Acoustic Monitoring and Prey Association for Beluga Whale, *Delphinapterus leucas*, and Harbor Porpoise, *Phocoena phocoena*, off Two River Mouths in Yakutat Bay, Alaska

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Introduction

Yakutat Bay on the eastern Gulf of Alaska is a glacial fjord influenced by the activity of major tidewater glaciers at its head and is a region of high marine biodiversity. Two marine mammal species that live there year-round are the beluga whale, *Delphinapterus leucas*, and the harbor porpoise, *Phocoena phocoena*.

The exact number of belugas in Yakutat Bay is unknown, but the best present estimate is 10–12 whales (O'Corry-Crowe et al., 2015; O'Corry-Crowe[1]). Genetic studies indicate that this small group of belugas is isolated from the nearest population, in Cook Inlet; thus they may be resident in the Yakutat Bay region year-round (O'Corry-Crowe et al., 2015). Because these whales have such a restricted home range and small population size but are reproductive, they have a unique ecology (O'Corry-Crowe et al.[1, 2]). The core area for these animals appears to be Disenchantment Bay, at the far northeast end of Yakutat Bay, located between four actively calving tidewater glaciers (Fig. 1). Both opportunistic historical sightings (Laidre et al., 2000) and traditional ecological knowledge from the Tlingit Tribe (Lucey et al., 2015) suggest that belugas have inhabited Yakutat Bay since at least the 1930's, but they likely originated from Cook Inlet (O'Corry-Crowe et al., 2015).

Little is also known about the numbers and distribution of harbor porpoise in the bay, although they are seen more frequently than are beluga by the residents of Yakutat. Yakutat Bay is one of the regions in southeastern Alaska that has relatively high densities of harbor porpoises (Hobbs and Waite, 2010). Harbor porpoises are sighted both within and outside the bay in nearshore waters (Dahlheim et al., 2000; Hobbs and Waite, 2010). While there is little knowledge on historical beluga presence in Yakutat Bay, harbor porpoises have occupied the area since before human settlement and at one time were hunted for food by Yakutat Tlingit (De Laguna, 1972).

Various human activities occur within the known Yakutat beluga distribution range, including cruise ship visits, commercial fishing, marine geophysical surveys, seal hunting, and scientific activities, but none of these have been evaluated for potential impacts on this small and isolated population. Therefore, improved knowledge of Yakutat's beluga seasonal distribution and habitat use is needed to better evaluate the potential effects of anthropogenic ac-

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[1] O'Corry-Crowe, G., W. Lucey, M. Castellote, and K. Stafford. 2008. Abundance, habitat use and behavior of beluga whales in Yakutat Bay, May 2008, as revealed by passive acoustic monitoring, visual observations and photo-id. Final Report to Protected Resources Division, Alaska Regional Office, National Marine Fisheries Service. NOAA Juneau, Alaska, 49 p. (Available at: http://alaskafisheries.noaa.gov/protectedresources/whales/beluga/yakutat/yakutat_2008belugas_0309.pdf).

[2] O'Corry-Crowe, G., W. Lucey, C. Bonin, E. Henniger, and R. Hobbs. 2006. The ecology, status, and stock identity of beluga whales, *Delphinapterus leucas*, in Yakutat Bay, Alaska. Rep. to U.S. Mar. Mamm. Comm., NMFS-YSB-YTT, 22 p.

ABSTRACT—Little is known about the ecology of beluga whales, Delphinapterus leucas*, and harbor porpoises,* Phocoena phocoena*, inhabiting Yakutat Bay, Alaska. Using passive, acoustic monitoring techniques, their year-round presence was monitored during June 2012–Mar. 2013 off the mouths of two glacial rivers: Esker Creek and Grand Wash. Fishery trawl transects were run in both areas during Mar.–Aug. 2013 to assess fish and invertebrate diversity and to identify potential beluga and harbor porpoise prey. Results supported year-round presence for both species, with restricted home range for beluga and a wider distribution for porpoise. Opposite diel patterns in beluga and harbor porpoise presence suggest potential competitive overlap in prey between species. Based on trawl abundance and ubiquity, several fish and crustacean species were identified as potential prey for beluga and harbor porpoise. Results support the belief that shrimp, crab, and mysids may be an important part of beluga and porpoise diet in Yakutat. Both river mouth areas are used by harbor porpoises but their seasonality might not be driven solely by prey diversity or abundance. Beluga detection results during a coho salmon,* Oncorhynchus kisutch*, run were indicative of predation by belugas on this species during their spawning migration. This pilot study demonstrates the utility of remote, passive acoustic monitoring technology to better understand the seasonal distribution patterns and prey association of beluga and harbor porpoise in Yakutat Bay.*

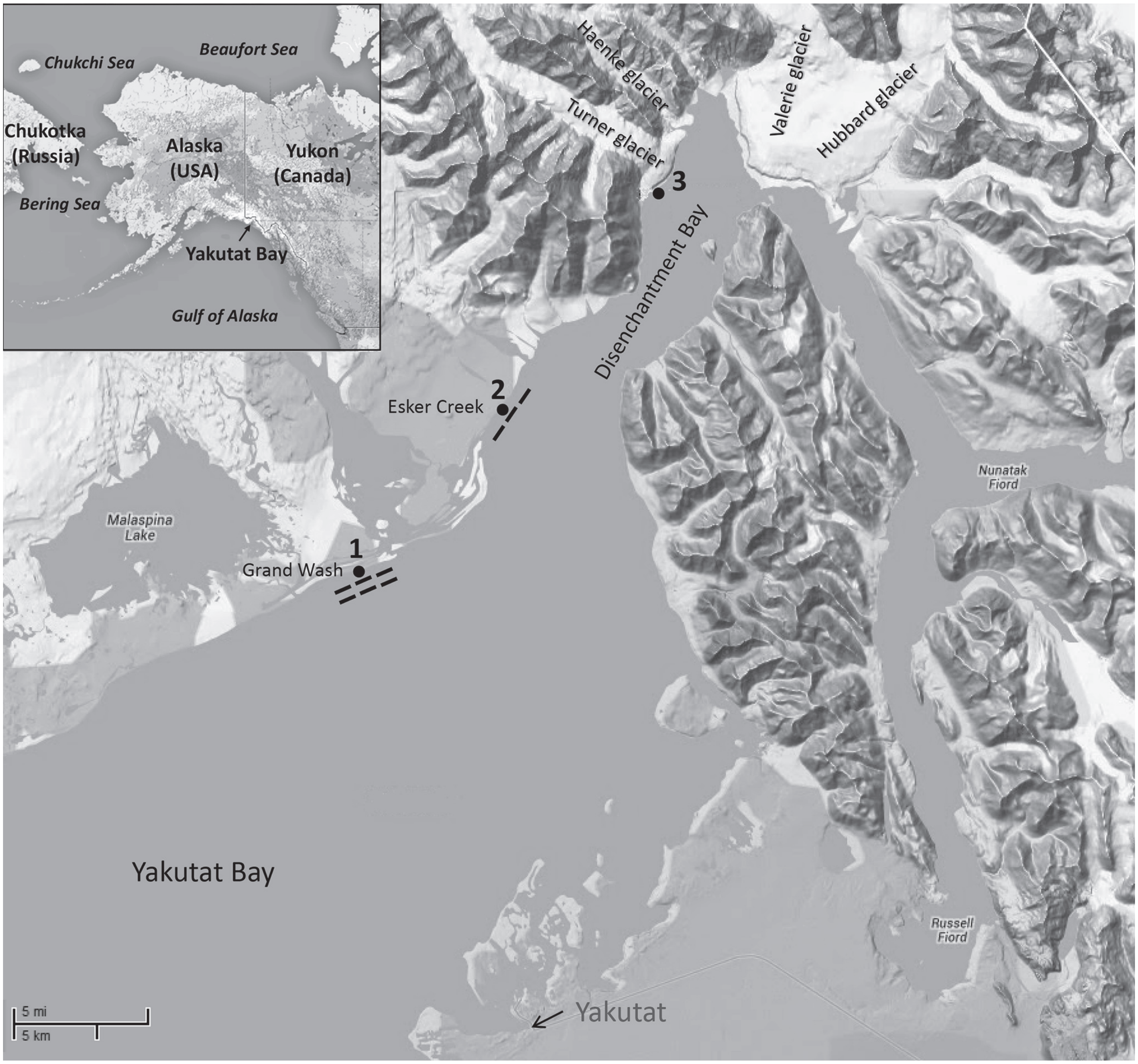

Figure 1.—Disenchantment and Yakutat Bays, mooring deployment locations (dots) and trawl transects (lines).

tivities and to define proper conservation management measures.

To study such a small, cryptic, and remote population, passive acoustic monitoring was proposed. This method has proven to be very effective for cetacean studies because it can be used in all weather conditions and seasons (Mellinger et al., 2007). Long-term monitoring of belugas in estuarine environments with moored passive acoustic recorders has proven fruitful in Cook Inlet, Alaska (Lammers et al., 2013). Therefore, echolocation loggers, a low-cost passive acoustic technology, were used to monitor for the presence of beluga and harbor porpoise to determine the seasonal and geographic usage of the waters around two river mouths, Esker Creek and Grand Wash, in Yakutat Bay.

This technology has been used successfully for monitoring both belugas and harbor porpoises (Castellote et al., 2013; Wilson et al., 2013). These two species are readily distinguished by differences in frequency range and the center frequency at which each echolocates. Beluga produce typical delphinid broad-band echolocation clicks with center frequencies between 50 kHz and 110 kHz, while harbor porpoise produce typical phocoenid narrow-band high frequency clicks with a center frequency of 110 to 150 kHz. (Au, 1993 ; Au et al., 1999; Lammers and Castellote, 2009; Madsen et al., 2010; Castellote et al., 2013).

The goals of this study were to determine the seasonal distribution of beluga and harbor porpoise in Yakutat and whether their presence in river mouths was related to its potential prey field.

Methods

Acoustic Monitoring

Acoustic moorings were composed of an echolocation logger (C-POD, Chelonia Ltd.[3]) that monitored continuously for cetacean echolocation signals in the range 20–160 kHz and logged the date, time, and acoustic parameters of detected signals. This instrument was attached 1 m above an acoustic release (CART, ORE Edgetech) that releases the mooring from its sacrificial anchor when activated by an acoustic signal from a deck unit. The mooring configuration was linear, with a vinyl subsurface float 1 m above the C-POD and an anchor comprised of five gravel-filled bags with a total weight of about 150 lb, 3 m below the release. The estimated C-POD detection radius for harbor porpoise is 500 m (Nuuttila et al., 2013), while larger (lower frequency) species, including beluga, can be detected out to 900 m (M. Castellote[4]).

Three acoustic moorings were deployed on 20 June 2012, one in the core area of known beluga distribution in Disenchantment Bay (by Turner Glacier), and two off the mouths of Esker Creek and Grand Wash River (Fig. 1) at depths of 27–40 m. These two glacial streams are known to be visited by belugas according to traditional knowledge (Lucey et al., 2015).

Unfortunately the mooring in Disenchantment Bay was subsumed by the advancement of Turner Glacier and lost. Therefore, only data from Esker Creek and Grand Wash River are discussed here. The moorings at Esker Creek and Grand Wash River were successfuly serviced in Oct. 2012. Data were collected for the full period in Esker Creek (20 June 2012–19 Oct. 2012), but the C-POD deployed in Grand Wash River stopped logging on 5 Sept 2012. On 7 Mar. 2013, the Grand Wash River mooring was recovered and data were collected for the full period (19 Oct. 2012–7 Mar. 2013), but the mooring flotation failed in Esker Creek and the instrument could not be recovered, limiting the monitoring effort in this location to 5 months (June–Oct. 2012).

C-POD data were analyzed with custom written software from the manufacturer (CPOD.exe version 2.043, Chelonia Ltd.) using the default settings; i.e., “Hi and Mod train quality,” “all cetacean species,” unmodified “train values,” and “click filters.” All automatic detections and their click train type classification (narrow-band high frequency clicks, termed NBHF, or other cetaceans’ clicks) were manually validated to properly distinguish among echolocation detections of belugas and porpoises. Manual analysis permitted the exclusion of multiple false detections caused by noise, which were easily recognized by the broad frequency coverage and lack of coherence in temporal scale, pulse bandwidth, number of cycles, and envelope. Misclassification of porpoise echolocation as “other cetaceans” instead of NBHF was never encountered in the processed data, probably due to the considerable differences in frequency range and click bandwidth between porpoise and beluga echolocation (Au, 1993).

Beluga and porpoise detection results were converted into detection positive hours (hours with at least one echolocation click train, DPH). DPH were summed for each day to obtain DPH/day and further summed for each month to obtain DPH/month. Diel patterns were evaluated by calculating the frequency of occurrence of DPH by time of day.

Time intervals between clicks in echolocation click trains, termed inter-click intervals (ICI), have been used as a behavioral indicator in several odontocetes, including harbor porpoise (DeRuiter et al., 2009; Verfuss et al., 2009) and beluga (Roy et al., 2010; Castellote et al., 2013). Previous studies have reported the occurrence of click trains during porpoise foraging behavior, with progressively decreasing ICI’s ending in a high rate terminal “buzz”, with ICI’s close to or less than 2 ms during the final prey capture (Verboom and Kastelein, 2003; DeRuiter et al., 2009; Miller, 2010; Wisniewska et al., 2012). This same echolocation behavior has been suggested for feeding belugas (Roy et al., 2010; Castellote et al., 2013).

Several studies have shown the utility of C-POD data to identify feeding behavior based on this acoustic parameter (Castellote et al., 2013; Nuuttila et al., 2013; Pirotta et al., 2013). Therefore, minumum ICI values for each beluga and harbor porpoise click train logged by the C-POD’s in Esker Creek and Grand Wash River were analyzed to identify those containing terminal buzzes. All click trains with ICI’s between 1 and 2 ms were manually inspected to confirm the presence of a buzz in the click sequence; click trains with ICI’s between 1 and 2 ms but without a buzz were not considered feeding buzzes (Castellote et al. 2013). The percentage of feeding buzzes over the total number of click trains detected per month for each species was calculated.

Salmon Run Data

Pacific salmon, *Oncorhynchus* spp., run data were obtained from the Alaska Department of Fish and Game for Esker Creek and Grand Wash River for the 2012 season. A coho salmon, *O. kisutch*, run occurred in Esker Creek from 25 Aug. until 5 Oct., and no salmon runs were detected in Grand Wash River during the study period. To evaluate if the presence of a coho salmon run in Esker Creek had any effect on cetacean presence, DPH/day was grouped into three periods:

[3]Mention of trade names or commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.

[4]Castellote, M. Feb. 2011. Unpubl. data on file at NOAA, NMFS, Alaska Fish. Sci. Ctr., National Marine Mammal Lab., Seattle, WA 98115.

pre-salmon run (11–24 Aug.), peak-salmon run (1–28 Sept.), and post-salmon run (6–19 Oct.). Differences in the DPH/day for both beluga and harbor porpoise between the three periods were tested using Kruskal–Wallis one-way analysis of variance by ranks and post hoc paired comparisons. Median percentiles and maximum/minimum DPH by day for both beluga and harbor porpoise for each period were calculated and plotted for comparison.

To evaluate any evidence of cetacean foraging behavior on the coho salmon run in Esker Creek, presence of foraging buzzes (click trains containing a terminal buzz with ICI between 1 and 2 ms) was assessed for both beluga and harbor porpoise in the same three periods: pre-, peak-, and post-salmon run.

Fishery Trawl Data

Fish and invertebrate data were collected in 2013 using a bottom trawl at both Esker Creek and Grand Wash River (Fig. 1) as part of a separate study conducted by the City and Borough of Yakutat in cooperation with the U.S. Army Corps of Engineers. The trawl mouth was 2.6 m wide by 1.2 m deep, and it was attached to a 6.3 m long bridle of 2.1 cm braided line. The trawl had two weighted doors (33 cm by 61 cm) and was 5.2 m in total length; inside the outer skirt of 29 mm stretch mesh was a 1.7 m long cod end of 3.2 mm stretch mesh. The trawl was towed at about 2–2.5 kt for 5 min. The scope of the tow line (1.6 cm polypropylene) was 3:1.

Trawl transects were established near the Esker Creek and Grand Wash River acoustic monitoring sites. Esker Creek had three transects in 10–12 m of water, each of which was trawled once on 22 June, 24 July, and 19 Aug. 2013. Grand Wash River had six transects in 7–12 m of water, each of which was trawled once on 28 Mar., 27 May, 22 June, 24 July, and 19 Aug. 2013. GPS locations were recorded at the beginning and end of each trawl.

After trawl retrieval, the entire catch was sorted into live tanks, and individually sorted to lowest taxon. A total count was taken and a subsample of up to 50 individuals was measured to the nearest millimeter for total length. Life stage was assigned to fish in the field based on ontogenetic characteristics. Fish were considered adults when their length exceeded species-specific estimates of length-at-first-maturity (Bisby et al., 2012). Invertebrates were also individually counted and classified to the lowest possible taxon.

Catch data are expressed in relative abundance signified by catch per unit of effort (CPUE; i.e., number of fish captured per trawl) and percent frequency of occurrence (FO; i.e., number of tows in which species was captured). To identify potential prey species with similar seasonality to beluga and porpoise presence, beluga and porpoise DPH/day from 2012 were averaged for each month and qualitatively compared to CPUE/month from 2013 for the overall fish and invertebrate catch based on the assumption that monthly relative abundance and ubiquity in benthic prey did not vary greatly between 2012 and 2013.

Results

Beluga and harbor porpoise presence were acoustically monitored for 120 days in Esker Creek and 261 days in Grand Wash River. Acoustic detections of both beluga and harbor porpoise echolocation were identified in each location. Belugas were detected at both locations, but were more common at Esker Creek. Beluga presence averaged 4 h per day over the entire time period in Esker Creek with most activity occurring from June to Sept. at peaks of 14–16 DPH/day, and fewer detections later in the year (Fig. 2A). Belugas were only detected during 2 h at Grand Wash River on 12 Nov. 2012 (Fig. 2B). Harbor porpoise were present in both locations for the entire period with an average of 10 DPH/day in Esker Creek and 17 DPH/day in Grand Wash River. Porpoise presence increased in July and early Aug. in Grand Wash River and in Oct. in Esker Creek (Fig. 2).

Diel differences in acoustic activity were examined for both beluga and harbor porpoise. The distribution of DPH per time of day in Esker Creek suggests that beluga visited this area more often between 0700 to 2200 h (local Alaska time), and harbor porpoise visited between 0000 and 0700 h (Fig. 3). No diel pattern in porpoise presence was identified in Grand Wash River.

A total of at least 19 fish species and 12 invertebrate species were captured in the benthic trawls in the same regions in which C-POD's were deployed the previous year (Table 1). Unlike the salmon data, trawl data were not available for 2012 when the acoustic monitoring took place; therefore, 2013 data were only used to determine what possible prey species occur in the region at the same time of the year as beluga or harbor porpoise. Beluga DPH in Esker Creek showed a gradual decreasing pattern in monthly presence, with highest values in June and lowest in Aug. (Fig. 4A). Total CPUE/month for fish also peaked in June but did not follow a gradual decreasing pattern. For invertebrates, total CPUE/month peaked in July. There was no obvious association between beluga DPH and total prey CPUE/month.

Monthly porpoise DPH and total fish CPUE in Esker Creek had inverted patterns when compared to each other (Fig. 4A). However, total invertebrate CPUE had a similar pattern to porpoise monthly presence. In Grand Wash River, neither total fish CPUE nor invertebrate CPUE per month had any relationship to monthly porpoise DPH (Fig. 4B).

Percentages of foraging buzz detections were obtained for belugas and harbor porpoises in Esker Creek from June to Oct. 2012, and for harbor porpoises in Grand Wash River from Jan. to Mar. 2013 and from June to Dec. 2013 (Fig. 5). The highest percentage of foraging buzzes was found in Aug. and Sept. for both species in Esker Creek. This peak occurred slightly later (Sept. and Oct.) for harbor porpoises in Grand Wash River. The proportion of detected foraging buzzes was highest for harbor porpoises in Esker Creek, with an average of 3.6%

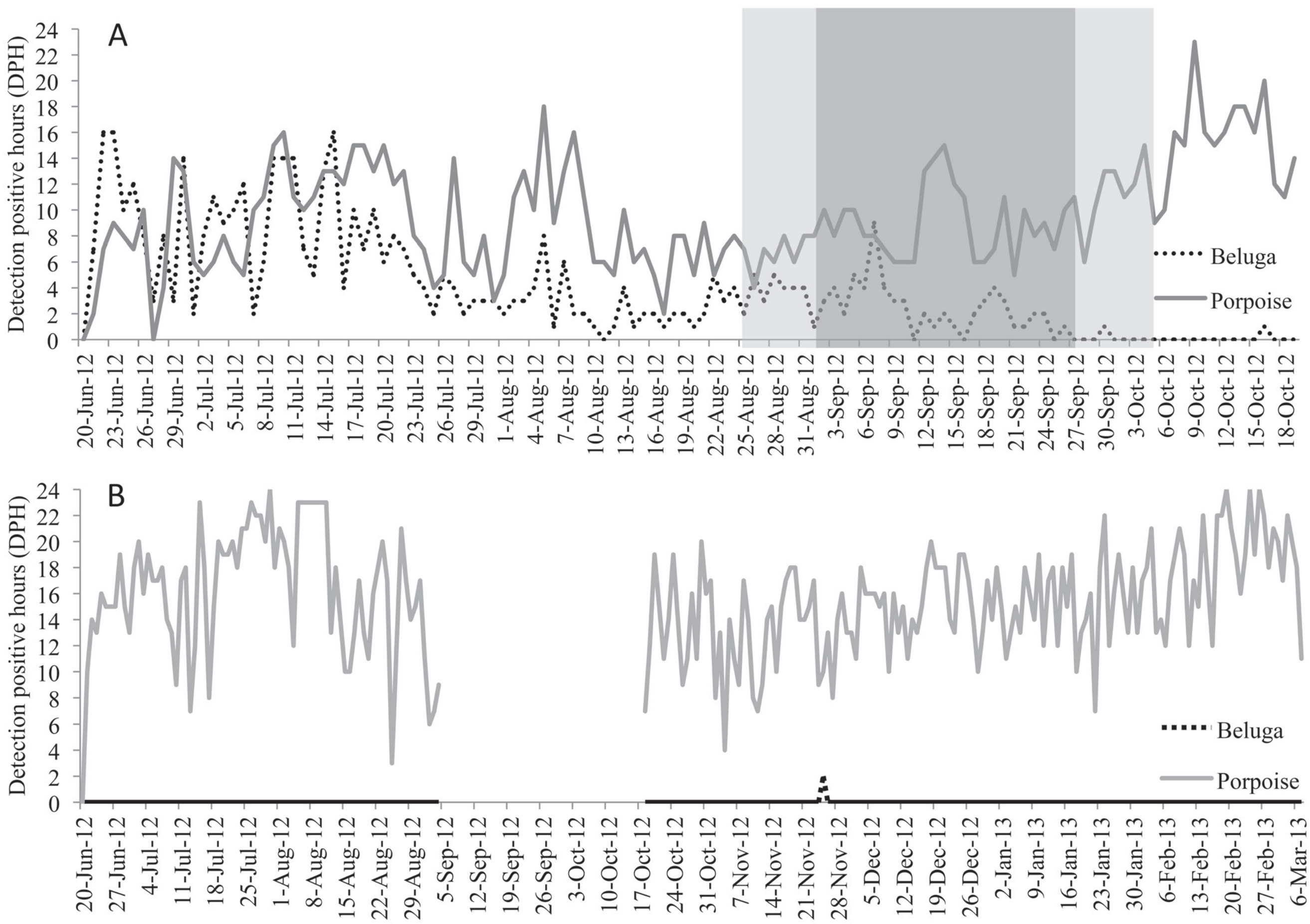

Figure 2.—Detected positive hours (DPH) per day for beluga (dashed line) and harbor porpoise (gray line) for the full deployment period in A) Esker Creek and B) Grand Wash River. In Esker Creek, the coho salmon run period is denoted by a light gray block with peak-run period by a dark gray block (note the different date scales between panels).

(max 5.6%), followed by harbor porpoises in Grand Wash River (average of 2.3%, max 2.9%), and belugas in Esker Creek (average of 0.2%, max 0.4%).

When DPH per day was grouped by salmon run period (pre-, peak-, and post-), highly significant differences were found between periods for both beluga ($H_{2,56}$=22.6, p<0.01) and harbor porpoise DPH ($H_{2,56}$=31.3, p<0.01). Post-hoc paired comparisons highlighted differences between the post-run period and the two other periods, but no differences between the pre- and peak-run periods for both beluga and harbor porpoise. There were significantly more beluga DPH during the pre- and peak- salmon run periods than during the post-run period, and significantly more porpoise DPH during the post-run period than during the pre- and peak-run periods (Fig. 6).

Only five beluga foraging buzzes were identified during the salmon run periods (pre-, peak-, and post-), all falling within the peak salmon run. No foraging buzzes were identified for harbor porpoises in any of the three salmon run periods.

Discussion

Beluga

Beluga presence in the Grand Wash River area was limited to a single detection on 25 Nov. 2012 composed of multiple click trains over 2 h. The overall CPUE of both fish and invertebrates at Grand Wash River was higher than at Esker Creek (Fig. 2); assuming 2012 and 2013 were similar in prey occurrence, a lack of beluga detections in this region was therefore not due to a lack of prey. Opportunistic sightings of belugas have rarely been reported outside Disenchantment Bay (Lucey et al., 2015), and the data presented here confirm that belugas rarely move south of the Disenchantment Bay area.

Results from the mooring in Esker Creek, at the entrance of Disenchantment Bay, showed continuous presence of belugas from June to Oct. 2012, suggesting that this area is an important part of their summer distribution, and that the limit of the core

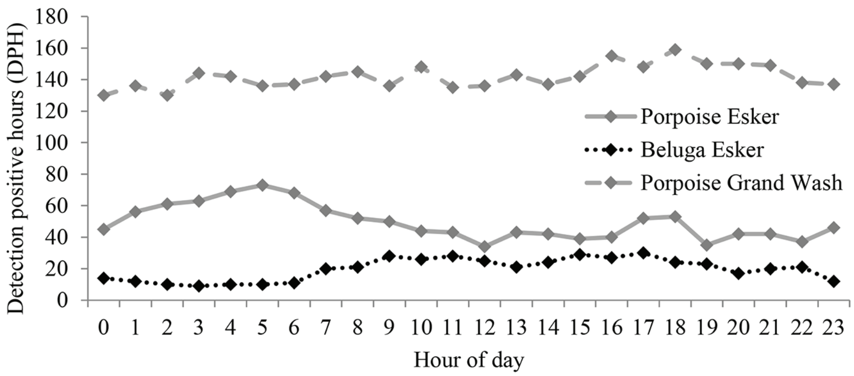

Figure 3.—Distribution of summed number of DPH for beluga and harbor porpoise by hour of day in Esker Creek and Grand Wash River.

habitat for Yakutat belugas is somewhere between the Grand Wash River and Esker Creek sites. Unfortunately the Esker Creek mooring did not surface during recovery attempts in June 2013; thus, beluga presence in this area in fall and winter is unknown.

Visual observations in Disenchantment Bay confirm that beluga movements in this area occur very close to shore (O'Corry-Crowe et al.[1]), and most opportunistic sightings are reported near shore (Lucey et al., 2015). Therefore, if belugas moved south from Esker Creek they should have been detected in the Grand Wash River area. However, the gradual decrease in beluga presence in Esker Creek from June to early Oct. and a lack of detections throughout Oct., coupled with 2 h of activity in Nov. at the Grand Wash mooring, suggests that belugas do not leave Disenchantment Bay in the fall but may move to another area north or northeast of Esker Creek. Alternatively, belugas in Disenchantment Bay could move out of the Disenchantment area in fall, following the eastern shoreline toward Yakutat. However, very few sightings have been reported on the eastern shore of Yakutat Bay (Lucey et al., 2015).

Only data from Esker Creek allowed for a comparison between beluga DPH/day and fish and invertebrate CPUE and FO. It is interesting to note that even with a higher amount of fish density and prey species composition,

Table 1.—Total catch, mean catch per unit of effort (CPUE, unit = tow), and percent frequency of occurrence (FO) of fish and invertebrate taxa captured with a bottom trawl at Esker Creek and Grand Wash River, Yakutat Bay, Alaska. Species richness values are listed in the FO total cells. A total of 35 trawls were made during June–Aug., 2013 at Esker Creek (n = 9) and Mar.–Aug., 2013 at Grand Wash River (n = 26).

			Esker Creek			Grand Wash River			Total		
Common name	Scientific name	Family	Catch	CPUE	FO	Catch	CPUE	FO	Catch	CPUE	FO
Fishes											
Longfin smelt	*Spirinchus thaleichthys*	Osmeridae				327	12.6	85	327	9.3	63
Pacific tomcod	*Microgadus proximus*	Gadidae	33	3.7	56	280	10.8	65	313	8.9	63
Capelin	*Mallotus villosus*	Osmeridae	1	0.1	11	164	6.3	38	165	4.7	31
Snake prickleback	*Lumpenus sagitta*	Stichaeidae	47	5.2	56	1	0.0	4	48	1.4	17
Sturgeon poacher	*Podothecus accipenserinus*	Agonidae	8	0.9	33	22	0.8	38	30	0.9	37
Pricklebreast poacher	*Stellerina xyosterna*	Agonidae				23	0.9	35	23	0.7	26
Pacific sandfish	*Trichodon trichodon*	Trichodontidae	3	0.3	22	11	0.4	23	14	0.4	23
Butter sole	*Isopsetta isolepis*	Pleuronectidae	1	0.1	11	10	0.4	23	11	0.3	20
Showy snailfish	*Liparis pulchellus*	Liparidae	1	0.1	11	9	0.3	12	10	0.3	11
Juvenile snailfish		Liparidae	1	0.1	11	7	0.3	15	8	0.2	14
Scalyhead sculpin	*Artedius harringtoni*	Cottidae	7	0.8	33				7	0.2	9
Starry flounder	*Platichthys stellatus*	Pleuronectidae				5	0.2	19	5	0.1	14
Sand sole	*Psettichthys melanostictus*	Pleuronectidae	1	0.1	11	3	0.1	8	4	0.1	9
Spinyhead sculpin	*Dasycottus setiger*	Psychrolutidae	4	0.4	33				4	0.1	9
Eulachon	*Thaleichthys pacificus*	Osmeridae				2	0.1	4	2	0.1	3
Fish larvae		Division Teleostei	2	0.2	11				2	0.1	3
Northern rock sole	*Lepidopsetta polyxystra*	Pleuronectidae	2	0.2	11				2	0.1	3
Buffalo sculpin	*Enophrys bison*	Cottidae	1	0.1	11				1	0.0	3
English sole	*Parophrys vetulus*	Pleuronectidae				1	0.0	4	1	0.0	3
Pacific spiny lumpsucker	*Eumicrotremus orbis*	Cyclopteridae	1	0.1	11				1	0.0	3
Prickleback larvae		Stichaeidae				1	0.0	4	1	0.0	3
Saffron cod	*Eleginus gracilis*	Gadidae				1	0.0	4	1	0.0	3
Smelt larvae		Osmeridae				1	0.0	4	1	0.0	3
			113	12.6	13	868	33.4	14	981	28.0	19
Invertebrates											
Mysid	*Neomysis* spp.	Mysidae	72	8.0	78	647	24.9	88	719	20.5	86
Crangon shrimp	*Crangon* spp.	Crangonidae	164	18.2	78	421	16.2	81	585	16.7	80
Pink shrimp	*Pandalus eous*	Pandalidae	241	26.8	56				241	6.9	14
Dungeness crab	*Cancer magister*	Cancridae	33	3.7	67	47	1.8	31	80	2.3	40
Unidentified jellyfish		Class Scyphozoa				74	2.8	31	74	2.1	23
Dock shrimp	*Pandalus danae*	Pandalidae	7	0.8	22				7	0.2	6
Unidentified copepod		Subclass Copepoda				6	0.2	4	6	0.2	3
Pacific glass shrimp	*Pasiphaea pacifica*	Pasiphaeidae	1	0.1	11	1	0.0	4	2	0.1	6
Unidentified amphipod		Order Gammeridea				2	0.1	4	2	0.1	3
Unidentified Pandalid shrimp	*Pandalus* sp.	Pandalidae				2	0.1	4	2	0.1	3
Coonstripe shrimp	*Pandalus hypsinotus*	Pandalidae	1	0.1	11				1	0.0	3
Hermit crab	*Pagurus* sp.	Paguridae				1	0.0	4	1	0.0	3
Unidentified worm		Phylum Annelida				1	0.0	4	1	0.0	3
			519	57.7	7	1,202	46.1	10	1,721	49.2	12

belugas were rarely detected off Grand Wash River. The occasional presence of transient killer whales, *Orcinus orca*, may play an important role in limiting beluga distribution in Yakutat Bay.

Belugas could be more exposed to a higher risk of predation in river mouths further west of Esker Creek. Features such as water turbidity and presence of ice might be important for beluga to avoid predation by killer whales (Castellote et al., 2013). In this regard, Esker Creek is still highly influenced by the conditions of Disenchantment Bay while Yakutat Bay conditions have a stronger influence on the Grand Wash River area.

A recent review of beluga diet in Alaska by Quakenbush et al. (2015) analyzed stomach contents from 355 belugas taken in subsistence harvests or from belugas found dead from all five recognized stocks (Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet). Diet was highly variable among stocks, highlighting the opportunistic nature of beluga feeding habits. The northernmost stocks feed mostly on Arctic cod, *Boreogadus saida;* shrimp, *Crangon* spp., *Pandalus* spp., and *Pasiphaea pacifica*; and octopus, *Benthoctopus* spp. To the south, saffron cod, *Eleginus gracilis,* replaces Arctic cod, and octopus is no longer prevalent. For the two southernmost stocks (Bristol Bay and Cook Inlet), Arctic and saffron cod are largely replaced by salmon and smelt. Shrimp are common prey for all beluga stocks in Alaska.

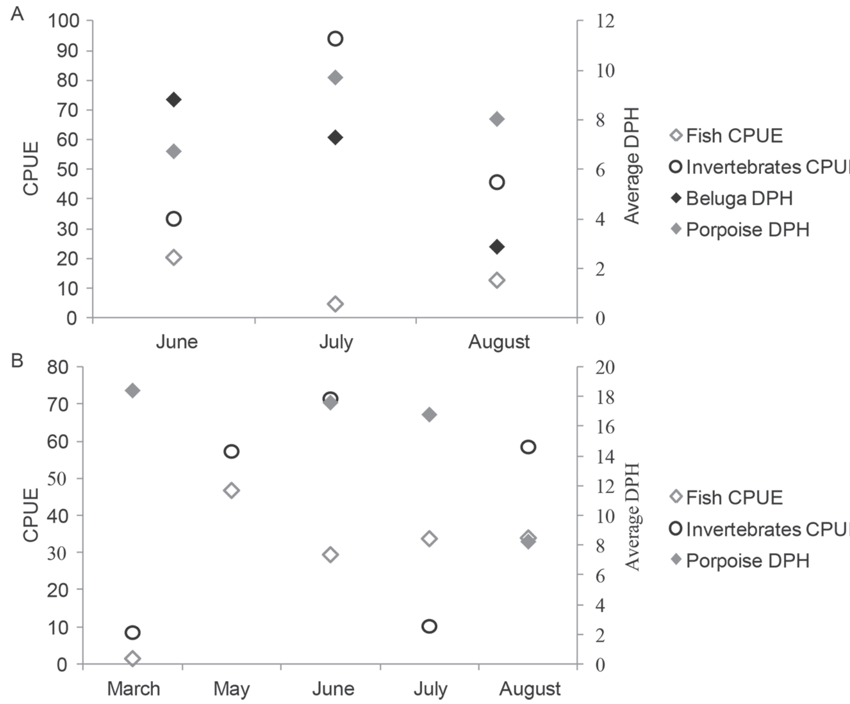

Figure 4.—A) Monthly values in Esker Creek for overall CPUE for fish and invertebrates in June–Aug. 2013 and DPH for beluga and porpoise in June–Aug. 2012. B) Monthly values in Grand Wash River for overall CPUE for fish and invertebrates in Mar.–Aug. 2013 and DPH for porpoise in Mar.–Aug. 2012.

When comparing the CPUE and FO for fish and invertebrate species obtained in the Esker Creek trawls and the prey species described in Quakenbush et al. (2015), snake prickleback, *Lumpenus sagitta*, (found in the Cook Inlet beluga diet), northern rock sole, *Lepidopsetta polyxystra*, (found in the eastern Bering Sea and Bristol Bay beluga diets), and shrimp (pink shrimp, *Pandalus eous*, and crangon shrimp, *Crangon* spp., found in all beluga stock diets), were very abundant and ubiquitous in the Esker Creek area and thus potentially eaten by beluga. Crabs (Majidae, *Hyas lyratus*, *Chionocetes bairdi*, and *Chionocetes opilio)* are part of the beluga diet in all stocks except in Kotzebue; dungeness crab, *Metacarcinus magister*, was also an important contributor to the total CPUE with high FO in Esker Creek. Shrimps and crabs were very abundant in all months sampled in both river areas, and might therefore be important prey species for Yakutat beluga. Mysids have been described as part of the beluga diet in Kotzebue and Cook Inlet (Quakenbush et al., 2015) and were among the most abundant invertebrates collected in the trawls in both locations and all months. Thus, it is possible that Yakutat belugas also feed on these crustaceans.

Pacific tomcod, *Microgadus proximus*, was a dominant species with high FO in trawls from both river areas, and although this species has not been identified as beluga prey, it is similar to Arctic and saffron cod which are important beluga prey.

The presence of coho salmon in Esker Creek influenced the number of beluga DPH/day. There were significant differences between the salmon run and the 2 weeks after the run, but not with the 2 weeks before the run. Figure 6 shows a slight increase in DPH/day during the peak salmon run, but DPH/day during the days prior to the salmon run were also high. The percentage of beluga foraging buzzes in Esker Creek was highest in Aug. and Sept., concurrent with the coho salmon run (Fig. 5), although foraging buzzes were not detected during the 2 weeks prior to the onset of the run or during the 2 weeks after the run. These results suggest that while the increase in beluga presence in Esker Creek occurred several days before the onset of the salmon run, foraging behavior did not increase until coho salmon started running upstream.

Pacific salmon behavior during their spawning migration includes periods of osmoregulation and thermoregula-

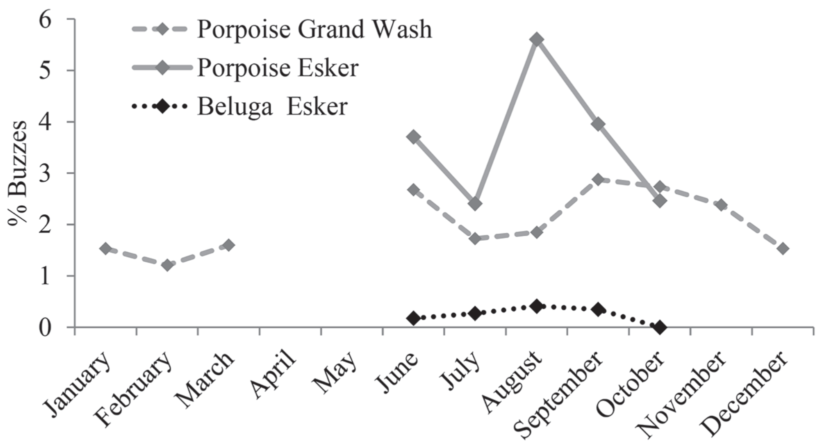

Figure 5.—Percentage of beluga and harbor porpoise foraging buzzes (click trains containing terminal buzzes with ICI between 1 and 2 ms) per month in Esker Creek and Grand Wash River.

tion prior to river entry, which might involve milling behavior for extended periods of time (Banks, 1969). River entry is also affected by flow characteristics, and salmon might start their upriver migration only at specific flow rates (Jonsson, 1991). To our knowledge, the relationship between salmon behavior during these acclimation periods and beluga foraging behavior has never been studied. These results could be indicative of beluga preying on coho salmon under specific behavioral conditions. Accessibility to coho salmon (i.e., how easy they are to capture), more than presence or density, at Esker Creek mouth might better explain these results and should be explored in future studies.

Beluga presence in Esker Creek was highest in June and July. However, the percentage of foraging buzzes was lower than during the coho salmon run in Aug. and Sept., suggesting that foraging was not the predominant behavioral state or that foraging was directed towards other types of prey, such as benthic invertebrates. If echolocation is directed towards the bottom, the chances of detecting foraging buzzes are reduced because of the high directionality of this type of acoustic signal, unless the instrument is deployed in the same plane as the targeted prey. In any case, the obtained percentages of foraging buzzes should be considered an underestimation of their real occurrence, as only a small fraction of these signals might get logged by the C-POD. Additional monitoring techniques (e.g., behavioral observations and acoustic tags) are required to help elucidate what prey and foraging behavior is preferred by beluga in Esker Creek.

Harbor Porpoise

Harbor porpoise were regularly detected in both Esker Creek and Grand Wash River mouth areas. However, the DPH was higher at Grand Wash River, both on a seasonal (Fig. 2) and daily basis (Fig. 3). Although harbor porpoise presence was continuous in both the Esker Creek and Grand Wash River areas for the entire sampling period, monthly variation in porpoise detections did not match variations in fish or invertebrate CPUE/month in either sampling location. This suggests that although both areas are frequented by porpoises, changes in fish and/or invertebrate diversity or abundance may not affect foraging resources for porpoises, reinforcing the opportunistic nature of this species' foraging behavior. These results agree with data from surveys conducted in southeastern Alaska just south of Yakutat Bay, where harbor porpoise did not show any seasonality in their occurrence, and tended to have somewhat restricted distributions (Dahlheim et al., 2009).

Some fish and invertebrate species present in the Esker Creek trawls have been identified in both river areas as potential prey items for Yakutat harbor porpoise. Mysids and crangon shrimp dominated the total CPUE in Grand Wash River, and together with pink shrimp dominated in Esker Creek. Their FO was among the highest for all three groups, together with dungeness crab. It is interesting to note that the single Yakutat porpoise stomach contents analyzed to date showed a significant amount of shrimp, primarily crangon shrimp (ADFG[5]). Other species known to be part of the porpoise diet in Alaska are pink salmon, *O. gorbuscha*; walleye pollock, *Theragra chalcogramma;* saffron cod, Pacific sand lance, *Ammodytes hexapterus*; and Pacific sandfish, *Trichodon trichodon*. Other prey species from the stomach obtained in Yakutat are surf smelt, *Hypomesus pretiosus;* eulachon, *Thaleichthys pacificus;* and Pacific herring, *Clupea pallasii* (ADFG[6]). Yet, from all these known fish prey species, only Pacific sandfish was caught in trawls in both river areas, but in very small numbers. Pacific herring, pink salmon, Pacific sand lance, and walleye pollock were not caught in trawls.

However, other fish species that have not been identified as part of the harbor porpoise diet were abundant and ubiquitous in the trawls, including Pacific tomcod (dominant in both river areas), longfin smelt, *Spirinchus thaleichthys*, and capelin (both dominant in Grand Wash River), and snake prickleback (dominant in Esker Creek). These species could well be part of the Yakutat harbor porpoise diet as similar species have been identified in harbor porpoise stomach contents. Similar to the beluga results in Esker Creek in June and July, harbor porpoise were abundant in Oct., but the percentage of foraging buzzes was

[5]ADFG. Oct. 2011. Unpub. data on file at Alaska Dep. of Fish and Game.

[6]ADFG. Oct. 2011. 11 stomachs since 2003. Unpub. data on file at Alaska Dep. of Fish and Game.

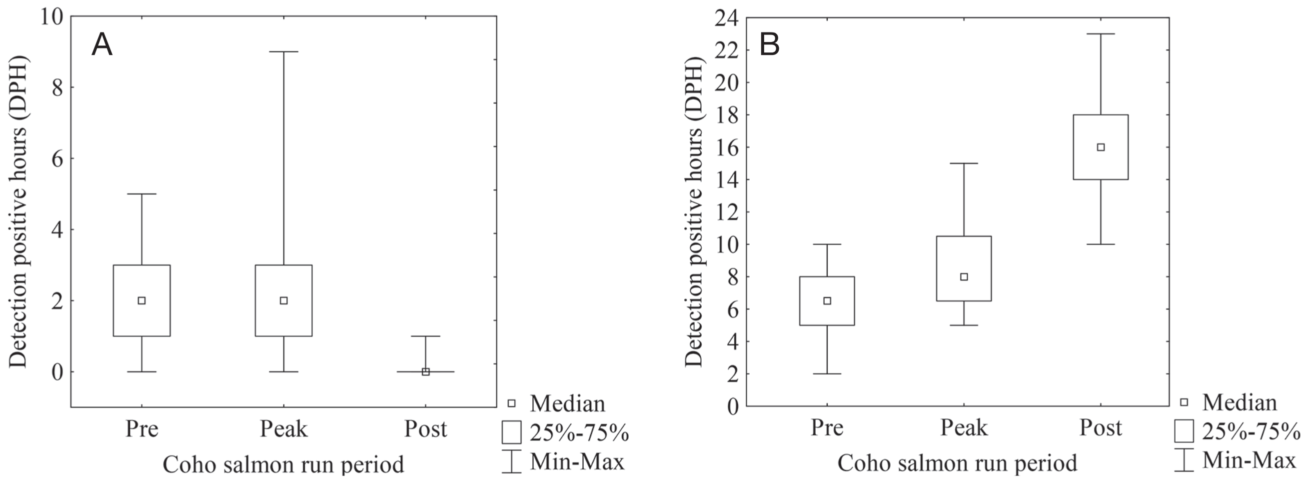

Figure 6.—Median, percentiles, and maximum/minimum DPH/day for A) beluga and B) harbor porpoise, and the salmon run periods (pre-, peak-, post-) in Esker Creek.

lower than in Aug. and Sept., which might reflect differences in foraging strategies or less foraging behavior.

Diel Patterns and Ecological Niche Separation

Diel patterns in beluga and harbor porpoise presence were only observed in Esker Creek (Fig. 3). Beluga had a preference for this site at night when harbor porpoise detections were lower. This opposite diel pattern between both species in Esker Creek and the lack of a pattern in Grand Wash River for harbor porpoise suggests the possibility of competitive overlap in prey between beluga and harbor porpoise. Harbor porpoise might actively avoid Esker Creek when beluga are present. In fact, there were very few occurrences in which both species were acoustically detected within the same hour in Esker Creek, and the few beluga detections in Grand Wash River did not coincide with harbor porpoise detections.

Both species share common prey species such as crangon shrimp, walleye pollock, saffron cod, Pacific sand lance, Pacific sandfish, surf smelt, eulachon, and Pacific herring (Quakenbush et al., 2015; ADFG[6]), several of which were trawled in the Esker Creek transects. Foraging for the same prey at different times is a successful strategy to maintain different ecological niches when two ecologically similar species coexist (Schoener, 1974; Pianka, 1976).

There was no statistical relationship between porpoise presence and coho salmon primarily because porpoise detections increased at the end of the salmon run (Fig. 6). Therefore it is not clear that coho salmon are prey for harbor porpoise in this area. While the percentage of foraging buzzes was highest in Aug. and Sept., during the coho salmon run months (Fig. 5), foraging buzzes occurred before or after the peak salmon run period, and not during the peak period, as opposed to the beluga results.

Foraging beluga may displace harbor porpoise during the peak salmon run in the Disenchantment Bay area as part of their competitive interaction. Alternatively, harbor porpoise may exploit other prey species present in Esker Creek concurrently with coho salmon.

Based on our results, high biomass values and the availability of known beluga prey in the Grand Wash River area does not seem to attract beluga. Similarly, harbor porpoise seasonality in Esker Creek and Grand Wash River areas has little relationship to the presence of known prey species. However, the presence of a coho salmon run in Esker Creek might be a significant driver for beluga and merits further consideration because this area could be of biological value for the survival of this small population of Yakutat beluga. Considering the unique conditions in which this isolated group of beluga live, understanding their habitat preferences and the potential link to prey seasonality within Disenchantment Bay should be considered a priority.

Conclusions

Passive acoustic monitoring of Yakutat beluga and harbor porpoise, although technically challenging, has proven to be feasible and effective. Lessons have been learned regarding mooring design that will improve the recovery success of future monitoring efforts. The core habitat area of Yakutat belugas is a challenging study area as it encompasses active tidewater glaciers, high sediment transport, and shifting river mouths.

Future research efforts should consider deployment of passive acoustic instrumentation in the deeper, central region of the fjord to prevent mooring interactions with ice. Data from the Turner Glacier mooring would have provided valuable information on beluga distribution changes and seasonal presence in their presumed core habitat.

Beluga likely inhabit Disenchantment Bay year-round, seldom venturing into southern areas of Yakutat Bay. Based in terms of abundance and ubiquity from trawl data collected in June–Aug. 2013 in Esker Creek and Grand Wash River, and 2012 salmon run data, coho salmon, Pacific tomcod, snake prickleback, northern rock sole, crangon shrimp, pink shrimp, mysids, and dungeness crab were identified as potential prey species for Yakutat beluga.

Both the Esker Creek and Grand Wash River areas are used by harbor porpoise, but their seasonality might not be driven solely by prey diversity or abundance. Porpoise might also prey on Pacific tomcod, longfin smelt, capelin, snake prickleback, crangon shrimp, pink shrimp, and mysids.

Some of these taxa have not yet been described as part of the beluga or harbor porpoise diet in Alaska. The results presented here support the idea that both species are highly opportunistic in their feeding habits and invertebrates might be an important part of both beluga and harbor porpoise diets in Yakutat Bay. It is strongly recommended that year-round passive acoustic monitoring be used in Yakutat Bay as this study demonstrates the applicability of using this cost-effective remote monitoring technique to better understand the distribution, seasonal presence, habitat preference, and potential diet of Yakutat beluga and harbor porpoise.

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