0.0
	Aug	0	8	0.0	1	32	0.0	117	1298	9.0	219	250	87.6	0	0	0.0
	Sep	0	3	0.0	0	4	0.0	39	608	6.4	4	22	18.2	0	7	0.0
	Oct	0	3	0.0	0	3	0.0	0	33	0.0	-	-	-	0	2	0.0
Winter	Nov	2	97	2.1	2	23	8.7	1	25	4.0	-	-	-	0	0	0.0
	Dec	1	212	0.5	6	51	11.8	0	0	0.0	-	-	-	6	29	20.7
	Jan	0	11	0.0	0	2	0.0	0	-	-	-	-	-	0	30	0.0
	Feb	1	103	1.0	0	0	0.0	0	-	-	-	-	-	0	33	0.0
	Mar	9	192	4.7	0	6	0.0	0	-	-	-	-	-	2	109	1.8
	Apr	21	54	38.9	1	34	2.9	0	-	-	-	-	-	0	56	0.0

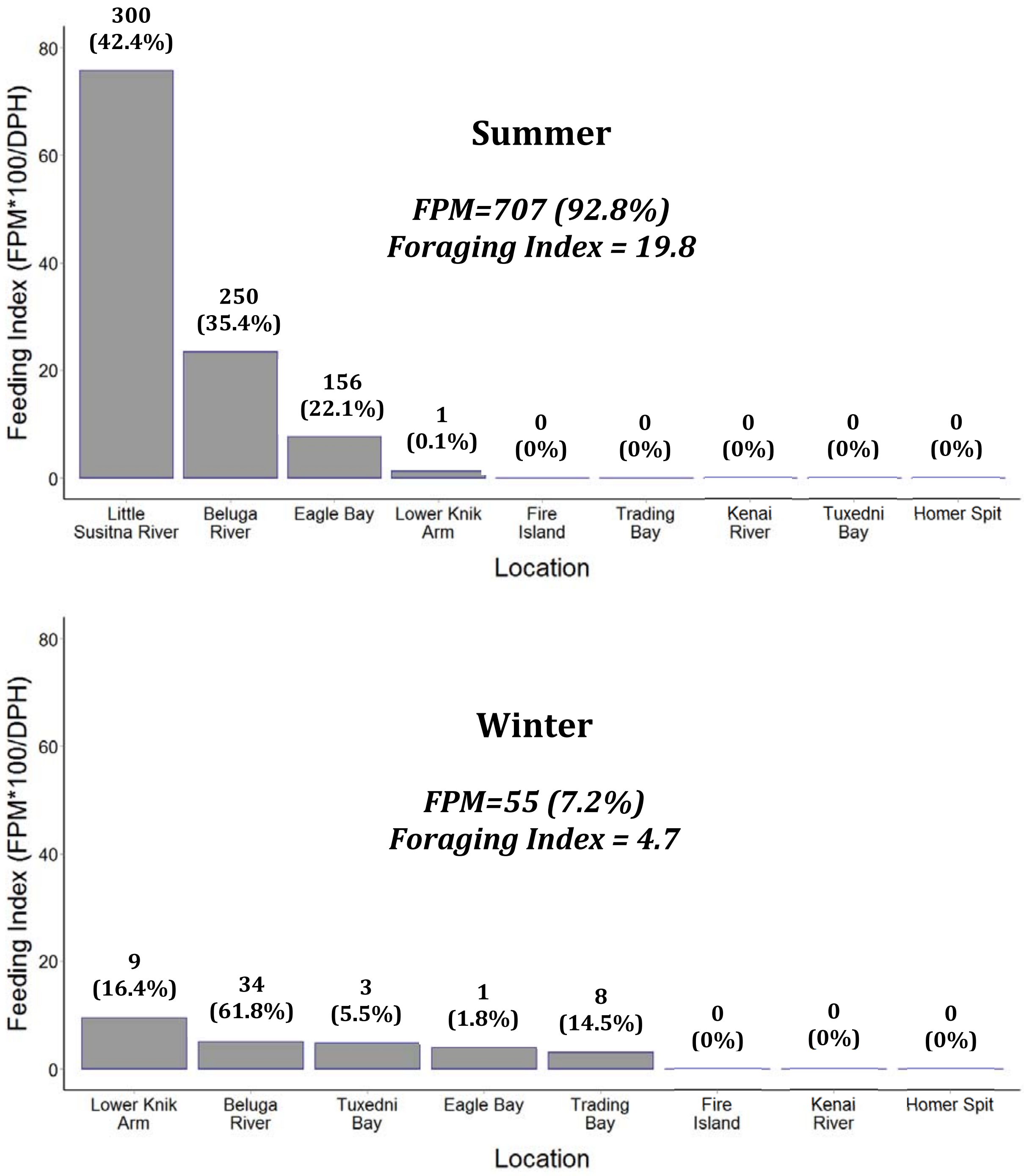

Figure 7: Beluga foraging index, in decreasing order, by season (summer/winter) and location, based on acoustic detections of belugas during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013. The number of foraging positive minutes (FPM) and their respective seasonal percentage are shown above the foraging index for each location.

When foraging behavior is assessed by accounting for DPH, the foraging index results between seasons and among locations is quite similar to results based only on FPMs, with some differences in winter (Fig. 7). During summer, the highest foraging indices were also in the upper inlet, with 75.8 at Little Susitna, which was ~3-times the 23.5 index at Beluga River, which was ~3-times the 7.7 index at Eagle Bay. During the winter period, although the highest FPMs was at Beluga River, that location had substantially more DPH, which resulted in the highest winter foraging index of 9.5 occurring at lower Knik Arm, nearly double the 5.1 index at Beluga River. Foraging was detected at three other locations spread widely across the inlet, with indices similar to Beluga River: 4.0 at Eagle Bay 3.1, 3.1 at Trading Bay, and 3.4 at Tuxedni Bay.

The spatial distribution of our acoustic monitoring effort (AEH) and beluga detections (DPH) for the entire study period across all of Cook Inlet is shown in Figure 8 for summer and Figure 9 for winter. During summer, the minimum AEH were at Little Susitna, because the mooring was deployed for only a few months, and also at Fire Island due to several lost moorings. The great difference in DPH among locations is clearly evident, with detections in only the upper inlet, and highest values at Eagle Bay and Beluga River. During winter, effort was lowest in Eagle Bay. The spatial distribution of beluga presence (%DPH) and foraging index is shown in Figure 10 for summer and Figure 11 for winter, which allows a comparison of the relative amount of foraging by belugas when they are present at each monitoring location. For example, although %DPH was lower at Little Susitna and Beluga River compared to Eagle Bay during summer (Fig. 10), the foraging index at those first two sites was higher, indicating the whales spend a larger portion of their time foraging there compared to Eagle Bay.

On a broader spatial scale, we compared beluga presence (%DPH) and foraging behavior (i.e., foraging index) among locations in three regions of Cook Inlet during both summer and winter: Knik Arm, upper inlet, and lower Inlet (Fig. 12). In Knik Arm, beluga presence in Lower Knik Arm was low, 0.6%, and the same during both summer and winter, which was in stark contrast to Eagle Bay where there was a substantial decrease between summer, 12.4% (highest level recorded inlet-wide), and winter, 1.3%. Across the two seasons, foraging behavior was most prevalent in Knik Arm compared to the upper and lower inlet, yet the highest foraging index was in the upper inlet during summer; foraging essentially did not occur in the lower inlet. Belugas were not present in the lower Inlet during summer, and although they were present in winter, at Kenai River and Tuxedni Bay, their presence was low when compared to the upper inlet and Knik Arm.

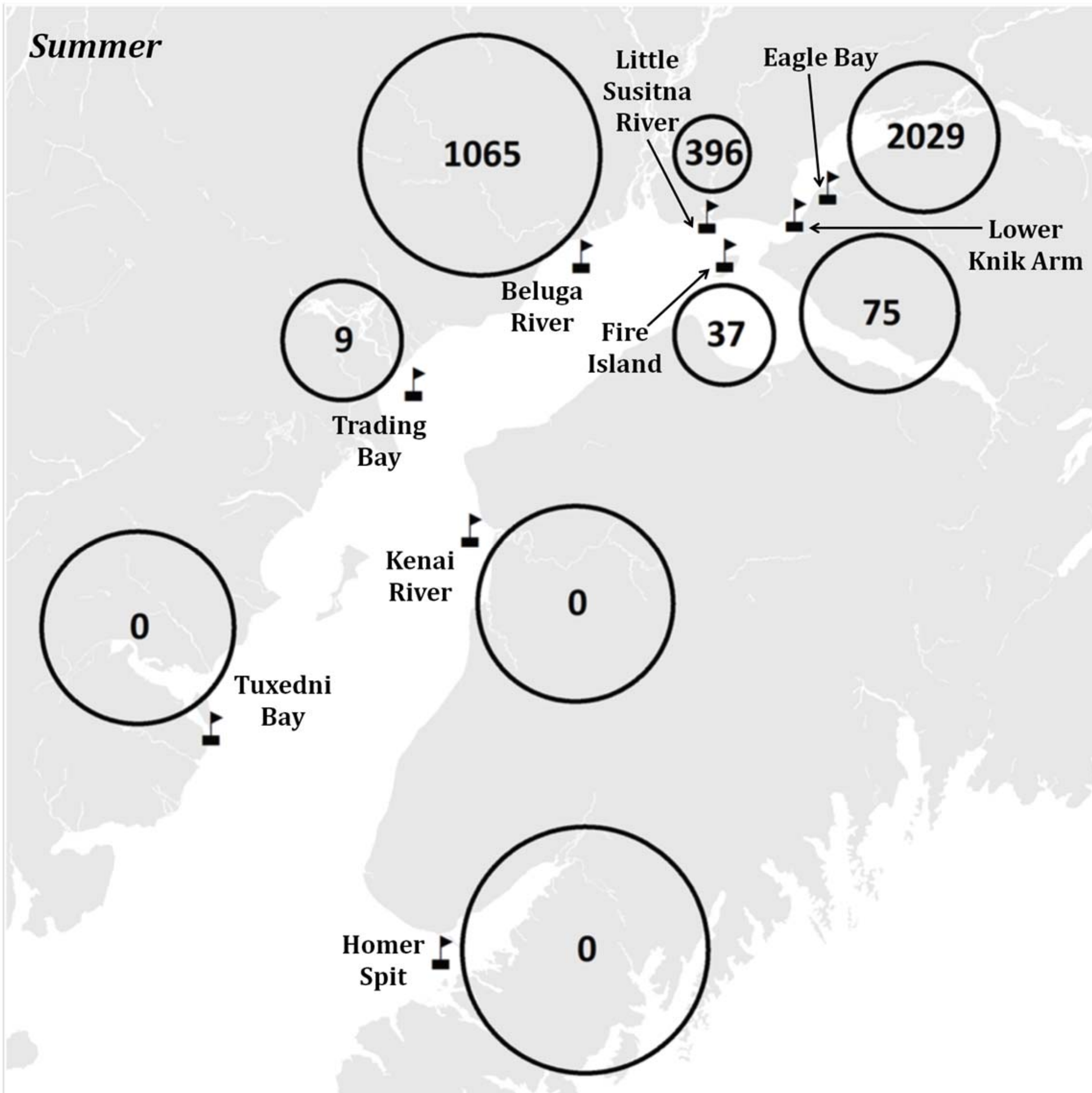

Figure 8. Relative amount of acoustic effort hours (AEH) represented as open circles and the number of beluga detection positive hours (DPH) within each circle obtained in summer during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013.

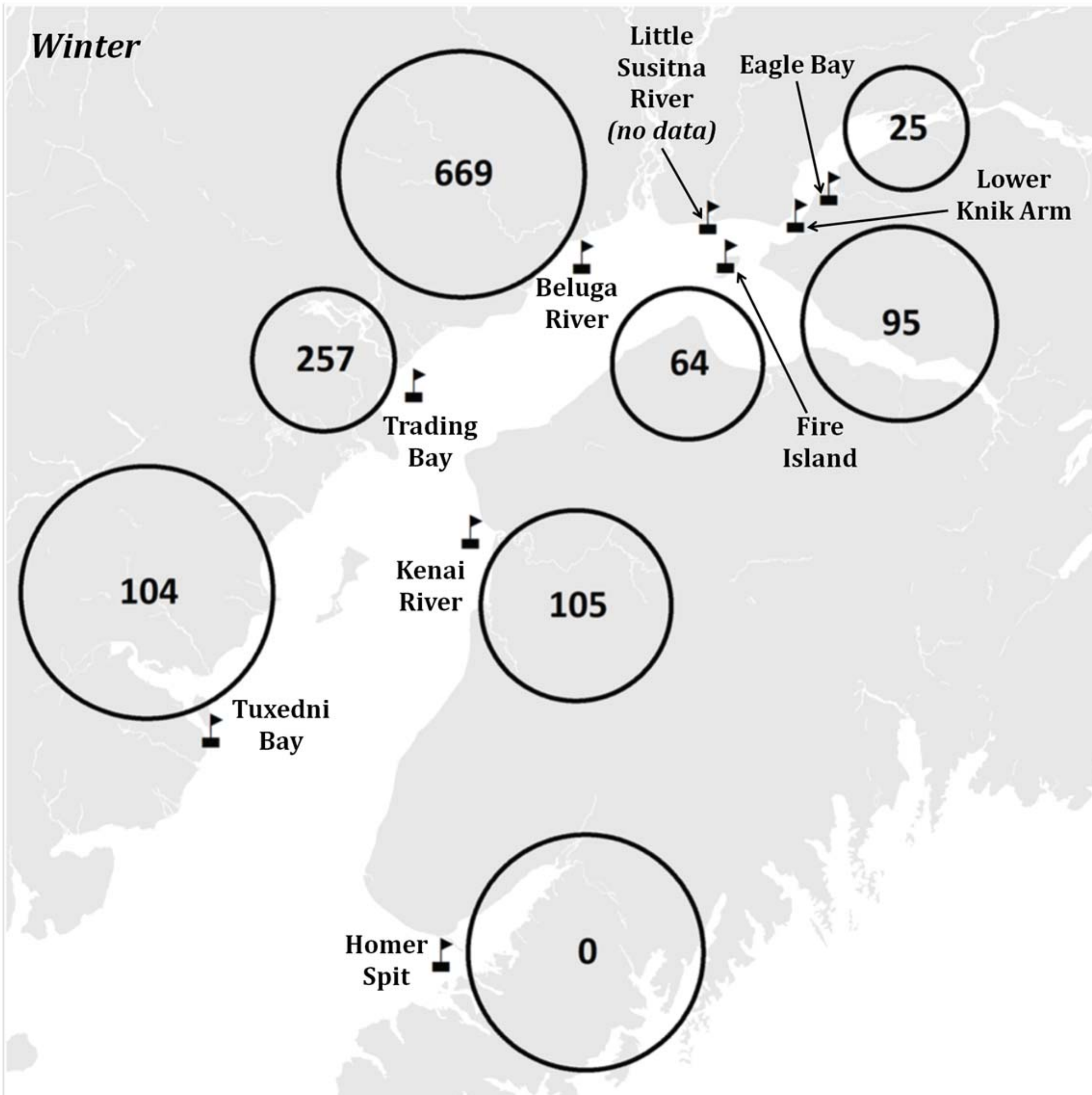

Figure 9. Relative amount of acoustic effort hours (AEH) represented as open circles and the number of beluga detection positive hours (DPH) within each circle obtained in winter during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013.

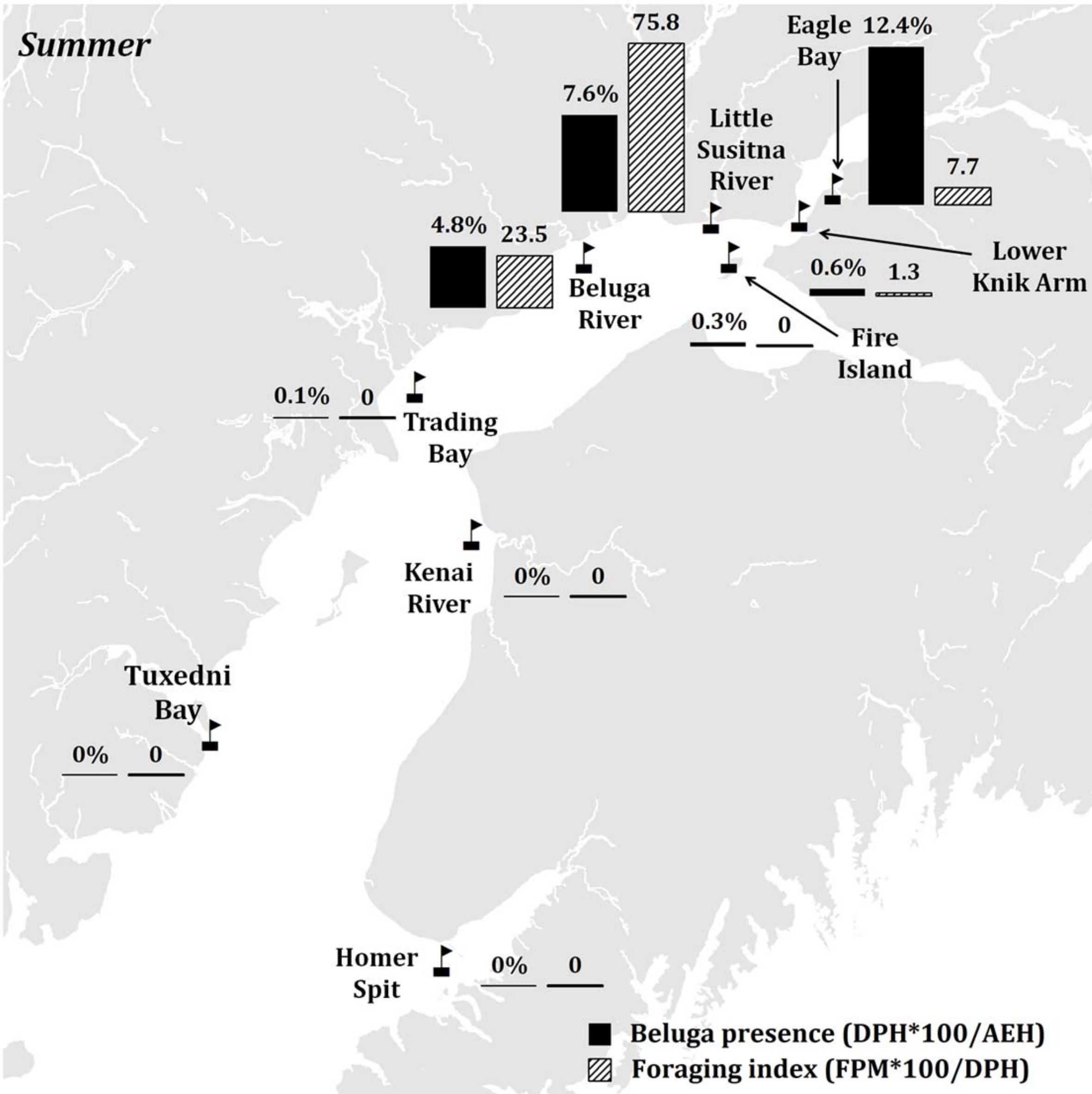

Figure 10: Beluga %DPH (solid black) and foraging index (hatched) during summer, based on acoustic monitoring data obtained during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013.

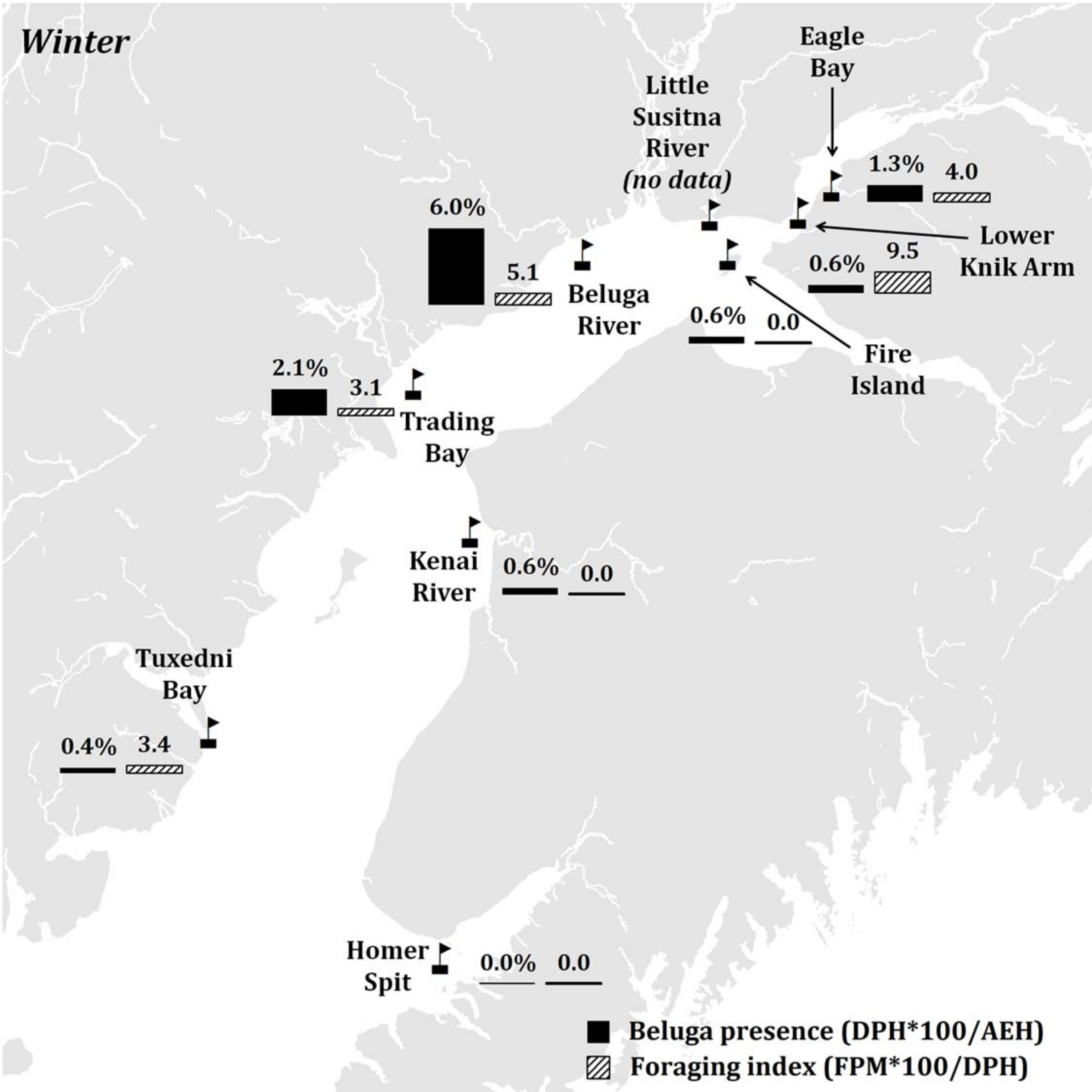

Figure 11: Beluga %DPH (solid black) and foraging index (hatched) during winter, based on acoustic monitoring data obtained during the CIBA research program in Cook Inlet, Alaska, July 2008 to May 2013.

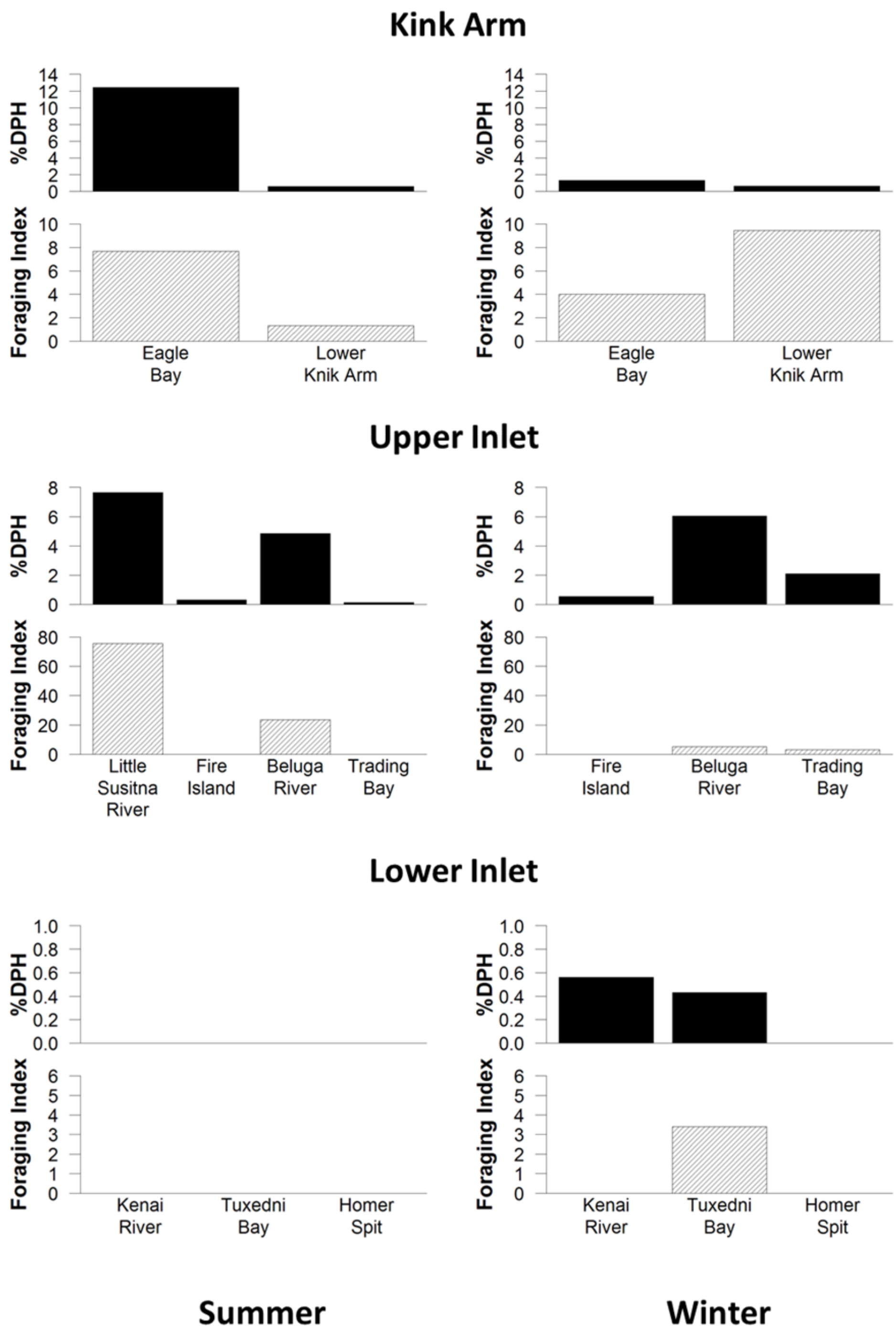

Figure 12: Beluga %DPH and foraging index during summer and winter among locations in three regions of Cook Inlet, Knik Arm (top), Upper Inlet (middle), and Lower Inlet (bottom), based on acoustic monitoring data obtained during the CIBA research program, July 2008 to May 2013. Scale on y-axis is different for each region for presentation.

6. DISCUSSION

6.1 Seasonal Distribution

Year-round passive acoustic monitoring was achieved successfully at most of the monitoring locations across Cook Inlet, which provided detections for an assessment of beluga presence both seasonally and annually. Knik Arm was the only region where monitoring was challenging, due to the combination of shallow depths, strong currents, vegetative debris, and ice coverage in winter. However, partial datasets (i.e., < 12 months) were collected from different mooring sites within that region, providing information on beluga presence year round for the lower area of Knik Arm and for summer months in the upper area of Knik Arm (Eagle Bay).

The combination of data collected simultaneously by the two acoustic instruments (EAR and C-POD) increased the detectability of belugas in Cook Inlet. Belugas where often detected by only one of the two instruments, indicating that combining the two detection datasets enhanced the assessment of beluga presence. Castellote et al. (*In Press*) provide a detailed comparison of beluga detection data from EAR and C-PODs in Cook Inlet, yet some discussion on the topic is warranted in this report. For example, we considered acoustic effort equal across monitoring locations when either one or both instruments were sampling, recognizing beluga detection probability was not equal between the two instruments. Specifically, the detection range of the EAR is greater than that of the C-POD, and the EAR monitoring was on a 10% duty cycle whereas the C-POD monitored continuously. However, detection probability was highly variable due to numerous environmental parameters in Cook Inlet that affect underwater sound propagation, including water depth, salinity, and temperature, along with water current speed (e.g., the C-POD shuts down when at a horizontal orientation. As such, we did not consider the differential detection probability between instruments a concern in our analyses; however, the instrument specific differences would have to be accounted for if estimating beluga call density was an objective.

Even if the acoustic detection range of Cook Inlet belugas is rather limited around the mooring locations, estimated to be up to 3.3 km from the mooring (Lammers et al. 2013), our year-round point sampling at 9 locations, plus at 4 locations seasonally, allowed a general description of beluga seasonal distribution across all of Cook Inlet. In general, the observed seasonal distribution is in accordance with descriptions based on aerial surveys in June and July (Rugh et al. 2000, 2005; Shelden et al. 2013) and satellite telemetry (Hobbs et al. 2005) for a broader period. Beluga detections are higher in the upper inlet during summer, peaking in Little Susitna, Beluga River, and Eagle Bay. These sampling locations are within the summer core concentration area, and detections are reduced in these locations during winter. Detections during winter at Kenai River and Tuxedni Bay suggest beluga distribution expands into the lower inlet during winter. Overall %DPH in summer was much higher than in winter, suggesting that belugas do not concentrate at any of the mooring locations in winter. The summer beluga concentration is thought to be driven primarily by prey availability, particularly at major river mouths with anadromous fish runs (Moore et al. 2000). The fact that beluga presence was not concentrated in winter suggests that winter prey is more dispersed spatially than in summer, or alternatively, prey might concentrate in areas that we did not monitor.

Plots of the weekly mean beluga DPH show similarities in detection patterns between 2010 and 2011 in North Eagle Bay with a peak in August (Fig. 3A), however data from Eagle River (Fig. 3B) indicates two patterns, one with a high number of detections in August and September (2009 and 2010) and another one with lower detections in these same months (2011 and 2012). These results document a peak period of beluga presence in summer in Knik Arm and suggest that their temporal presence is highly similar across years but the amount of time spent in the sampled locations or the number of individual whales is highly variable across years. This variability could be related to the presence of prey, notably salmon runs, in the rivers of Knik Arm. In fact, in Eagle River, data from 2010 shows a high number of DPH and data from 2011 shows a much lower number of DPH; however, both years yielded a very similar number of DPH in Eagle Bay North. These differences in beluga presence suggest that in 2011 belugas had a lower interest in Eagle River, yet maintained the same interest as in 2010 for Eagle River North. This could be explained if salmon runs in Eagle River were lower in 2011 than in 2010, but prey availability was sustained for both years in rivers north of Eagle Bay.

Weekly mean of daily beluga DPH from Little Susitna (Fig. 3D) was obtained only in summer 2011. These data show two peaks, an incomplete peak (onset of the peak not sampled) in late May - early June and a second peak in August. This bimodal distribution of beluga detections could be related to the known availability of the two main anadromous summer prey species for Cook Inlet belugas, eulachon (*Thaleichthys pacificus*) and Pacific salmon (*Oncorhynchus* spp.). Belugas switch from consuming eulachon in the spring to other lipid-rich species such as Pacific salmon in the late spring and summer (Abookire & Piatt 2005, Litzow et al. 2006). The maximum weekly mean of daily beluga DPH in Little Susitna was lower than the peaks obtained in Eagle River in 2009 and 2010. Thus, overall, Eagle River shows the highest values of beluga presence from all the sampled locations in our study. However, in summer 2011, the DPH peak in Eagle River was much lower than the peak in Little Susitna River within the same months, suggesting that at least in summer 2011, Little Susitna River was a much more important river for belugas. Because these differences are probably related to prey availability in the different rivers visited by belugas each summer, data from multiple years would be required in order to properly classify Cook Inlet rivers by degree of importance to belugas. Our results indicate that Eagle River is as important for belugas, if not more, as is Little Susitna River.

Weekly mean of daily beluga DPH from Beluga River also shows similarities in detection patterns across years. Three peaks of occurrence are detected, one from mid-February to early April, the strongest peak in June to mid-July, and the third peak in mid-November and December. The early spring peak could be explained by the occurrence of eulachon runs, as at Little Susitna. When beluga presence in spring is compared in both rivers, our data suggests that this peak could cover a period as long as mid-February to Mid-June. But because our data-sets are interrupted in both locations, this cannot be confirmed; information on the duration of eulachon runs in these rivers could test this hypothesis. The main peak in Beluga River in June to mid-July might correspond to the occurrence of salmon runs. This happened approximately two months before the main peak in Little Susitna and Eagle rivers in 2011. The delay between these two peaks among the three rivers could be explained by differences in the timing of targeted salmon runs (i.e., beluga might target a different salmon species in Eagle River than in Beluga and Little Susitna Rivers) but could also be related to habitat preference during the salmon run season, implying that Beluga River is the preferred foraging location June to mid-July and Little Susitna and Eagle River are preferred in August to September.

Weekly mean of daily beluga DPH from Cairn Point, Point MacKenzie, and Six Mile are surprisingly low compared to the DPH obtained in the upper part of Knik Arm. Saxon Kendall (2013) suggested that belugas might be displaced from the east side of the lower Knik arm due to construction activities at the Port of Anchorage, or that belugas might reduce their vocal activity when transiting through this area, or that beluga acoustic signals might be masked by anthropogenic noise. There is evidence of a decrease or even a cessation of acoustic activity of belugas in the presence of natural predators (i.e., killer whales) or engine noise disturbance. This acoustic response has been observed in both captive and free-ranging belugas and has been interpreted as a survival strategy to avoid detection by predators (Morgan 1979; Lésage et al., 1999; Castellote and Fossa 2006). Therefore, a reduction in acoustic detections could be plausible in areas of high anthropogenic noise, such as the lower Knik Arm. However, due to the high turbidity of this area, belugas maintaining their echolocation activity in order to navigate would be expected. Results by Saxon Kendall (2013) also indicate that echolocation was the only signal detected in their study site, supporting this hypothesis. If belugas decreased their emission of social signals but maintained their echolocation behavior, a higher number of C-POD detections would have been expected in the lower Knik Arm when compared to other locations. Furthermore, masking due to anthropogenic noise is relevant for lower frequencies where social signals are detected, but would rarely influence the ultrasonic frequency range of echolocation; therefore, if belugas traveled near the deployment sites they would have been detected by the echolocation loggers.

A westward displacement would imply that beluga detections would be consistently higher at the Point MacKenzie and Six Mile locations when compared to Cairn Point, however when looking at the concurrent sampled periods at these three sites (Fig. 3E, 3D and 3F), differences are not readily apparent. Specifically, weekly mean of DPH seems slightly higher at Point MacKenzie, but overall remains a low detection site, as are Cairn Point and Six Mile. Therefore, if there is a displacement effect, this might be happening on a small scale. A possible explanation for the low number of %DPH obtained could be that belugas most often used the central area of the lower Knik Arm and thus remained out of range for C-PODs deployed at Cairn Point, Six Mile, and Point MacKenzie. Further, assuming belugas reduced their social communication due to elevated anthropogenic noise, EARs would not detect them even if whales were within the detection range. An alternative explanation would be that belugas actually spend less time in lower Knik Arm as compared to the upper arm, implying that when they enter the arm, they spend several days in the upper part of the arm without travelling back or transiting through the lower Knik Arm. This would fit with the proportion of %DPH observed in Eagle Bay and lower Knik Arm. Satellite telemetry data suggests that this is a common movement pattern. A beluga instrumented with a satellite link time-depth recorder entered Knik Arm on August 18th and remained in the arm until September 12th (Ferrero et al. 2000). Satellite tagging efforts during 2000 and 2002 obtained data from 14 belugas (Hobbs et al. 2005), and results from this study showed that approximately 50–75% of the recorded locations in August were inside Knik Arm, concentrated near Eagle River.

When considering beluga presence in %DPH, summer results are in accordance with a general concentration of belugas in the upper inlet, particularly near coastal mudflats and river mouths (Calkins 1989, Smith & Martin 1994, Moore et al. 2000, Rugh et al. 2000, Goetz et al. 2007, Hobbs et al. 2005). Eagle Bay (primarily influenced by Eagle River), Little Susitna and Beluga River, in decreasing order, were the three upper Inlet river areas monitored in this study and the ones with highest summer beluga occurrence from all the study areas (Fig 5). These three rivers, together with the Susitna River, are known to be primary early summer beluga foraging habitat (Rugh et al. 2000). Later in the summer, high concentrations also tend to be observed in Knik Arm, particularly in Eagle Bay (Huntington 2000; Hobbs et al. 2005).

Beluga presence during winter was highest at Beluga River (Fig. 5). Satellite telemetry results, the only available information for winter distribution, show how belugas use the upper inlet, including Knik Arm until November, but starting in December tagged belugas moved offshore and satellite locations were distributed throughout the lower inlet, with minimal use of focal areas in the upper inlet and broad use of the central offshore waters (Hobbs et al. 2005). Acoustic results show an overall reduction of %DPH in winter, suggesting that belugas spend less time within the monitored areas, which were all coastal. However, belugas were detected (at low %DPH levels) at Kenai River and Tuxedni Bay only during winter, which suggests that beluga distribution is larger in winter than in summer, through an expansion into the lower inlet. These results are in accordance with satellite telemetry results. However, the fact that Beluga River was the winter location with highest %DPH, and Eagle Bay was third, suggests that during winter, the Upper Inlet might be more important than previously considered. Unfortunately, most of the winter data from Knik Arm was collected only in the lower part, but winter results suggest that belugas entered the arm in November, December, January, March and April (Fig. 3A to 3F). Trading Bay was second in decreasing order of beluga presence during winter. This result matches the location patterns of satellite tagged belugas, with a relatively high probability of occurrence in Trading Bay from December to March (Hobbs et al. 2005). Interestingly, belugas were detected in Kenai River from December to April, although at a low level (0.68 %DPH/month on average), but only 2 satellite tagged belugas visited this location and only in February (Hobbs et al. 2005). Belugas were also detected in Tuxedni Bay, from January to April, and similar to Kenai River, the amount of time spent in this area or concentration of belugas was always low (0.64 %DPH/month on average). Only three satellite tagged belugas ventured south of the forelands, spending a relatively long time north of Kalgin Island, and although all three made limited movements south of the island, only one reached Tuxedni Bay and Chinitna Bays (Goetz et al. 2012); the tagged whales visited these areas between June and November, unlike the detections from January to April. Belugas were never detected in Homer. These results support the premise that Cook Inlet beluga distribution is generally restricted to the upper and northern portion of the lower-inlet, yet indicate that at least Kenai River and Tuxedni Bay are occasionally visited by belugas during winter.

6.2 Foraging Occurrence

Echolocation data allowed us to successfully explore when and where presumed foraging buzzes occurred. Only 0.3% of all the DPH contained foraging buzzes, and these were detected at 8 of the 13 sampled locations: North Eagle Bay, Eagle River, Point MacKenzie, Cairn Point, Little Susitna River, Beluga River, Trading Bay, and Tuxedni Bay. These results suggest that foraging behavior is widespread, yet rarely detected or occurs infrequently. The probability of detecting foraging behavior is very low because echolocation signals are highly directional (Au et al. 1987) and thus foraging buzzes will only be detected by C-PODs when belugas are echolocating towards prey in the direction of the mooring.

Seasonally, foraging behavior was more prevalent during summer (FPM = 707; 92.8% of total foraging detections), particularly at upper inlet rivers, than during winter (FPM = 55; 7.2%). Foraging index was highest at Little Susitna (Fig. 7), with a peak in July-August and a secondary peak in May (Table 4). These peaks could correspond to the presence of different anadromous fish runs in this river, as discussed in the previous section; specifically, both eulachon and Pacific salmon are known to be beluga prey and are present in Little Susitna in May and August respectively (Seaman et al. 1982, Barrett et al. 1984). Beluga River was second in order of decreasing foraging occurrence in summer. Most summer DPM occurred in June and July, yet April contained the highest number of DPM (Table 4), a month considered winter in our analysis. Also, foraging buzzes were detected only at Beluga River in April and at Little Susitna in May, clearly indicating that belugas alternated the foraging use of these two rivers in spring and summer; specifically, Beluga River in April, then in Little Susitna in May, then back to Beluga River in June and July, and back to Little Susitna in August. Foraging buzzes were not detected past July at Beluga River, yet were detected during August and September in Eagle Bay, suggesting that the distribution of beluga foraging shifted into Knik Arm by late summer.

This foraging spatial pattern matches the summer beluga distribution pattern described in the previous section; however, the highest foraging index value was at Little Susitna (Fig. 7), whereas the highest beluga presence was at Eagle Bay (Fig. 5), a difference likely related to the location of moorings. First, the mooring was deployed well inside the Little Susitna River, approximately ~1.5 km upstream from the mouth, in contrast to the Eagle River mooring that was deployed ~0.3-0.5 km outside the mouth (in Eagle Bay) in deeper water in an attempt to be maintained overwinter. Second, the relatively small data sets from the three moorings in Eagle Bay (Eagle Bay North, Eagle Bay South, and Eagle River mouth) were pooled, and thus data from two moorings relatively far from Eagle River, where lower foraging behavior is presumed to occur, is included. Thus, we presume foraging behavior was prevalent in the Little Susitna River, including near our mooring, whereas in Eagle Bay foraging behavior was not as frequent near the two moorings north and south of the mooring near Eagle River; specifically, we likely detected many belugas accessing or exiting the foraging area (i.e. Eagle River).

Overall foraging index values for winter were much lower than summer, 4.7 vs. 19.8, which confirms that for the 13 locations we monitored there is no evidence for concentrated foraging in winter at levels observed during spring and summer in upper inlet rivers. Hobbs et al. (2005) reported that from December through March satellite telemetry movements were less focused with any particular area, and beluga distribution was thus broader and appeared somewhat random, similar to our acoustic detection results. Surprisingly, the highest foraging index in winter was in Lower Knik Arm, even though beluga presence and FPM were highest at Beluga River. This contradictory result is from belugas spending relatively little time in Lower Knik Arm, yet when present in that area they often engaged in foraging behavior. In contrast, belugas visited Beluga River over five times more often than lower Knik Arm, yet engaged in foraging behavior proportionally less frequently.

For winter, the highest monthly FPM occurred during March (9) and April (21), both at Beluga River, where there was minimal FPM (1-2) from November through February, except no FPM in January (Table 4). The relatively high FPM in March and April was the earliest, and only, sign of foraging concentration throughout the winter months, and could be related to the presence of eulachon, which are known to spawn as early as January (Moffitt et al. 2002). The only other relatively high level of winter foraging behavior (both FPM and Foraging Index) was during December, at both Lower Knik Arm and Trading Bay; however, DPH was low, indicating that some of the little time belugas spent at these two areas was dedicated to foraging.

Based on our definition of winter as November to April, our results indicate that beluga foraging in winter is very limited compared to summer, with concentrated foraging at only one location (Beluga River) at winter's end. Our monitoring effort was restricted to nearshore areas, and thus our results do not allow an assessment of offshore foraging during winter, when belugas may forage on more dispersed prey (Moore et al. 2000). Another important consideration relative to detecting foraging behavior is the high directionality of echolocation signals. Specifically, if the predominant type of beluga prey during winter is benthic, as suggested by preliminary diet studies (ADF&G unpublished), belugas would direct their echolocation signals towards the seafloor when foraging, greatly reducing the ability to detect foraging buzzes with moored C-PODs. Exploring the available winter dive behavior (from satellite telemetry) may provide insights on how often belugas spend time at the bottom of the Inlet during winter, and the ability to acoustically detect foraging behavior.

7. CONCLUSION

The CIBA research project collected the information needed to address the three objectives listed in Section 3, and this report completes the required deliverables associated with those objectives. Specifically, (1) social vocalizations and echolocation activity of beluga whales were obtained and shifts in beluga presence were described seasonally and annually throughout Cook Inlet, with an emphasis on the waters adjacent to JBER; and (2) beluga echolocation was analyzed to document foraging behavior at all monitoring sites.

Relevant to the objective of documenting foraging behavior, concerted field research efforts failed to successfully deploy a DTAG on belugas in Eagle River. Data collected from a DTAG allows a more comprehensive understanding of beluga echolocation during foraging, because the tag simultaneously collects acoustic activity and fine-scale movement information associated with prey pursuit and capture. DTAGs have recently been deployed in Bristol Bay, Alaska, and the results from analyzing the data collected from those deployments will be applied to the echolocation data collected by the CIBA project. In addition to the results from the DTAG deployments, a comparison of concurrent echolocation data (from the C-PODs) and social vocalizations (from the EARs) will further enhance a more thorough and comprehensive understanding of beluga foraging behavior in Cook Inlet; a manuscript will be submitted for publication based on these new results.

The information on seasonal distribution in this report, especially the spatial differences between summer and winter and the consistent within-season use patterns across years at some locations, represents a substantial contribution on beluga whale ecology in Cook Inlet. This information will be prepared in a manuscript for publication that will include a comparison with beluga distribution data from aerial surveys, and satellite telemetry and photo-ID studies.

As discussed in this report, the seasonal distribution of belugas in Cook Inlet is likely closely related to the availability of key prey species, both spatially and temporally; thus foraging behavior and seasonal distribution are most likely strongly linked. After the more comprehensive analysis and documentation of beluga foraging behavior in Cook Inlet is completed (as described in the second paragraph above), an integrated quantitative analysis will be conducted on the relationship between beluga presence and foraging, including the covariates that may influence that relationship. Diurnal tide cycles, ice coverage, seasonal prey distribution and abundance, and diel patterns are covariates that will be included in the quantitative analysis, which should provide a substantial contribution on the factors that determine how, and why, belugas utilize the different habitats available within Cook Inlet.

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