Interactions between beluga whales (*Delphinapterus leucas*) and boats in Knik Arm, upper Cook Inlet, Alaska:

Behavior and Bioacoustics

Contract Report

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Introduction

The beluga whale population in Cook Inlet is isolated geographically and is evidently genetically distinct from other beluga whale groups in Alaskan waters (cf. O'Corry-Crowe et al. 1997, O'Corry-Crowe et al. 2002). It has declined by about 77% since the 1970s, including a ca 50% decline from 1994 through 1998 (Hobbs et al. 2000, Angliss and Outlaw 2006) and now is estimated to number around 300 whales (NOAA 2007). Much of the decline was evidently owing to unregulated subsistence harvest though the population has not evidently begun to recover since harvest quotas were imposed in 1999. The large decline in population size overall, the apparent continued decline after hunting was limited, a consequent statistical prediction that this population (a Distinct Population Segment [DPS]; NOAA 2007) may soon go extinct, and a petition submitted to NOAA (Trustees for Alaska 2006) to list beluga whales under the Endangered Species Act (ESA; 16 U.S.C. §1531 et seq.) provoked a recent recommendation by NOAA Fisheries that the Cook Inlet DPS be listed as an endangered species under the ESA (NOAA 2007). Though extant information may not be adequate to establish critical habitat should the listing be codified, recent studies have documented seasonal patterns of distribution of belugas in Cook Inlet indicating a northward movement of whales in spring and summer into upper Cook Inlet including ingress into Knik Arm, a key area where whales may reside from July through September (e.g., LGL Alaska Research Associates 2005). The seasonal appearance of whales in the upper reaches of Cook Inlet coincides with increasing recreational and other boat activity. Moreover, concern has been articulated about the potential physical and acoustic impacts on beluga whales that transit and linger in those areas from a proposed construction of a traffic bridge across Knik Arm near Anchorage and from other commercial development in and near those waters. Though recent studies have documented the seasonal occurrence, habitat associations, and movements of beluga whales in upper Cook

Inlet (e.g., Hobbs et al. 2005, LGL Alaska Research Associates 2005, Goetz et al. 2007) and of the ambient airborne and waterborne noise that whales may be exposed to there (cf. Blackwell and Greene 2002), little is known about the responses of beluga whales to boat activity and associated noise (cf. Stewart et al. 1982, Finley et al. 1990) and its potential impacts on their use of regional habitats for feeding, calving, mating, molting, and refuge from predators.

I made behavioral and acoustic observations of beluga whales in upper Cook Inlet from 28 July through 14 September 2008, including daily shore-based observations of beluga whales in the lower Knik Arm (LKA; Cairn Point to Eagle Bay) periodic boat-based to evaluate the frequency of occurrence of interactions between beluga whales and small boats and the behavioral responses of whales.

Objectives

The objectives of the behavioral studies were to: 1) document patterns of movement, associations with particular habitats, and behavior of undisturbed beluga whales when passing through and lingering in the narrow reach of LKA; 2) document patterns of boat movement and activity in the LKA; 3) document nominal interactions between boats and beluga whales in the LKA; 4) document the behavioral responses of whales in the LKA to the physical presence and associated noise of boats operating in and near the LKA; and 5) evaluate the potential effects of boat activity, boat noise, and proposed construction and operation of bridge crossing lower Knik on the use of marine habitats in upper Cook Inlet and Knik Arm by beluga whales. The objectives of pilot supplemental acoustic studies, in collaboration with Dr. Tomonari Akamatsu (Japan National Research Institute of Fisheries Engineering), were to: 1) estimate the number of beluga whales present in observed groups from detection of their vocalizations using a stereo hydrophone array and acoustic data loggers; and 2) estimate the distance to observed beluga whales from the observation boat by triangulating to sounds produced by phonating beluga whales.

Methods

The study was conducted in lower Knik Arm (LKA; Fig. 1) from 28 July through 14 September 2008 when beluga whales were expected to most likely present there (cf. LGL Alaska Research Associates 2005). A NOAA scheduled aerial survey of the area made on 12, 13, and 14 August 2008 (Fig. 2; Sheldon et al. 2008) helped to determine the whereabouts of beluga whales in upper Cook Inlet and to structure shore-based and boat-based observation logistics. I subsequently made land-based observations daily from 0830 to from 15 August through 14 September along the east coast of LKA from Point Woronzof north to Eagle Bay; Figs. 1, 3). I also made periodic boat-based behavioral and acoustic observations between Lower Susitna River and just north of Eagle Bay (Figure 1) as weather and tidal conditions and NOAA boat availability allowed. I noted the daily presence and activities of beluga whales and boats (small recreational and commercial) during shore-based and boat-based observation using binoculars, spotting scopes and unaided eye. I used focal-animal and focal group methods (e.g., Altmann 1974) to document relative abundance, behaviors (e.g., swim direction, relative swim speed, respiration rate) and movements of beluga whales in relation to distance, movement direction, general boat speed, and type of boats operating within several kilometers of whales and observation sites.

Underwater recordings of ambient and anthropogenic noise and beluga whale vocalizations were made from a drifting or anchored NOAA RIB when possible using a single omni-directional hydrophone (cf. Stewart et al. 1982, Blackwell and Greene 2002) or a passive hydrophone array (cf. Akamatsu et al. 2008; Li et al. 2008; Turvey et al. 2007; Xiujiang et al. 2008).

*Passive towed hydrophone array studies (*with Dr. T. Akamatsu, Japan National Research Institute of Fisheries Engineering*)*

A pilot acoustic study of size and dispersion of groups of beluga whales in the upper Cook Inlet was made from 4 through 11 August using a passive, towed hydrophone array system. This method was successfully used recently during studies of baiji river dolphins and finless porpoise in the Yangtze River, China (Akamatsu et al. 2008; Li et al. 2008; Turvey et al. 2007; Xiujiang et al. 2008), under similarly turbid but more noisy and congested river conditions.

The passive, towed hydrophone array included two acoustic data loggers (i.e., A-tags; ML200-AS2, Marine Micro Technology, Saitama, Japan) for monitoring high frequency sound and a towed *Aquafeeler* (System Intech Co. Ltd. Tokyo, Japan) for monitoring low frequency sound (Figure 4). The hydrophone sensitivity of the acoustic data logger was -201 dB/V at 120 kHz (100 kHz to 160 kHz within a -5dB band). Each data logger had two hydrophones, 11 cm apart, to record the difference in arrival time of each sound pulse, with a resolution of 271 ns. The loggers stored the intensity of each received pulse every 0.5 ms in the dynamic range 136.1-160.7 dB peak to peak, referred to a 1 µPa reference (cf. Marine Technology Society Journal 39(2):3-9). Front and rear data loggers were attached to the cable at 80m and 100m behind the survey boat.

The hydrophone sensitivity of the towed *Aquafeeler* array was -190 dB/V at 1kHz (100Hz to 90kHz within -10dB band). Two hydrophones, spaced two meters apart, recorded the difference in arrival time of low frequency tonal sounds with a sampling frequency at 44.1 kHz. The towed *Aquafeeler* array had a 110 m-long cable to reduce engine noise created by the survey boat. The cable was neutrally buoyant, allowing the array to be used in the shallow upper Cook Inlet and the LKA habitats. A laptop computer (Let's note R3, Panasonic, Japan) and analogue-USB converter (DAVOX, I-O Data, Japan) was used for CD quality recording of all detected sounds. The hydrophone array was towed behind a 5 m-long NOAA RIB travelling at 18 km/hr

(Figure 5). I used a portable GPS (Garmin 76s) receiver to continuously record the boat's location.

Results and Discussion

Movements and behaviors of beluga whales

Aerial surveys on 12, 13, and 14 August estimated between 25 and 61 beluga whales in the LKA (Sheldon et al. 2011; Table 1; Fig. 2), including groups in Eagle Bay of the LKA. I began shore based observations at Six Mile Creek, LKA, on 15 August and continued them daily between 0830hrs and 2200 hours each through 14 September. I supplemented those observations with visits to other nearby sites (e.g., Point Woronzoff, Ship Creek, Cairn Point, Six Mile Tower, bluff) that allowed views of parts or most of the LKA and the Port of Anchorage basin) as possible.

During shore-based observations at Six Mile Creek, I observed small groups of beluga whales on 14 of 31 days from 15 August through 14 September 2008 (Table 2). I did not see any whales in the area after 4 September (Table 2). I monitored the transit times of those groups by noting when they were first visible downriver off Cairn Point or upriver off Six Mile Tower until they moved out of view at either the upriver or downriver sites (Table 2). Whales occurred in the surveyed area between 1000 hrs and 1700 hrs overall, but on most days between 1000 hrs and 1400 hrs (Table 2). They travelled primarily along the east side of the LKA close to the shoreline near high tide or closer to the middle of the channel as the tide quickly fell and near low tide. Thirty-six (68%) of the 53 movements of 21 groups of whales detected were up the river, with no apparent temporal pattern of either upriver or downriver movements. Virtually all of the movements of whales (89%) occurred during falling tides; whales moved upriver with the falling tide during 51% of those and downriver with the falling tides during 49% of them.

The whales were highly mobile throughout the study and generally moved continuously except when they occasionally stopped to loiter for several minutes or more near the outlets of Ship Creek, Six Mile Creek, and Eagle River, and in North Eagle Bay and off Point McKenzie. When loitering at those sites, the whales appeared to be hunting and feeding at times, particularly near high tide, and more ofen simply socializing and regrouping at most other times. They were relatively silent when travelling in the LKA (and along the coast near Point Woronzof) but, in contrast, were mostly very acoustically active at the sites where they periodically loitered (i.e., Ship Creek, Six Mile Creek, Eagle Bay, Little Susitna River). Stewart et al. (1982, 1983) noted similar relative silence of beluga whales when travelling in the Snake River in Nushagak Bay. The reason for this relative silence while travelling in aquatic habitat where turbidity is extreme and eliminates vision as a modality for navigating, maintaining social contact, and feeding is puzzling, particularly considering the absence of potential predators in the area. The typical echolocation sounds that were detected near Little Susitna River and in Eagle Bay might have been associated with feeding (as also suggested by behavioral observations made during this study and by active sonic monitoring by C. Garner, pers. comm.) and perhaps detection of conspecifics. The preponderance of non-echolocation sounds there, and near Six Mile Creek and Ship Creek, suggests that these might be important areas for whales to meet, reform groups, and realign social relationships at times after periods of transit and perhaps separation in the turbid aquatic environment of upper Cook Inlet and the LKA. In that event, an increase in boat traffic near or through those areas owing to recreation or to industrial activity and construction might disrupt these important activities for beluga whales in the upper Cook Inlet. I suggest additional studies be directed at better understanding the use of transit and loitering habitats of beluga whales in the upper Cook Inlet using behavioral and passive (and perhaps active) acoustic methods. Moreover, I suggest that those further studies attempt to continuously monitor the behaviors and movements of whales from small boats to clarify the use of the larger area when the whales are apparently resident in late summer. This approach would help clarify and better understand the importance of particular aquatic habitats to beluga whale group integrity and population vitality in the area, in contrast to brief aerial surveys which might help estimate general regional abundance but have poor resolution in addressing these issues of habitat use and importance. Aerial surveys are regularly conducted to estimate presence and abundance of beluga whales in Cook Inlet and have been recently used to identify and predict "essential summer habitat" (e.g., Goetz et al. 2012), though those surveys and the interpretations of are effectively greatly limited by a gross lack of information on what the whales were doing when detected during those very brief moments and where they had been and then went after they were detected.

The key activities of beluga whales in the AKA appeared to be: 1) calving and protection of young calves during early development; 2) foraging near creek and river entries into the LKA; and 3) milling (and perhaps resting near slack tides), socializing, reunions, and group of realignments at particular sites, particularly at Six Mile Creek, North Eagle Bay, Eagle River, Point McKenzie, and Ship Creek. I suggest further detailed studies to clarify the dynamics of these activities and the habitats used for each of them while beluga whales are present in the Upper Cook Inlet in late summer, particularly as recreational and industrial activities in the area continue to increase.

Presence and interactions of small boats and beluga whales

Small boats appeared infrequently in the LKA. Single boats were observed in the LKA on each of ten days. Beluga whales were present during those occurrences on eight of those ten days.

<u>Inflatable boats</u>:

a) one slowly pursued a group of beluga whales at a distance of around 150 to 200 m. The whales dove in response, increased speed in the same course and then reversed course and swam downriver and disappeared.

b) one was transiting at =>400 m distance. The beluga whales showed no obvious response.

Skiffs:

a) one slowly pursued a group of whales at 50-100m distance. The whales dived, increased transit speed, and maintained course.

b) two were transiting the LKA at > 400m distance; there were no obvious responses by the beluga whales.

c) one transited the LKA about 200m from a group of beluga whales. The whales changed course and dived.

Hovercraft: Two transited the LKA at about 200m distance. The whales dived and continued on course.

*Passive towed hydrophone array pilot studies (*with Dr. T. Akamatsu, Japan National Research Institute of Fisheries Engineering*)*

Sounds from phonating beluga whales were recorded on 7, 8 and 11 August 2008 in Eagle Bay, near Six Mile Creek, and near the outlet of the Little Susitna River (Figure 6). The recordings on 8 August from 1138hr to 1200hr had a fine signal to noise ratio and were consequently closely examined. A variety of anthropogenic and other noise was also detected during those surveys, including construction noise at the Port of Anchorage, unidentified pulsed sounds, dredging noise, and fast travelling small boats (Fig. 7).

Variations in beluga whale phonations: A variety of sounds were recorded from phonating beluga whales including low frequency whistles, high frequency sonar signals (Fig. 8) and buzz-like sounds characterized by broad band spectrum caused by very short inter-click intervals or very short periods of sound repetition (Figure 8). Lower frequency components of ultrasonic sonar signals were also recorded by the low frequency element of the hydrophone array (Figure 8).

Number of animals: Biosonar signals from beluga whales were identified by their regular inter-click intervals (Fig. 8). The difference between arrival of those sounds at each of the two data loggers which corresponded to the bearing angle of porpoise vocalizations always changed from positive to negative (Fig. 9), indicating that the whales were passing by the boat from bow to stern (or the survey boat was passing by them faster than the whales were moving). The time when a whale was detected was defined as the point at which the difference between arrival of the signals at each data logger was nearly zero (i.e., the *zero crossing point*). At that moment, the animal was perpendicular to the data logger and parallel to the survey boat course. When two or more whales could be discriminated in a group, the time at each *zero crossing point* was used for the analysis and the data obtained by the distal A-tag was used for the boat. If sound was detected away from the *zero crossing point* and the animal was not phonating near the data logger, the time of the sonar signal detection was used. To avoid double counting for short traces that were temporally close, it was conservatively estimated that traces within 3 min of each other were from the same whale. The 3 minute duration corresponds to 900 m distance that the survey boat travelled during that time (see Akamatsu et al. 2008 for the detailed methods).

Distance calculation: The distance from the survey boat to each phonating beluga whale was calculated as:

$$c*td=L*\sin(a) \qquad (1)$$

where,

L: the baseline of two hydrophone of the acoustic data logger (A-tag).

td: time arrival difference of sound between two hydrophones

a: relative angle of incoming sound

and

c=1500m/s,

a=angle (0=90degree perpendicular to the survey boat movement)

Considering that the positioning of the acoustic data loggers has a baseline length (i.e., serial number 6A003 the back of the cable, serial number 6A004 positioned 20 m ahead of the back logger).

Then the differential of eq.1 is:

$$d(td)/dt=w*L*\cos(a)/c \qquad (2)$$

$$w=da/dt$$

Consequently, the distance of the survey boat to the phonating beluga whale is:

$$r=v/w=v*L*\cos(a)/(c*d(td)dt) \qquad (3)$$

where v=18km/h(boat speed)=5m/s

Assuming a=0 when the animal was perpendicular to the hydrophone array (i.e., *zero crossing point*), cos(a)=1.

$$r=v*L/c * 1/d(td)dt \qquad (4)$$

then distance to the whales can be simply expressed as

r=A/(change of bearing angle count stored in the data logger per second) (5)

where A=v*L/c, v=5m/s, L=185mm(front logger), 135(back logger), c:sound speed

The distance to each phonating whale was calculated using boat speed and the change of bearing angle observed by a single stereo acoustic data logger (Table 3). The maximum calculated distance was 471 m, greater than that for finless porpoise (Akamatsu et al. 2008). This suggests that the source levels of the clicks of beluga whales is much greater that those of finless porpoises. Consequently, the greater detection range helps to cover a larger area and consequently potentially allow a better estimate of group size of beluga whales.

However, the group size detected in upper Cook Inlet by the passive array monitoring was only two at most, meaning perhaps that phonating whales might have been too close to each other for a couple of minutes, and consequently limited the ability of the system to discriminate a short baseline system. Otherwise, the resolution was sufficient to discriminate each sound source if the whales were about at least a body length apart, which suggests that individuals of a group were more scattered within the focal area.

These pilot studies demonstrated that a towed passive hydrophone array might be a useful tool to estimate the number of beluga whales in the upper Cook Inlet and the LKA, to perhaps calibrate aerial surveys of abundance of whales, and perhaps to attribute particular types of social communication sounds to interacting whales, helping to understand their function.

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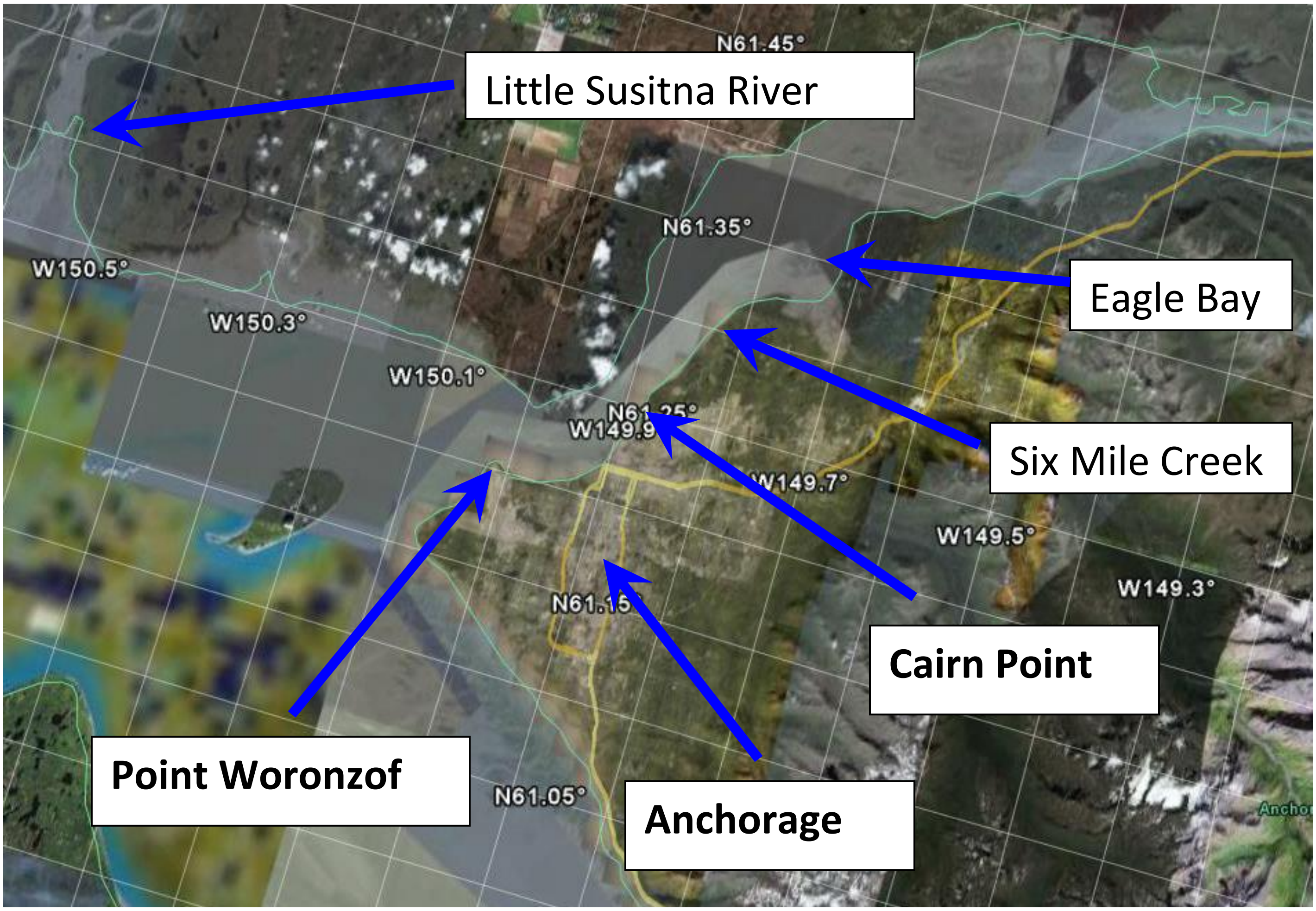

Figure 1. Upper Cook Inlet and lower Knik Arm.

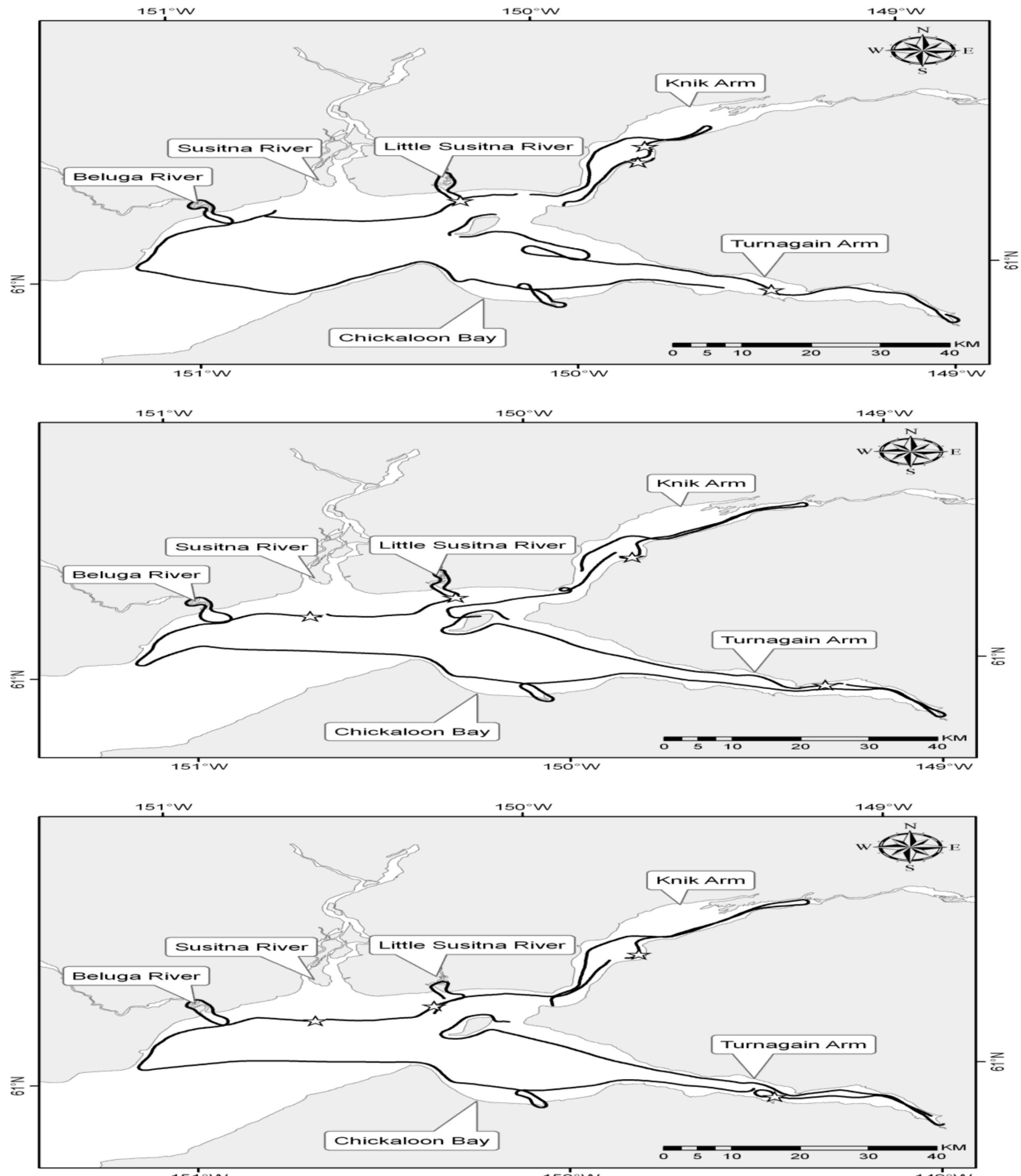

Figure 2. Aerial survey tracks and locations of beluga whales (stars) in upper Cook Inlet on 12 (top), 13 (middle), and 14 (bottom) August 2008 (from Sheldon et al. 2008).

Figure 3. Cook Inlet and the Kenai Peninsula (upper left), upper Cook Inlet and Knik Arm (lower left) and the lower Knik Arm (right) where land-based and boat-based observations (noted as circled areas) were made.

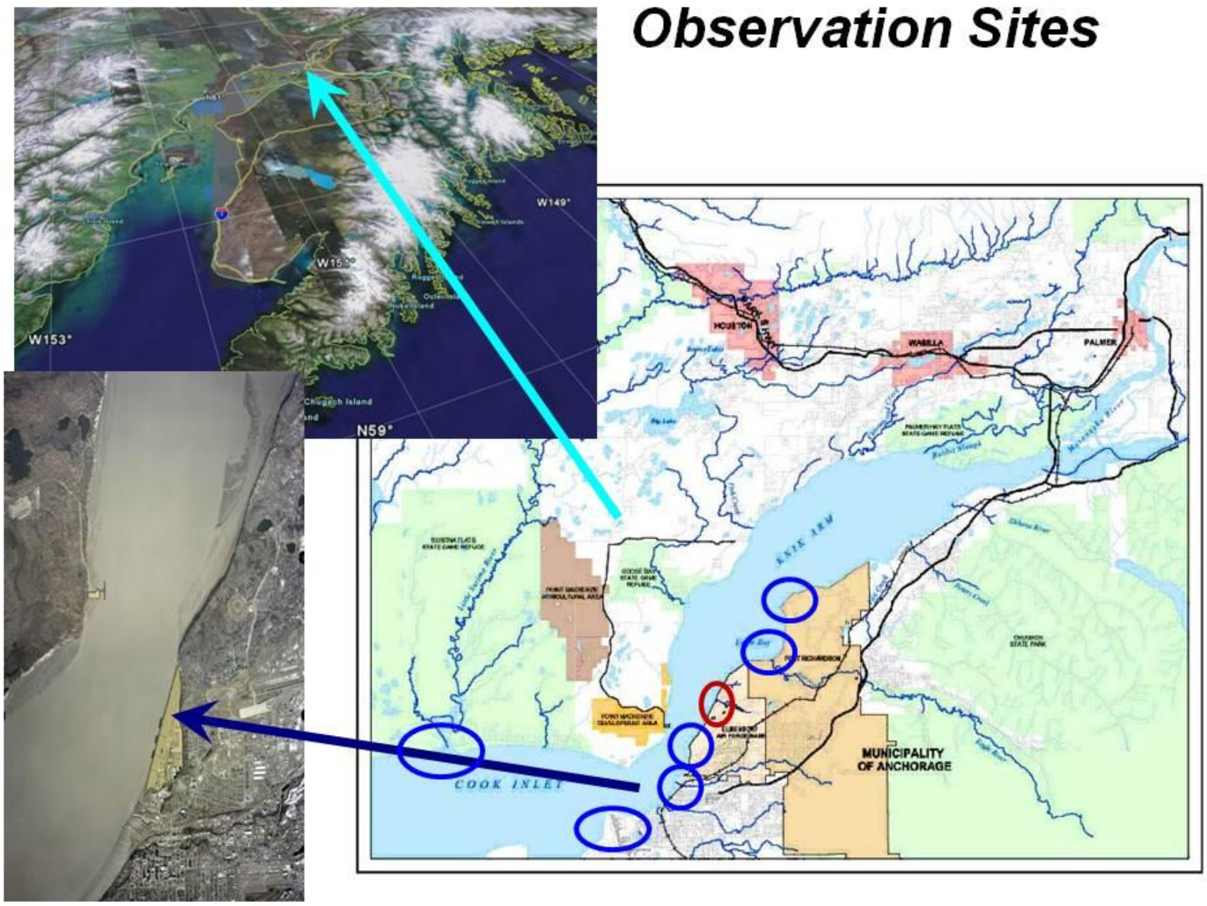

Figure 4. Towed *Aquafeeler* (black tube with yellow cable) hydrophone array and two acoustic data loggers (two bars at the center of the black tube circle). The towed *Aquafeeler* had a 110m-long cable to avoid contamination from motor noise of the survey boat. Low frequency sound was recorded directly to a laptop computer. High frequency pulsed events were stored in the acoustic data loggers which had 128 MB flash memory and internal battery. The acoustic data loggers were stand-alone systems that did not need signal conducting cables. Instead, they were attached directly to the *Aquafeeler* cable, 20 m apart from each other.

Figure 5. Passive *Aquafeeler* hydrophone array under tow in the LKA, Alaska, August 2008.

Figure 6. Tracks of NOAA RIB during acoustic surveys of beluga whales using a passive towed hydrophone array system in upper Cook Inlet in August 2008.

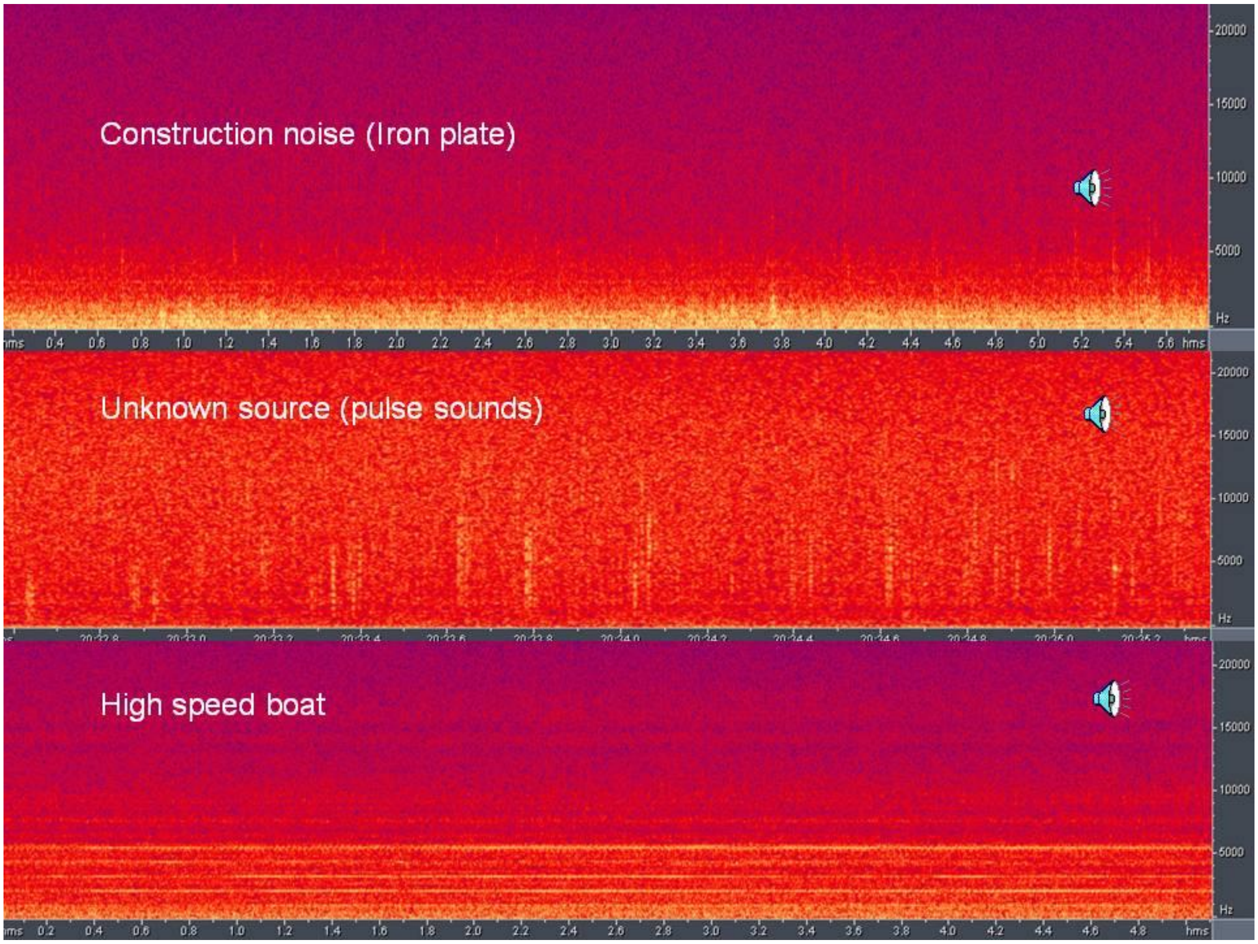

Figure 7. Anthropogenic and other noise detected during acoustic surveys for beluga whales using a passive towed hydrophone array.

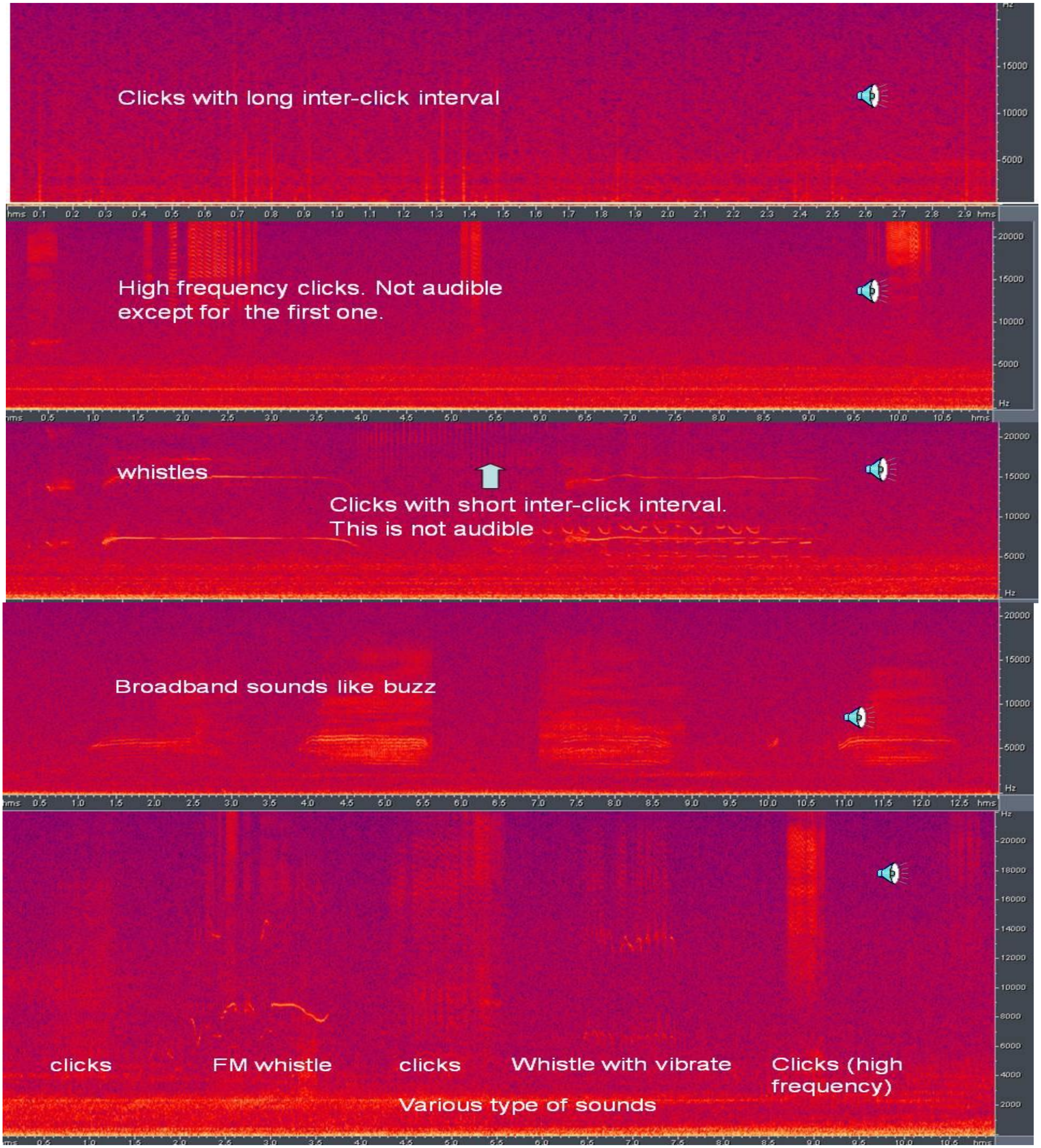

Figure 8. Variation in phonations of beluga whales recorded in upper Cook Inlet, August 2008.

Figure 9. Characteristics of beluga whale phonation sounds detected by the towed passive hydrophone array system in upper Cook Inlet in August 2008.

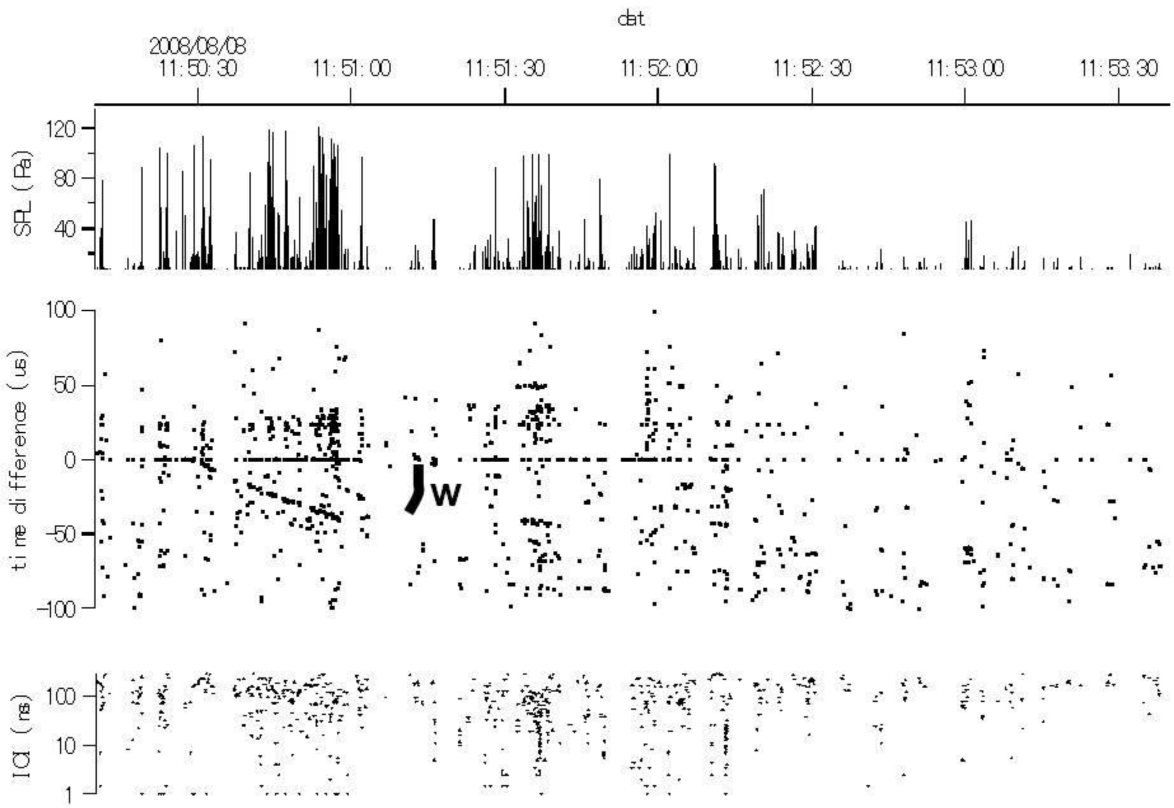

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Table 1. Estimates of beluga whale abundance made during aerial surveys of Cook Inlet in August 2008 (from Sheldon et al. 2008).

Location	8/12	8/13	8/14
Turnagain Arm	29	21	26
Chickaloon Bay/ Point Possession	0	0	0
Point Possession to Beluga River	0	0	0
Beluga River	0	0	0
Ivan River	0	0	0
Susitna River	0	69	80
Little Susitna River	55	26	38
Knik Arm	25	61	50
Fire Island	0	0	0
Totals	109	177	194

Table 2. Presence and movements of beluga whales past primary observation site at Six Mile Creek between 0830 and 2000 hrs (time of transit was determined as appearance of whales between Cairn Point and Six Mile Tower).

Date	**Time of Transit**	**Direction of Travel**	**Tide state**
15 August	1000-1310 hrs	upriver	Falling, near slack low
16 August	1100-1400 hrs	upriver	Falling, near slack low
17 August	1030-1045 hrs	downriver	Falling
18 August	1130-1220 hrs 1230 – 1400 hrs	downriver upriver	Falling Falling, near slack low
19 August	1300-1330 hrs 1320-1330 hrs 1330-1450 hrs	Upriver Downriver Upriver, downriver, upriver	Falling Falling Falling, near slack low
20 August	1000-1035 hrs 1300-1400 hrs 1500-1530 hrs	Upriver Downriver Upriver, downriver, upriver & downriver	Slack high tide Falling Falling
21 August	No whales		
22 August	1340-1553hrs 1600 – 1725 hrs	Downriver Downriver, upriver, downriver	Falling, near slack Falling, near slack
23 August	No whales		
24 August	No whales		
25 August	No whales		
26 August	No whales		
27 August	1020-1045 hrs 1425 – 1600 hrs	Downriver, upriver Upriver	Slack, rising Rising, near high slack
28 August	1000-1135	Downriver, upriver, downriver; feeding and socializing	Falling, near slack low
29 August	1120-1300 hrs	Upriver	Falling, slack low
30 August	1055-1130 hrs 1145-1250 hrs	Upriver Upriver	Falling Falling, near slack
31 August	1100-1130 hrs 1215-1330 hrs	Upriver Upriver	Falling Falling
1 September	No whales		
2 September	1020-1100 hrs 1620-1715 hrs	Downriver (fast) Upriver	Falling Rising
3 September	1555 – 1620 hrs	Upriver	Rising
4 September	No whales		
5 September	1345-1530 hrs	Upriver	Falling
6 September	No whales		
7 September	No whales		
8 September	No whales		
9 September	No whales		
10 September	No whales		
11 September	No whales		
12 September	No whales		
13 September	No whales		
14 September	No whales		

Table 3. Calculated distance to the sound source using equation (5).The maximum distance was 471 m. NSI means that there was not sufficient information to calculate distance perhaps, e.g., because of too brief phonation durations. The group size was estimated using the number of traces of bearing angle changes.

Detection Time	Group Size	Calculated Distance (m)
11:38:26	1	288
11:41:00	2	164
11:42:03	1	NSI
11:42:25	1	376
11:44:00	1	471
11:44:25	1	329
11:45:43	1	133
11:47:06	1	105
11:47:27	1	92.1
11:47:56	1	177
11:48:16	1	102
11:49:05	1	NSI
11:50:37	1	400
11:50:55	1	NSI
11:51:35	1	NSI
11:52:05	1	NSI