ABUNDANCE, HABITAT USE AND BEHAVIOR OF BELUGA WHALES IN YAKUTAT BAY, MAY 2008; AS REVEALED BY PASSIVE ACOUSTIC MONITORING, VISUAL OBSERVATIONS AND PHOTO-ID.

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Final Report

to

Protected Resources Division
Alaska Regional Office
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
Juneau, Alaska

With assistance from:

Rod Hobbs, Sam Williams, Jeremiah Pavlik, Les Hartley, Kaja Brix,
Barbara Mahoney, Doug DeMaster and Shannon Atkinson

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This report summarizes results from a successful deployment of acoustic loggers to record beluga whale vocalizations during a ten day period of intensive visual observations of this species in Yakutat Bay, Alaska in May 2008. The combined effort is unique in terms of the methodology and results, providing the first assessment of beluga vocalizations using TPOD acoustic loggers as well as the first detailed assessment of behavior (i.e., ethogram) of beluga whales, to our knowledge, in the North Pacific. The results and discussion of the passive acoustic monitoring (T-PODs only) are presented in Section I, while the findings and interpretation of the visual observations, which included the establishment of a photo-ID catalogue, are reported in Section II. The study also included the successful continuation of aerial surveys, tissue biopsy sampling and genetic analyses, and the deployment of two other hydrophones (all to be reported on separately).

The field study was conducted from May 10 – May 19, and involved: (A) the deployment of four T-PODs (Timing POrpoise Detector, version 5, Chelonia Ltd., U.K.), one EAR (Ecologic Acoustic Recorder, OSI Hawaii), and one hand-held hydrophone at a number of locations in Upper Disenchantment Bay; (B) simultaneous visual observations of whale presence, abundance, group composition and behavior; (C) high resolution digital photo-ID of whales; (D) documentation of daily environmental conditions (i.e. weather, ice cover); (E) tissue sample collection via remote biopsy; and (F) aerial surveys.

One or more T-PODs were deployed continuously for over 214 hours, primarily in a small embayment between the Hubbard Glacier and the Haenke (i.e., Black)and Turner Glaciers, known as Beluga Bay. The T-PODs logged 167,579 clicks classified with a high probability as beluga whale clicks, and the study determined the detection range for belugas for these devices. Belugas were detected on all days, and echolocation activity varied with tide and time of day and differed between locations. Differences in the timing of logged clicks among T-POD locations suggested movement between areas. This was confirmed by the visual observations. Changes in click number and click rate suggested changes in whale behavior.

Visual observations comprised over 40 hours of discontinuous directed effort as well as opportunistic sightings throughout the field study. Observational data documented whales every day and a week relationship between time spent on observation and the sighting frequency and number of whales. The majority of sightings were in Beluga Bay, but whales could be visually tracked near shore between this high use area and two other areas, Haenke Stream and Turner Glacier. The maximum number of whales observed was 10 individuals, including 2 young calves, several larger grays and three large, white adults. Observed behaviors were provisionally classified into 6 categories, with traveling and feeding the most common. Beluga Bay appears to be an important location for socializing, resting and possibly molting as well as foraging.

A photo-catalogue was initiated and successfully re-captured individuals over the course of the 10 day study. At least one individual had scars consistent with a killer whale attack, raising the possibility that predation pressure is a factor in the low abundance and restricted (known) summer range of these whales. Both avoidance and investigatory behavior was documented during the deployment and recovery of acoustic devices. Behaviors that may indicate disturbance, however, (i.e., absence of whales, low echolocation activity) tended to be temporary in nature.

This study demonstrated that acoustic loggers can be deployed to monitor beluga whale behavior and habitat use in relation to environmental conditions. The findings reported here are encouraging but preliminary, and further studies combining passive acoustic monitoring with visual observations are required. Linking beluga whale vocalizations to specific behaviors is central to any acoustic monitoring of this species. Establishing the function of specific vocalizations, and the context in which they are made will not only allow remote, acoustic documentation of beluga whale ecology but will facilitate quantification of whale presence/absence and potentially whale abundance. This is the ultimate goal of the current study, the long-term monitoring of beluga whales in Yakutat Bay and possibly other areas including Icy Bay throughout the year. Acoustic monitoring is also the goal of a number of new studies on belugas in Cook Inlet (R.J. Small, pers. comm.). We believe that the Yakutat study provides a unique opportunity to conduct the necessary baseline research on whale presence, abundance, behavior and proximity in relation to acoustic detection.

Another component of the comprehensive monitoring of the Yakutat belugas should be the tracking of whales via telemetry. The field study's current foot print is limited in both space and time. Apart from a few weeks each summer, our knowledge of the distribution, ecology and habitat use of Yakutat beluga whales is limited. Satellite-linked telemetry is the only way to gather the much needed information on whale movements, including whether the whales leave Yakutat Bay, and if so, where they go. Our research team is currently involved in developing projectile tags that eliminate the need to capture beluga whales in order to attach satellite-linked tags to free swimming whales.

The visual observations in concert with acoustic monitoring offers a unique opportunity to ground truth telemetry data in terms of known whale presence and behavior, something that has yet to be done for this species. As well as the large spatial scale - low-resolution data currently provided by most *Argos* linked tags, high-resolution location data will be required to identify key habitats including seasonal food sources such as fish runs at individual rivers.

The methods developed in this study will also facilitate the study of social organization, mating systems and predation in beluga whales, three fundamental aspects of this species' life history and population ecology yet to be studied in the North Pacific. Visual observations of focal animals in concert with photo-ID, acoustic monitoring, genetic mark-recapture and kinship analysis, and ultimately telemetry will facilitate investigations of beluga whale interactions and association patterns, group structure and genetic relationships. The expansion of the current study to include other species, including killer whales, is scientifically relevant and logistically feasible and has important management implications for beluga whales in Yakutat Bay and the entire Gulf of Alaska.

Section I: **Passive acoustic monitoring of beluga whales in Disenchantment Bay, Alaska.**

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ABSTRACT

Beluga whales (*Delphinapterus leucas*) can be difficult animals to study. Passive acoustic monitoring has become an effective method to study other odontocetes but to date there have been few efforts to test these techniques on beluga whales, despite their reputation as acoustically active cetaceans. Acoustic loggers (T-POD) developed for harbor porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus*) echolocation detection were tested with captive belugas. Results from captive belugas at at L'Oceanografic of Valencia during 2006 and free-ranging belugas in Svalbard, Norway in 2007 suggested that acoustic loggers have the potential to detect and therefore allow monitoring of beluga whales in their habitat. During spring 2008, four T-PODs were deployed concurrently with acoustic recordings and visual observations in Yakutat Bay as a pilot study to evaluate the efficacy of this acoustic monitoring method. The T-PODs, deployed at five locations over a ten-day period, detected 167,579 clicks from beluga echolocation activity. Beluga whales were present every day during the 10-day sampling period in the study area, showing preference for the inner bay at high tides and outer bay at low tides (Pearson's correlation <0.01*)*. Daylight cycle did not show any apparent effect in whale presence or habitat use. Beluga click rate varied with time of the day and area, suggesting different behavioral states such as feeding for fast click trains or resting for slow click trains. Visual and acoustic recorded data confirmed these interpretations, therefore passive acoustic monitoring using acoustic loggers proves to be an effective method to monitor beluga whales.

1. INTRODUCTION

Since 2002, field projects to study a small group of beluga whales (*Delphinapterus leucas*) have taken place in Yakutat Bay, Alaska. These focused primarily on shore-, boat- and aerial-based sighting surveys as well as genetic sampling. These studies, when combined with local sightings and Traditional Ecological Knowledge (TEK) of beluga whales in Yakutat Bay determined that the Yakutat belugas have been seen in the bay in all months of the year except December and January and are genetically distinct from the Cook Inlet population (O'Corry-Crowe et al. 2006). In 2008, an acoustics component was added to the established field protocol in order to assess the utility of acoustic monitoring of beluga whales in Yakutat Bay.

Acoustic loggers developed for harbour porpoise (*Phocoena phocoena*) detection (T-POD; Timing POrpoise Detector, Chelonia Ltd., U.K.) have been tested at L'Oceanogràfic of Valencia to explore the potential of detecting beluga whales during 2004-2006, modifying the detection and classification algorithms based on the results of an acoustic behaviour study with captive beluga whales (Castellote & Fossa, 2006; Mooney *et al.* 2008; Lammers & Castellote, 2008). Results from the captive study were tested in Svalbard, Norway, during spring 2007 with deployments of 2 T-PODs in Krossfjorden, near Ny-Ålesund scientific station area, obtaining detections from free ranging whales (Leeney *et al*. 2007; Leeney *et al.* 2008). Based on the outcome of the captive (2004-2006) and field (2007) work, we were interested in further testing T-PODs in different arctic regions in order to confirm the validity of this methodology and detect beluga whales to obtain presence as well as behavioral data from different populations.

Four T-PODs (version 5) and one EAR (Ecologic Acoustic Recorder, OSI,Hawaii) were deployed for 10 days in May 2008 in the head region of Disenchantment bay, Alaska (latitude N60º, longitude W139º) in collaboration with Harbor Branch Oceanographic Institution, Yakutat Salmon Board and the Applied Physics Lab of the University of Washington. Acoustic detection results from the T-PODs are presented in this report.

2. METHODS

Four T-PODs (version 5) were deployed at different locations at the head of Disenchantment Bay (Beluga Bay) for a period of 10 days (5/10/08 until 5/20/08) for beluga whale detection with simultaneous visual observation effort (Figure 1).

T-POD algorithms were set to detect beluga whale clicks at two different bands, based on results of click energy distribution measured in captivity, in the range 30 -113 kHz at a rate of 4.65 seconds per scan in a continuous duty cycle. Detected clicks of greater than 600 µs duration were rejected. Click duration and time were logged in the T-POD memory until download after recovery of the unit.

Click files were processed using provided software to identify click train sequences in which the variation between successive intervals is constrained to a 38% increase or decrease in the time interval between successive clicks. Random clicks generating a train by chance are rejected using a probability model that calculates the probability of the train arising by chance if clicks were arriving at the prevailing rate from non-echolocating sources. Only identified click trains coming from a true train source (cetacean) were used for the analysis.

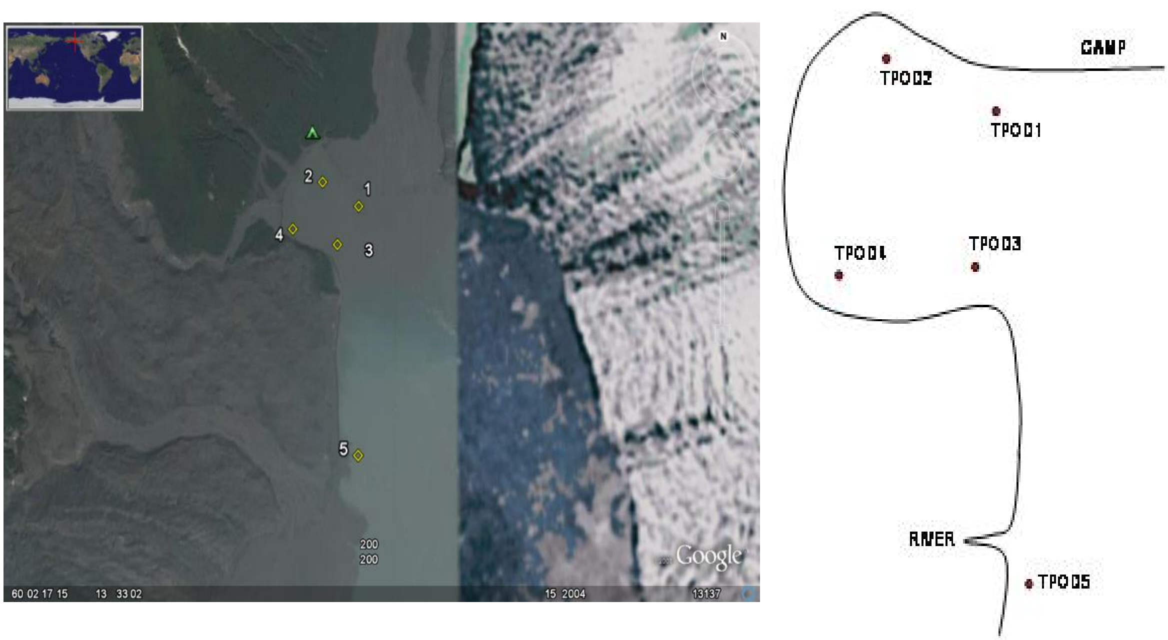

Figure 1: Google Earth map of the location and schematic representation of Beluga Bay showing T-POD deployment positions and camp site.

T-PODs were deployed during different times and positions based on visual observations of beluga whale use of the bay. Table 1 shows the sampling periods for all four T-PODs and total sampling time for the field work.

Position	10/05/08	11/05/08	12/05/08	13/05/08	14/05/08	15/05/08	16/05/08	17/05/08	18/05/08	19/05/08	20/05/08	**Total sampling time**
TPOD1	Dep. 14:24									Ret. 14:27		**8d 4h 7m**
TPOD2	Dep. 15:53		Ret. 17:48									**2d 0h 12m**
TPOD3		Dep. 15:50								Ret. 8:30		**7d13h 28m**
TPOD4					Dep. 10:57					Ret. 11:59		**4d 10h 44m**
TPOD5							Dep. 19:46				Ret. 9:15	**3d 2h 25m**

Table 1: Sampling periods for T-PODs in all five deployment positions and total sampling time. Deployment and retrieval times are marked in each case.

Because of the presence of dense glacial ice and strong tidal currents, several mooring line designs were tested. The standard deployment method with a moored line and surface buoy, as seen in Figure 2a, was problematic because the instrument was dragged about by moving ice. To try to limit this drag, we used local fishing methods to design a mooring system able that did not require a surface buoy in the water but allowing the T-POD location to be marked from the nearest shore point with a sinking line and a land marker (orange buoy). The marker line also acted as a link to the T-POD to facilitate recovery of the unit. Picture 2b shows the final mooring design. Picture 2c shows the land mark and a beluga passing by the deployed T-POD in position 4.

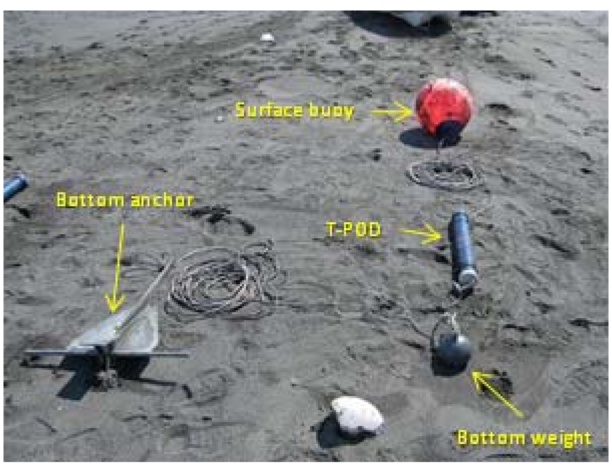

Figure 2a: Standard mooring line with surface buoy. **Figure 2b**: Mooring without surface buoy.

Figure 2c: Land mark and a beluga passing by the deployed T-POD in position 4

3. RESULTS

3.1 Beluga whale presence

There was a total of 59,171,083 clicks logged during the 10 day sampling period of which 167,579 (0.28 %) were classified with high probability of being beluga whale clicks, all others were rejected for the analysis. Since deployment periods were different for each position, we calculated the number of detected beluga clicks per hour for the deployment time for each position in order to compare beluga presence between positions. Figure 3 shows the differences between positions for detected clicks per hour.

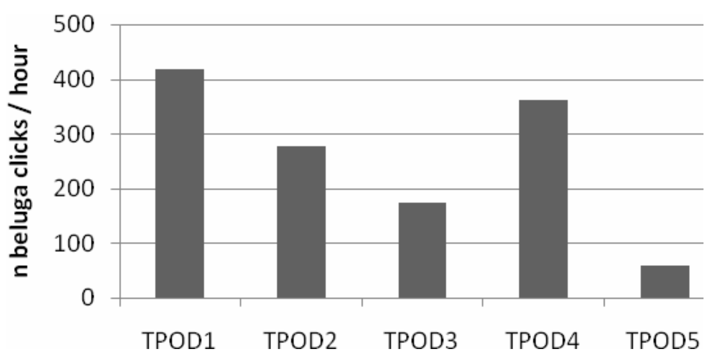

Figure 3: Beluga whale clicks per hour detected in each position for the different sample periods.

The number of detected beluga whale echolocation clicks was calculated for every T-POD position and day of deployment. Figure 4 shows the positions, sampling periods as well as the number of detected clicks from beluga whale echolocation activity for each position. Note that the day of deployment as well as the day of recovery do not cover the 24-hour period, see table 1 for sample periods.

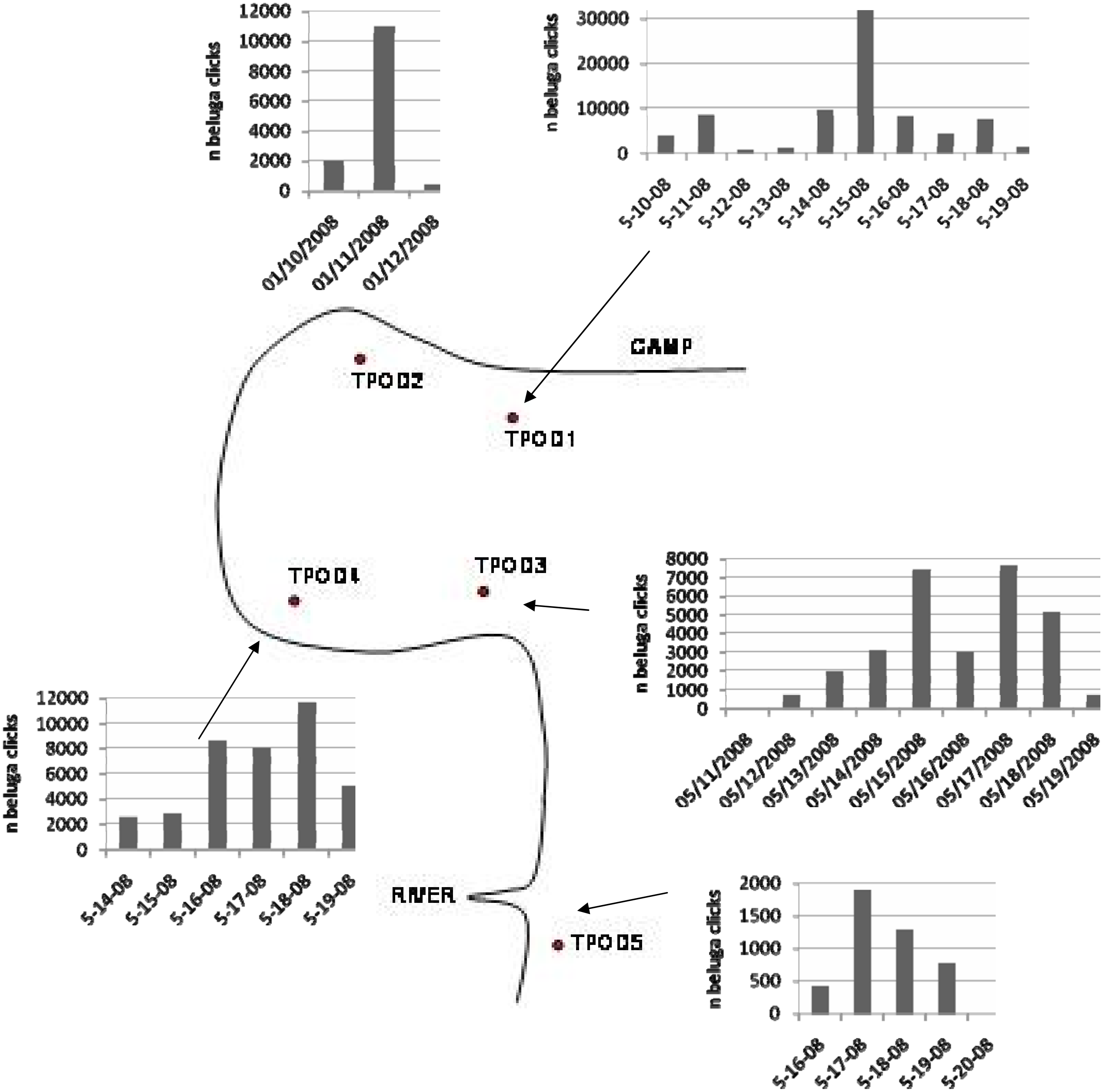

Figure 3: Schematic map of the field study area, positions of T-POD deployments, sampling periods and number of clicks detected per day for each T-POD position.

3.2 Beluga whale diel patterns

Cumulative averages of click detections for the 24-hour period for the whole sampling period was calculated for each position. As a result, beluga whale diel pattern for each position is obtained and presented in figure 5. Note that Y axis has different scales.

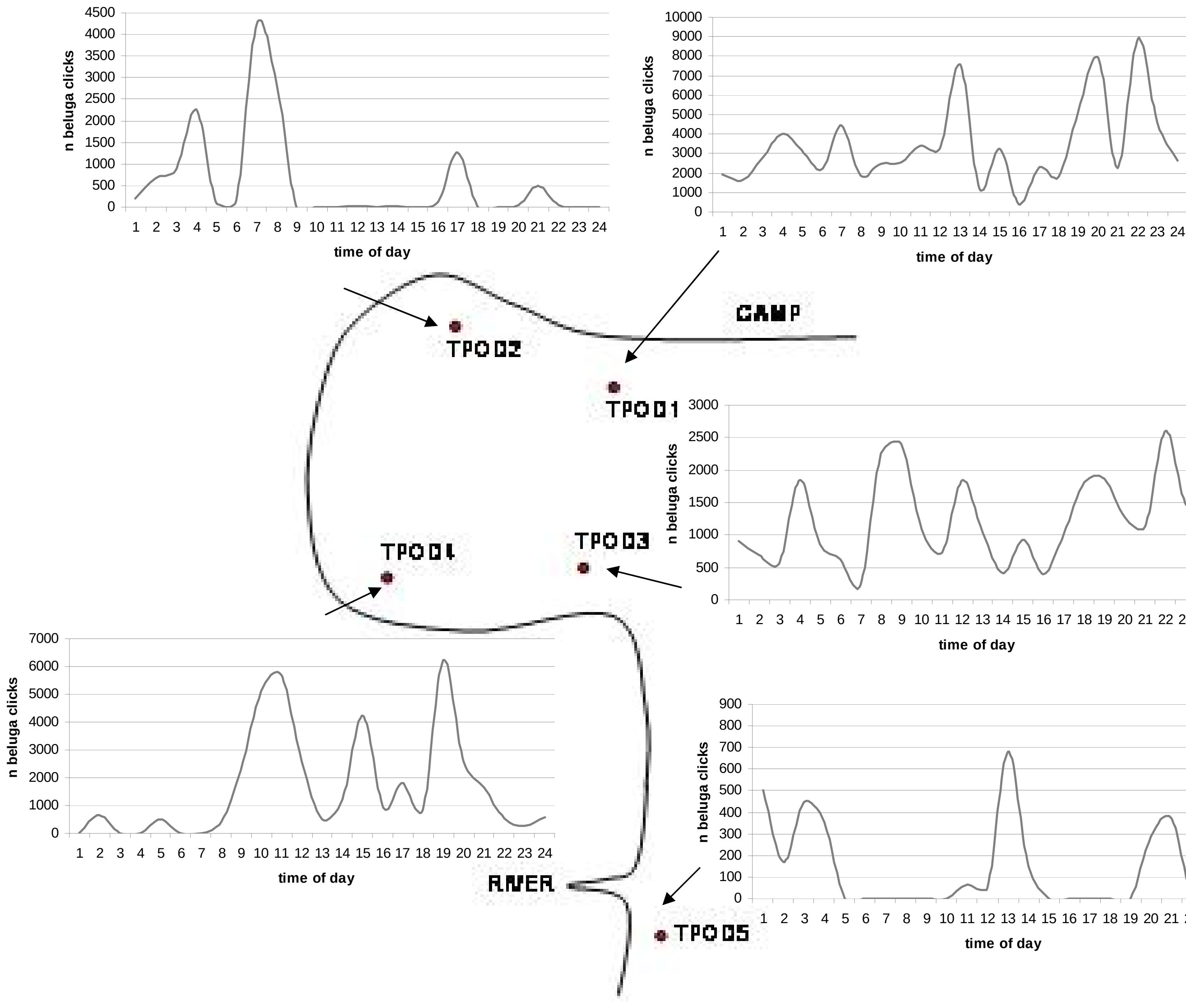

Figure 5: Schematic map of the field study area and beluga whale diel patterns for every T-POD position.

The average number of detected clicks per hour was calculated from beluga bay area (TPOD1, 2, 3 and 4) and compared to the diel pattern for the outside area (TPOD5). Figure 6 shows both diel patterns for comparison.

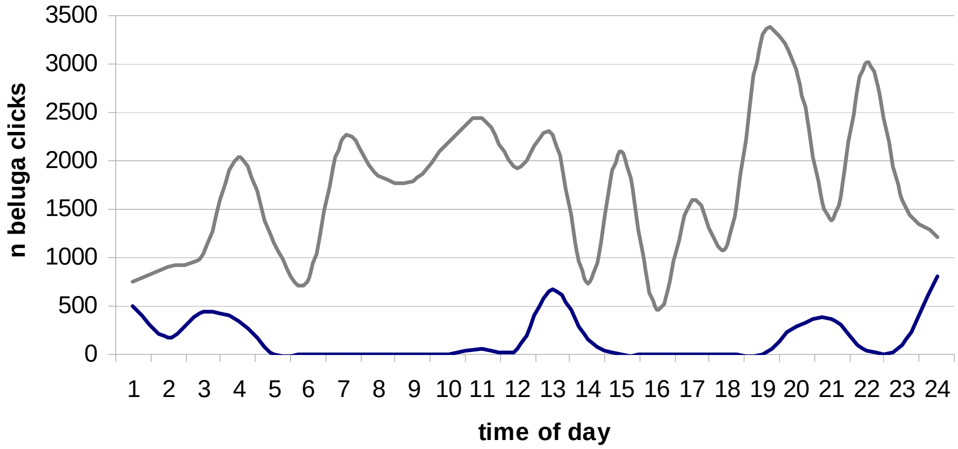

Figure 6: Beluga whale diel presence in Beluga bay (gray line) and outside area (blue line) for the study period.

In order to better understand possible diel patterns in beluga whale presence, day and night cycle was compared to the number of click detections. Sunset and sunrise times for the study area (http://www.srrb.noaa.gov/highlights/sunrise/sunrise.html) were compared to the click detection diel pattern obtained using all detections from all the T-PODs. Figure 7 shows all T-POD cumulative averages of click detections per hour for the whole sampling period and day/night period.

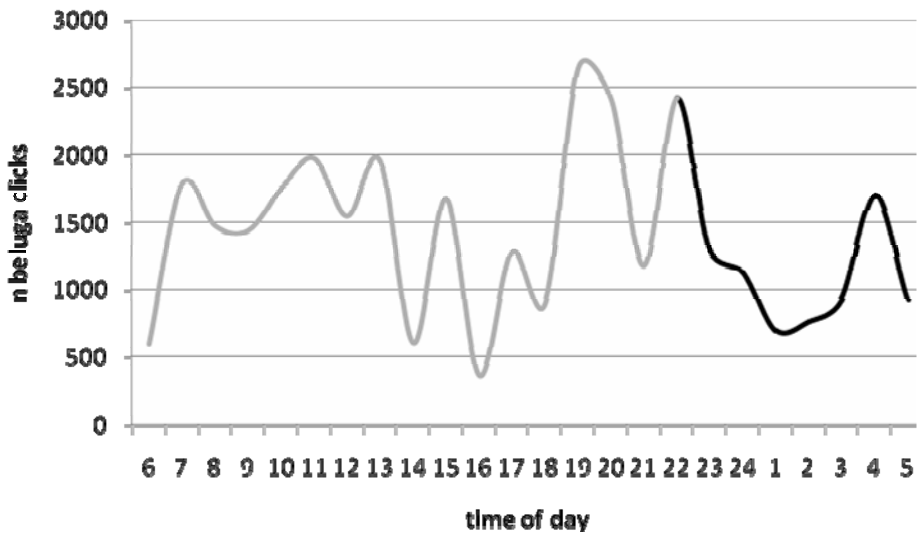

Figure 7: Cumulative averages of click detections per hour from all the T-PODs for the whole sampling period and day/night period marked as day=gray line and night=black line.

Further analysis showed a clear pattern between echolocation activity/whale presence and day/night cycle during the study period, (Kolmogorov-Smirnov test, $p<0.1$).

Another environmental variable that could drive beluga whale presence in the study area is the tidal cycle. Yakutat Bay tide levels were compared to logged T-POD angles in order to explore a possible relationship between both variables. When the T-POD is deployed it remains vertically positioned with the hydrophone oriented towards the surface, logging small angle values. If the T-POD is sidewise because of currents or low tides, the angles increase. In general, T-POD logged angles for their deployment periods were higher around low tide slack times and were lower during high tide times. Figure 8 shows the relationship between Yakutat tide level and T-POD angles in position TPOD4.

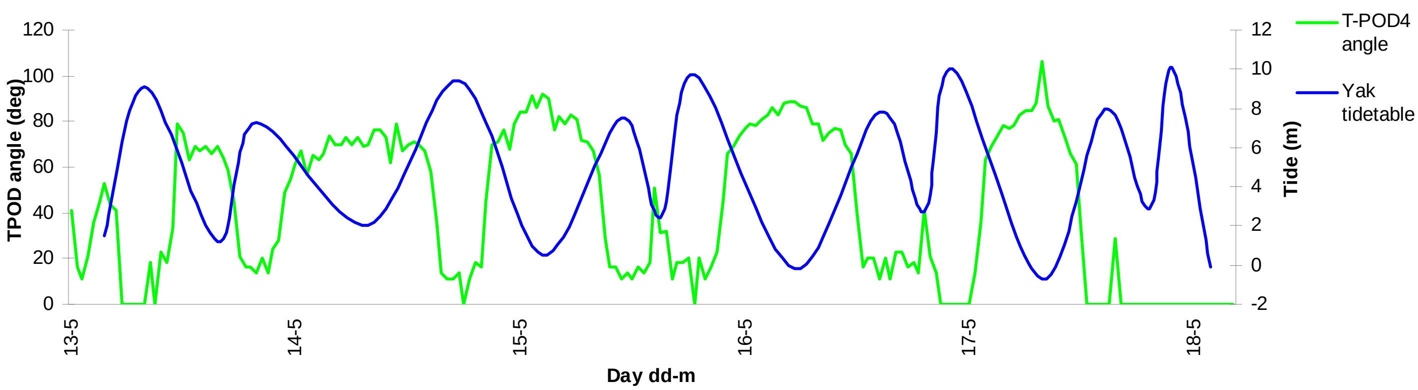

Figure 8: Yakutat tide times and T-POD angles for position TPOD4 for the period 5/13 to 5/18.

Figure 8 shows that T-POD angle is directly related to tide level, therefore comparing logged angles with logged beluga whale click detections could explain possible relationship between tide levels and beluga whale presence. Figure 9 shows the correlation between click detections and T-POD angles for all the positions.

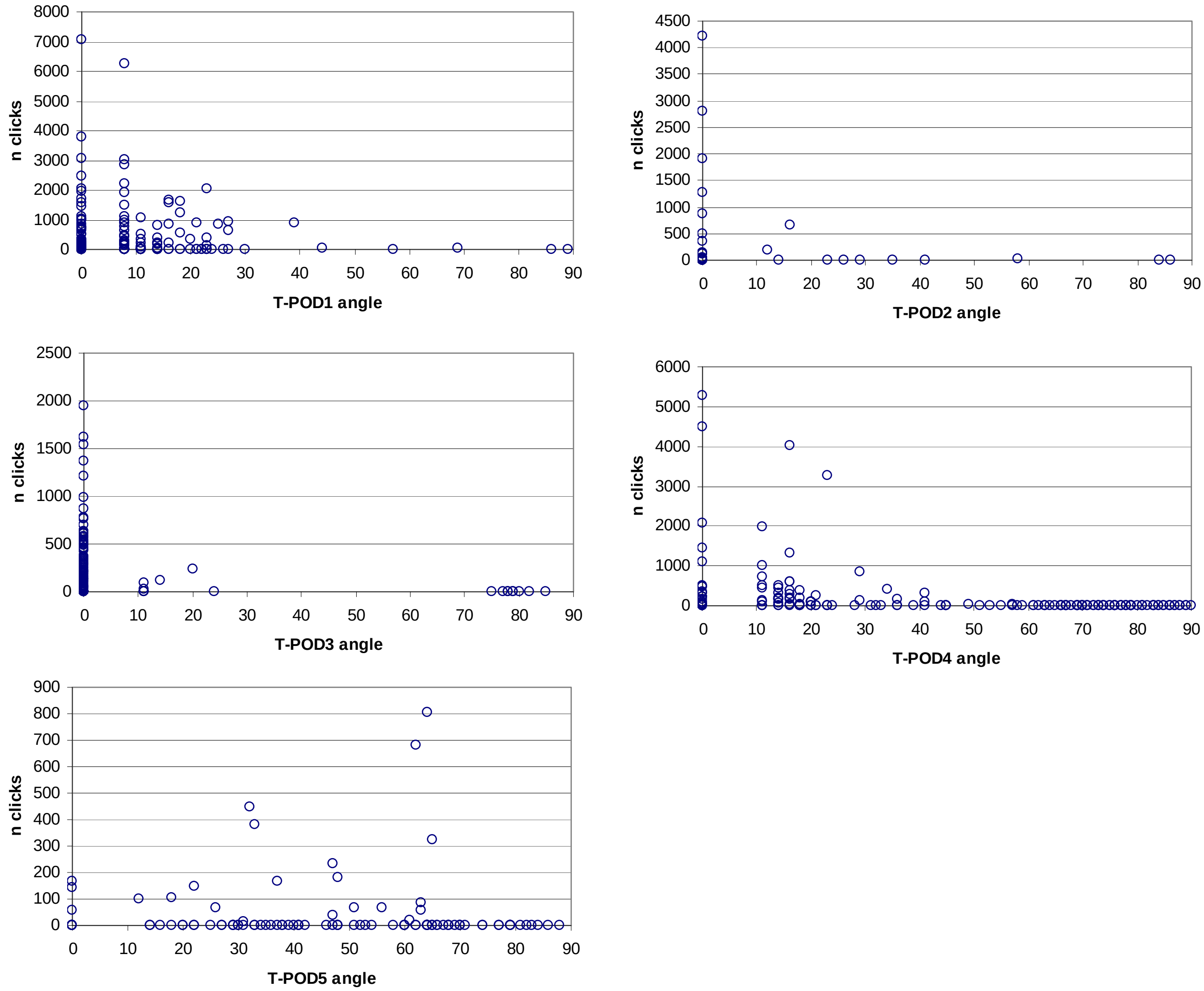

Figure 9: Correlation between number of click detections and T-POD angles for all the positions.

Pearson correlation analysis was significant ($p < 0.05$) for every position. The highest number of click detections for the positions TPOD1, 2, 3 and 4 occurred at low angles, therefore during high tide levels, however for the position TPOD5, the highest number of click detections occurred for higher angles meaning low tide levels.

3.3 Beluga whale behavior

Echolocation click rate is commonly used as an indirect measure of the behavior of small odontocetes (i.e. Au, 1993; Johnson et al. 2008). The pulse repetition rate of the logged click trains was analyzed in order to explore possible relationship between the click rate and the behavior of beluga whales. Cumulative values of mean, maximum and minimum pulse repetition rates (clicks/sec) for each hour of the day for each T-POD deployment position are shown in figures 10-14.

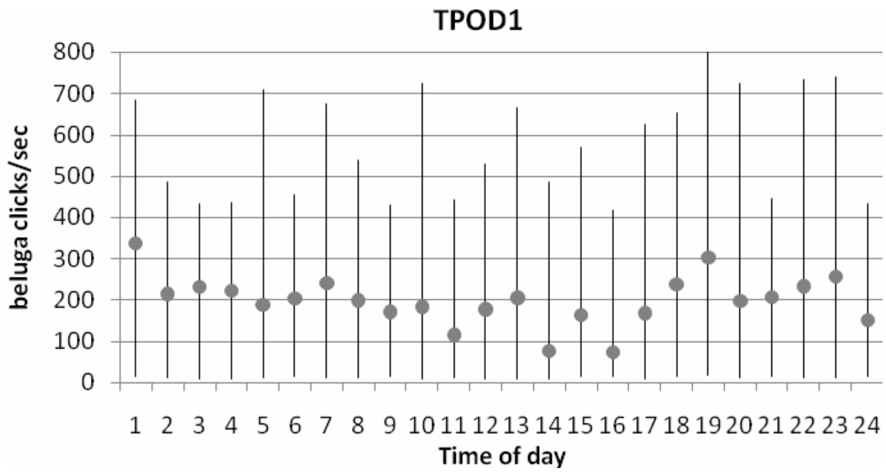

Figure 10: Cumulative values of mean, maximum and minimum click rates (clicks/sec) for each hour of the day in position TPOD1.

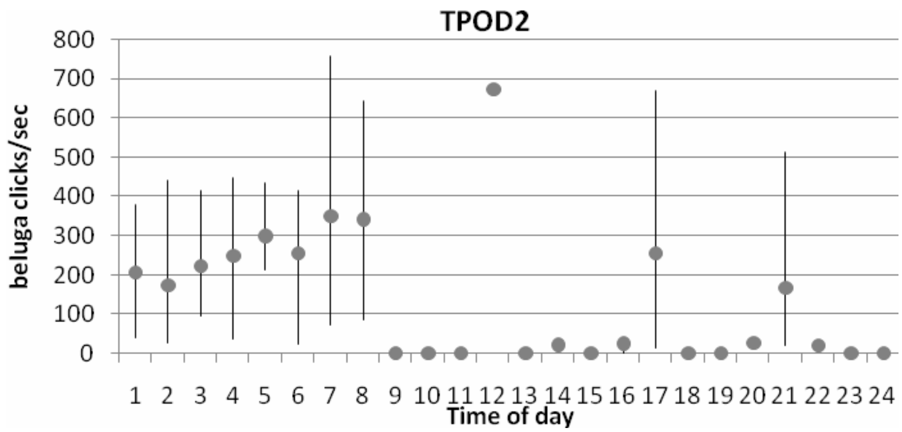

Figure 11: Cumulative values of mean, maximum and minimum click rates (clicks/sec) for each hour of the day in position TPOD2.

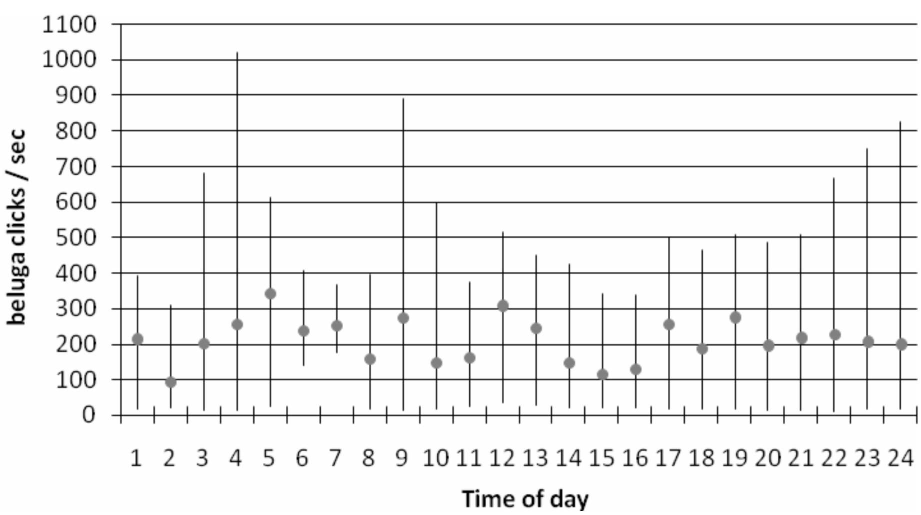

Figure 12: Cumulative values of mean, maximum and minimum click rates (clicks/sec) for each hour of the day in position TPOD3.

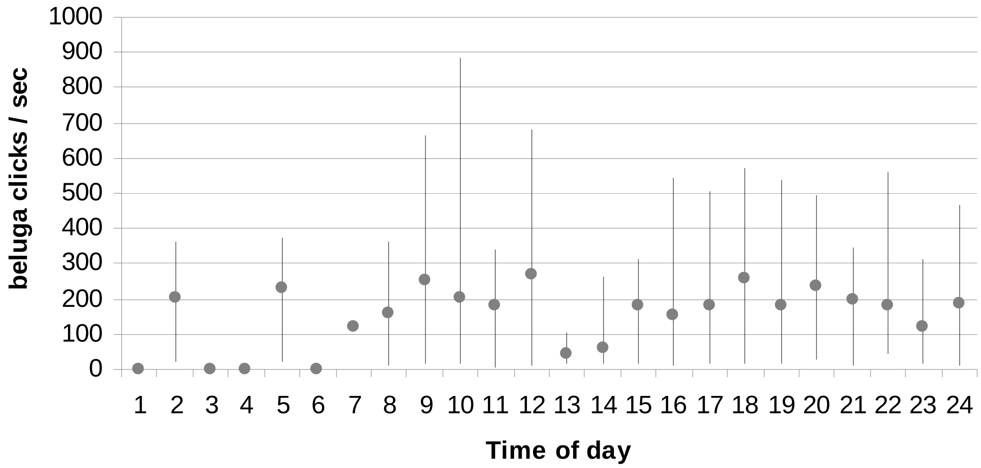

Figure 13: Cumulative values of mean, maximum and minimum click rates (clicks/sec) for each hour of the day in position TPOD4.

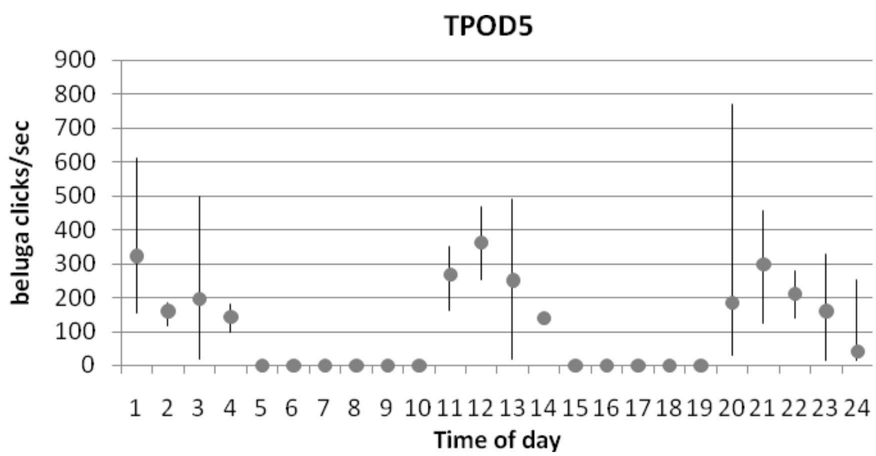

Figure 14: Cumulative values of mean, maximum and minimum click rates (clicks/sec) for each hour of the day in position TPOD5.

Average click rate for logged click trains in the study area was 199 to 218 clicks/sec. Maximum click rates were obtained at position TPOD2 (671 clicks/sec at 12pm). Interclick intervals ranged between 205 to 631 msec for the 5 positions. Table 2 summarizes pulse repetition frequencies and interclick intervals for all positions.

	TPOD1	TPOD2	TPOD3	TPOD4	TPOD5
Mean prf	199	218	210	156	210
Median prf	202	221	210	181	195
Max prf	338	671	342	269	361
max ICI	288	255	322	354	631
min ICI	230	210	326	253	205

Table 2: Mean, median and maximum pulse repetition frequency (prf, click rate) for click trains and maximum and minimum interclick intervals in all four positions.

T-POD algorithm scans were set a two different frequency bands. Percentage of detected clicks as well as the pulse repetition frequency (clicks /sec) for trains detected at each band are presented in Table 3.

mean clicks/sec		Position	% detected clicks	
High band	Low band		High band	Low band
324	284	TPOD1	17	83
306	275	TPOD2	47	53
232	211	TPOD3	39	61
186	196	TPOD4	24	76
193	171	TPOD5	69	31

Table 3: Percentage of detected clicks as well as the pulse repetition frequency (clicks /sec) for trains detected at each band of the scans.

The click rate (prf) is higher for the click trains logged in the higher frequency band except for position TPOD4. The overall percentage of detected clicks is higher for the low band except for position TPOD5.

3.4 Detection range

T-POD detection range for beluga whales has never been measured. Using the interclick interval data obtained in these deployments and assuming that click trains logged by the T-POD were directed towards the device, it is possible to estimate an approximate range. The maximum range (R in meters) at which a beluga whale can get an echo before making the next click can be calculated using the formula:

$R = (v_{sea}/ 2) * (ICI - 20)$

Where v_{sea} is the speed of sound in sea water in meters/milliseconds, ICI is the inter click interval in a click train in milliseconds and 20 ms are needed for the processing time of the animal (Au, 1993). Using this formula, we obtained detection ranges varying from 137 m up to 443 m.

3.5 Movement patterns

T-POD detections were explored in detail during two periods of multiple detections by all T-PODs in the area. TPOD1, 2 and 3 were deployed simultaneously for 50 hours from the 11th to the 12th of May within Beluga Bay. These instruments had a maximum separation distance of 432 m. When click trains were detected by one device, the other two also logged clicks within a 3-minute period for all the events within the 50 analyzed hours. Figure 15 shows an example of the number of detected clicks by each T-POD during 25 minutes of this sample period.

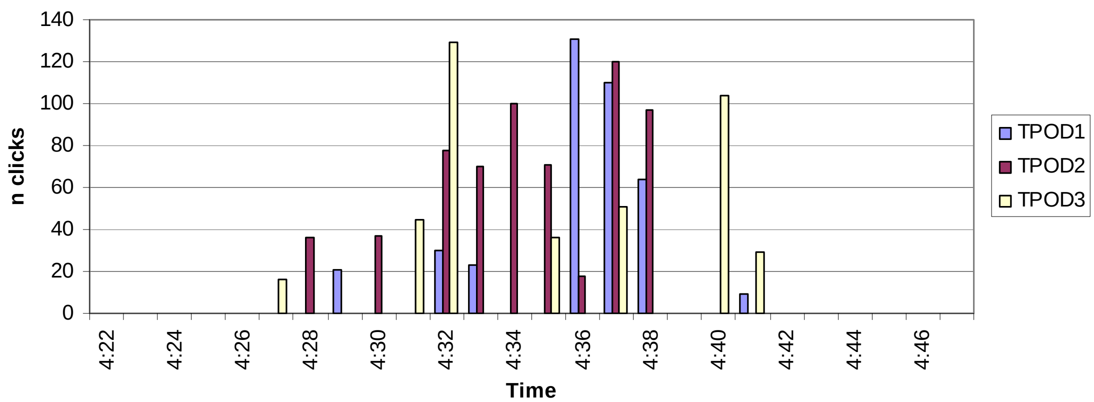

Figure 15: Detected clicks per minute by 3 T-PODs for a period of 25 minutes at 4am on May 12th 2008 as an example of concurrent detections within Beluga bay.

Therefore, beluga whales that visited the inner bay were detected by all three T-PODs for all the events observed within the sample period.

On May 16th afternoon, a T-POD was deployed in position TPOD5, away from the other 3 units, allowing the comparison of visual sightings and acoustic detections between both areas. Visual effort started on the 17th at 8:30am and ended at 15:40. This period was also explored with detail and compared to the visual observation data.

First sighting of whales occurred when one adult and 3 subadults were sighted coming from TPOD5 area towards Beluga Bay at 12:20. TPOD1 started detecting clicks at 12:07 and TPOD4 13 minutes later at 12:20 at the same time as the sighting. TPOD5 stopped logging clicks at 12:03, probably because these whales moved towards Beluga Bay and out of range of TPOD5 before being sighted. The visual data log indicates that whales stayed in Beluga Bay until 13:03 when they started to move back towards TPOD5. All T-PODs in Beluga Bay (TPOD1, 2, 3, and 4) stopped logging clicks at 12:50 and TPOD5 started to detect clicks at 13:11. Whales were sighted again at 13:59 approaching Beluga Bay from TPOD5 area. TPOD5 stopped logging clicks at 13:49. Whales were again sighted in Beluga Bay at 14:19. TPOD4 and TPOD3 started logging at 14:12 matching visual data. The visual effort stopped at 15:12 with beluga whales still in Beluga Bay. TPODs 1, 3, and 4 logged clicks for this period until 15:28. Figure 16 illustrates these results.

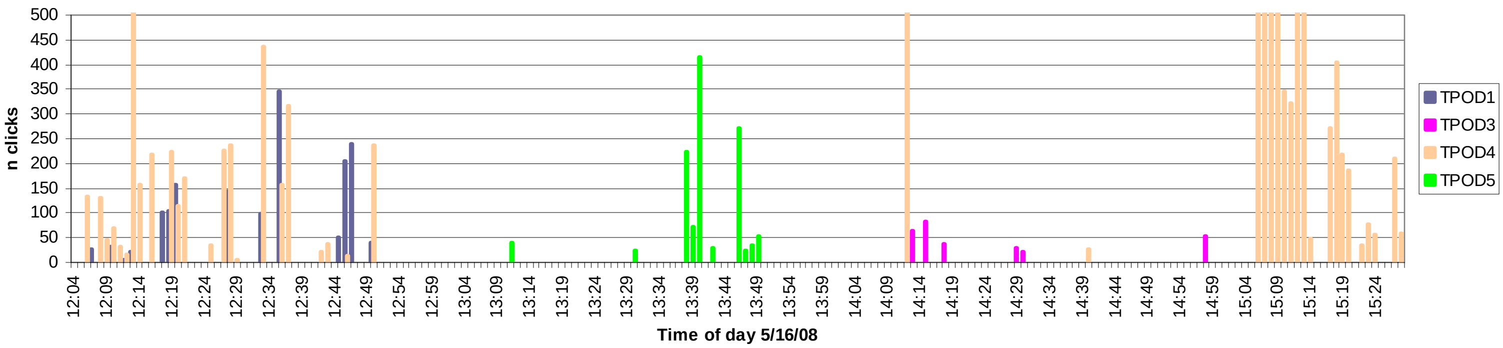

Figure 16: Detected number of clicks for each position during May 16th between 12:03pm and 15:28.

Visual data matched the detected click train periods for each position for the analyzed sample period. Beluga whales moved together from Beluga Bay area towards the TPOD5 area twice in the analyzed period, taking 20 minutes to move between areas.

4. Discussion

The five T-PODs detected millions of pulses of which only 0.28 % were classified as beluga whale clicks. This low percentage indicates that there are many sources of pulsive sounds in the area being logged, most probably ice cracking. However, the classification process successfully filtered echolocation click trains from all other sources. Robustness against false detections is proven by the visual data because there were no detections logged when belugas were absent from the study area. Figure 16 shows a graphic example of this confirmation.

The suggested detection range obtained in this study, from 137 to 443 m, matches the observed movements, because T-PODs deployed within this range detected simultaneously, or within a 3-minute difference, many echolocation clicks when whales were present in the area. Figure 15 shows how clicks were detected concurrently on TPODs 1,2 and 3. The very directional characteristics of beluga whale echolocation clicks, with 6 to 7 dB greater transmission directivity index than a bottlenose dolphin (Au *et al*. 1987), could explain the small differences in total number of clicks detected by each T-POD when belugas were within the detection range of several T-PODs simultaneously. There are only 3 published attempts to calculate the detection range of T-PODs for bottlenose dolphins, these range between 500 to 1500 m (Ingram *et al*., 2004; Philpott *et al.*, 2006; Reyes-Zamudio *et al*., 2006), however those T-PODs were deployed in much deeper areas and warmer water temperature, and the frequency band used was lower (30-50 kHz), therefore direct comparisons are not possible. However the suggested detection range for belugas in our study area is not far below the range for bottlenose dolphins, which could be explained by the shallow water and cold water propagation conditions as well as higher frequency bands used. Beluga whale detection range could probably be increased by deploying the devices deeper.

Beluga whales were acoustically detected every day of the study period as it is shown in figure 4, therefore they did not leave the area in the 10 days. Detections were more abundant for some particular days in the different positions. This could be explained by a particular increase of acoustic activity in these areas or because whales spent more time in these areas. Looking at figure 4, position TPOD1 shows a large amount of clicks for May 15th but all other days remain in a normal detection level. The detection data in TPOD1 for the 15th shows a big amount of logged clicks (>1000 clicks/min) at 5am and 8pm with a normal rate (<300 clicks/min) for the rest of the day. This could be explained by approaches of whale pods to explore the device and mooring system. Therefore the bigger abundance of detections in position TPOD1 does not represent a particular preference for this area but a high increase in the acoustic activity in short periods of time. Position TPOD2 shows an increase during May 11th. In this case the detection data is high for many hours, specially at night time, proving that beluga whales had a particular preference for this area at night. TPOD4 had a detection peak on May 18th, detection data shows high values for several hours during day time, again proving that beluga whales spent more time around TPOD4 during the day. TPOD5 has smaller numbers of detections per day compared to the other areas. Data from this position shows that belugas were absent many times per day but when they were present, number of logged clicks was similar to other positions instead of being less acoustically active. Therefore, beluga whales were acoustically detected every day with important differences between positions due to both increase of acoustic activity or spatial preferences.

Diel patterns observed in each position differ significantly. Position TPOD2 is preferred between 2am and 8am (figure 5), position TPOD4 is preferred between 9am and 8pm and position TPOD5 between 8pm and 4am with a peak outside this interval at 1pm. However positions TPOD1 and TPOD3 do not show a clear pattern with beluga whale presence during the 24-hour cycle. The big variability observed within a short deployment distance raises the suspicion that the sample size is not big enough to define a diel pattern, if there is any. Furthermore, considering that the suggested detection range puts TPOD1, 2, 3 and 4 within their own range, it would be preferable to combine all the detections from these positions together to explore the diel pattern. Figure 6 shows the diel pattern as the average number of detected clicks for the 24-hour period for the 4 positions located inside Beluga bay (TPOD1, 2, 3 and 4) versus TPOD5 diel pattern. A difference in the amount of detections is observable as it has been already stated, because beluga whales were not so commonly detected in position TPOD5 than in Beluga bay. Although not very marked, both diel patterns show interesting differences. There is a increase of detections in the inner bay at 3am, remaining high through the day until it decreases at 11pm in contrast to a decrease of detections in the outside area at 3am remaining low or absent until 11pm. Therefore these results suggest an inverse relationship of beluga whale presence between the inner bay and the outside area. This suggestion was further explored looking at the day/night cycle for the sample period in the area, as seen in figure 6, however there were no statistical differences between the number of overall detections during day time and night time.

The peak occurring at 1pm in the outside area does not match with a decrease in the inner area. The only explanation with the available data is that beluga whales don't always move together through the study area, however this hypothesis is not supported by all the detection periods analyzed in detail for each position, in which presence of clicks in T-PODs deployed in Beluga Bay never overlapped with presence of clicks in the T-POD deployed away, as can be observed in figure 16.

The absence of any effect in whale presence by the day/night cycle could be explained considering the high turbidity of the water in the study area and the acoustically nature of beluga whales. If their environment does not change depending on whether it is day or night, their presence would neither change, but no environmental data is available to further discuss this subject. However, big changes occur in their environment related to the tide cycle. Ice coverage, water salinity and most probably prey availability should have an effect in beluga whale presence. Therefore, tide effect in beluga presence was explored and a statistically significant effect was observed. T-PODs correctly moored are very sensitive to currents. Figure 8 shows a clear relationship between T-POD angle and tide level for position TPOD 4. However, not all the T-PODs presented such a clear relationship, most probably due to drifting ice getting entangled in the lines or marker buoys modifying the T-POD angle. Differences can be observed between positions when comparing T-POD angles with amount of detected beluga whale clicks. Figure 9 shows the correlation between T-POD angle and number of detected clicks. For all Beluga Bay positions (TPOD1, 2, 3 and 4), most of the clicks are detected at low angles, therefore during high tide levels (Pearson $r<0$). However TPOD5 position shows most of the detections at higher angles, therefore at low tide levels (Pearson $r>0$). These results clearly demonstrate that beluga whales in the study area have preference for the inner bay when tide is high and remain, at least a portion of them, near TPOD5 area when tide is low.

Beluga whale behaviour within each position was analyzed based in the temporal echolocation characteristics. Click rate is commonly used as an indirect measure of the behavior of small odontocetes however it has never been evaluated in beluga whales. Pulse repetition frequency (or click rate) should be faster when feeding behavior occurs and slower when milling or resting is the dominant behavior. The median click rate obtained in the study area, in Table 2, is 180 to 221 clicks/sec. This rate is very fast and higher to the 140 clicks/sec obtained from deployments in Svalbard (Leeney *et al.* 2007) and assumed to be related to feeding behavior. Click rates measured with two captive beluga whales at L´Oceanografic of Valencia during resting or milling behavior did never exceeded 50 clicks/sec. Therefore a direct interpretation of these results would lead to feeding behavior in the study area. However, when looking at the diel pattern analysis for each position (figures 9 to 13), click rates are very high most of the 24-hour period for all positions without a clear pattern and no resting (<50 clicks/sec) periods. This particular behavior could only be explained if beluga whales did never stop feeding that is unlikely or that different whales were visiting the study area, as a feeding spot. But this last hypothesis does not exactly match the visual data collected during the deployment period since several whales were identified and remained in the area for several days. Furthermore, minimum interclick intervals obtained here are 210 to 326 msec (table 2) that are longer than the 193 msec reported intervals from a captivity experiment with a static target at 80 m distance from a beluga whale (Au *et al*. 1987). Feeding behavior should generate shorter Interclick intervals than 193 msec since echolocation targets during feeding should be closer than 80 m. Therefore the significance of these behavioral results is not entirely clear and can not be conclusive. Further detailed analysis of selected click trains would possibly allow identification of sharply rising click rates described from various species at the onset of the feeding buzz which usually precedes prey capture in order to confirm feeding behavior in the different T-POD positions.

Energy content across the click bandwidth was analyzed by Au *et al.* 1985 with a captive beluga whale. They found a bimodal distribution with peaks at 100-120 kHz and 40-60 kHz, with stronger high frequency components for louder clicks used when the target was further away from the whale. Analyzed click trains form two captive beluga whales at

L´Oceanografic of Valencia show that fainter clicks have stronger energy contents in the 40-80 kHz band. Therefore it seems to be a relationship with click loudness and energy content in the frequency range of beluga whale echolocation clicks. In order to study the potential use of this characteristic, detected clicks were classified by their energy distribution between the two different frequency bands scanned by the T-PODs. The right panel of Table 3 shows these results. The percentage of detected clicks is higher for the low band in all positions except for TPOD5. Assuming that louder clicks will travel further away than fainter clicks (even though the attenuation factor is stronger for higher frequencies) these results could correspond to beluga whales detected close to the T-PODs in all positions except in position TPOD5 where the whales remained further away from the deployment area. Furthermore, knowledge of the beluga whale echolocation beampattern indicates that off-axis clicks are fainter and have peaks at lower frequencies (Au *et al.* 1985), therefore closer whales would increase the number of detections in the low frequency band scan. However, the lack of visual observations around the TOD5 position does not allow confirming this hypothesis, although these results match with observations around all other T-POD positions.

In the same way as the percentage of detected clicks, click rate was compared between click trains logged in each frequency band. The left panel of Table 3 shows these results. It was expected that click rate and click energy content would be related, being louder and higher in the frequency domain when the target was further away from the whale, and fainter and lower in the frequency domain when the target was closer. However, these results do not allow confirming this hypothesis since click rate is faster for high frequency clicks except in position TPOD4. Therefore the amount of logged clicks for each frequency band did not allow any clear interpretation of the target distances.

The relationship between click rates, target distances and the energy content across the frequency range seems promising for further interpretations of the behavior of free ranging beluga whales with acoustic loggers, however more research is needed regarding these echolocation characteristics.

5. Conclusions

Acoustic monitoring of beluga whales using T-PODs proved to be a very effective way to better understand the presence, diel patterns and even some behavior of a small group of whales in a small study area. The detection range was much greater than expected considering the acoustic propagation conditions of the area (ice blocks, very shallow depths, soft sea floor, variable salinity, etc.) which makes future studies simpler to design and more effective for spatial distribution analysis. Mooring design was effective for short time deployments; however subsurface moorings would be strongly advised based on the detection range results as well as mooring experiences during our field work. Beluga whales were present in the area for the full study period, showing an important affinity to this area and preference for Beluga Bay during high tides and outside the bay during low tides. Day light cycle did not appear to have any effect on whale presence. Spatial preferences on a finer scale were harder to determine because of a short sample period and inadequate sampling design. Deployment positions were found to be too close to each other, however differences in the acoustic activity as well as in time spent in each position were detected. Behavioral analysis is still difficult to accomplish with this species because of the lack of knowledge about echolocation behavior. Results from the echolocation train analysis suggests a strong predominance of feeding behaviour in the whole study area without a clear diel pattern, however this assertion needs to be further validated. More detailed analysis of the logged click trains could confirm this. The analysis of the proportion of logged high and low frequency clicks is promising to better understand the fine scale use of the study area but still needs more analysis refinement before reliable results can be obtained. Despite the above caveats, this study clearly demonstrated the viability of beluga whale acoustic logger monitoring in the Arctic environment and suggests further avenues of study to better understand the behavioral and acoustic ecology of the Yakutat Bay beluga whales.

6. Aknowledgements

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Section II: **Abundance, habitat use and behavior of beluga whales in Yakutat Bay, May 2008; as revealed by visual observations and photo-ID**.

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INTRODUCTION

Knowledge of the movement patterns, foraging and breeding behavior, trends in abundance and habitat use of marine mammals is essential to developing an understanding of population ecology and the impacts of ecosystem change and anthropogenic activities on individual fitness and population viability. This understanding in turn forms the basis of meaningful management strategies. Gathering these types of information, however, is particularly challenging in cetacean species. This is especially true in species that inhabit remote, extreme environments, such as polar or sub-polar marine ecosystems where determining basic parameters such as population and seasonal ranges, abundance and trends are often difficult.

The beluga whale, *Delphinapaterus leucas*, is a highly gregarious Arctic whale whose range extends to boreal latitudes. At these southern reaches of the species range, populations tend to be smaller and geographically isolated from larger, more northerly populations (O'Corry-Crowe 2008). One population, in Cook Inlet, Alaska, is genetically as well as geographically distinct from other populations, has witnessed a dramatic decline in recent decades, and has shown few signs of recovery nearly 10 years on from increased protection in 2000 (National Marine Fisheries Service 2008). In October 2008, this population, estimated to number 375 individuals, was listed as endangered under the U.S. Endangered Species Act (73 FR 62919).

Recovery of this and other small populations requires innovative methods of study that maximize the amount of behavioral, ecological, health and other kinds of data that can be collected in the field. Further, study locations need to be identified where access to animals is relatively predictable, where detailed observations can be made, and where the study population is small enough that known individuals can be monitored throughout their lifetimes. In 2002 we identified such a location, Yakutat Bay, Alaska (Fig.1). The small group of beluga whales that has been documented in this glacial fiord over the past decade or so (numbering just ~12 individuals as of 2005; O'Corry-Crowe et al. 2006) provides a rare opportunity to investigate population viability and recovery in small populations or groupings of this species. A field ecology study initiated in 2005 documented areas of high use in summer (May) and demonstrated that whales could be observed daily from a number of vantage points on shore, that photo-ID was viable, and that whales could be sampled for genetic and other molecular analyses via remote biopsy (O'Corry-Crowe et al. 2006).

Beyond the advantages to beluga whale research this small group of whale's offers, the beluga whales of Yakutat Bay are of interest in their own right. Located at the southeastern extent of the species' North Pacific range, geographically and potentially

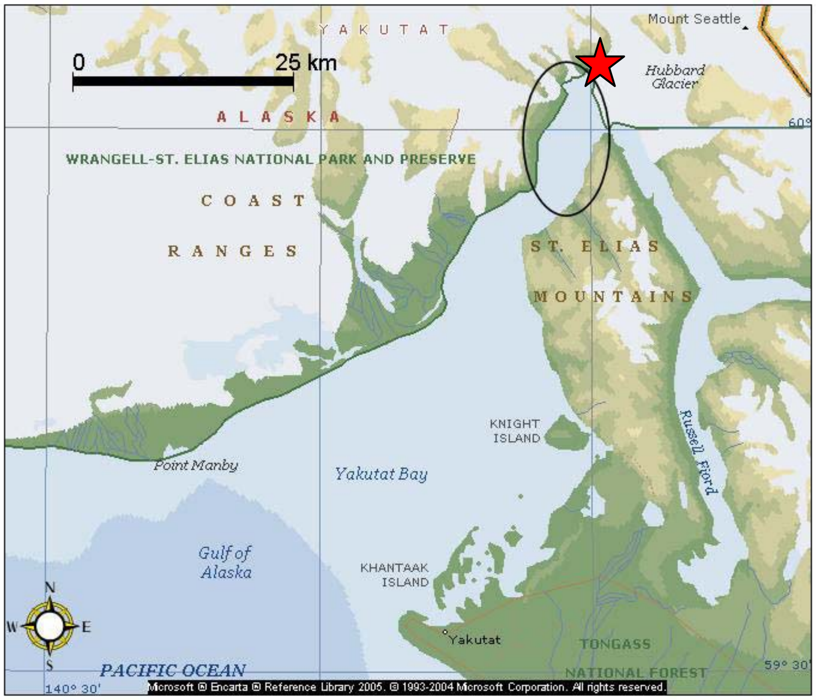


Fig. 1. Yakutat Bay, Alaska with Disenchantment Bay circled and the study site indicated by a red star.

genetically isolated from other populations, and occupying an environment unique to belugas in this hemisphere, namely a deep glacial fiord fed by tidewater glaciers, the Yakutat belugas are somewhat of a mystery. A recent study of Traditional Ecological Knowledge (TEK) on beluga whales in the region revealed that beluga whales were known to occur in Yakutat Bay as far back as the 1930s (W. Lucey and H. Huntington, pers. comm.). Sporadic sightings over the past few decades reported belugas in Yakutat Bay in all seasons (Calkins, 1983; Hubbard et al. 1999; Laidre et al., 2000; O'Corry-Crowe et al. 2006) while genetic findings to date suggest a distinct resident group but have yet to conclusively resolve whether the Yakutat whales are in contact with the Cook Inlet stock. Finally, the recent field studies indicate a small, reproductive group of whales with a unique ecology tied to the ice-covered waters of upper Disenchantment Bay that face new challenges from increased cruise ship traffic as well as predicted climate and ecosystem change (O'Corry-Crowe et al. 2006).

These concerns highlight the need for further research on seasonal movement patterns, the genetic relationships to the Cook Inlet population, habitat use throughout the year and group structure and behavior. In 2008, we proposed an expansion of the observational studies, biopsy sampling and molecular analysis, and the initiation of new research employing new methodologies, including acoustics and photo-ID.

In May, 2008, we initiated a new phase of the field research program that focused on the deployment of passive acoustic devices (hydrophones and click-train detectors) to record beluga whale vocalizations during a short, intensive summer field season (see Section I for details). This was conducted in concert with continued systematic shore-based observations to estimate abundance, document habitat use and elucidate social structure and mating systems (Section II). A third aspect of the field study involved initiating a photo-ID program with a view to establishing of a catalogue of known individuals (Section II). The fourth element of the field project involved continuing the remote biopsy sampling of free swimming whales for genetic and other molecular analyses. This report summaries our findings of the first, second and third phases. It presents detailed data and preliminary analyses.

MATERIALS AND METHODS

A field camp was established on the shores of the small bay between the Hubbard Glacier and the Haenke and Turner glaciers as the head of Disenchantment Bay on May 9, referred to since 2005 as Beluga Bay (N60°02'; W139°33', Fig. 2). All field activities, including passive acoustic monitoring (see Section I), visual observations, photo-ID and tissue biopsy sampling were conducted from this location. The biopsy program and genetic analyses as well as the aerial surveys will be reported in a subsequent report.

Equipment and personnel were transported by skiff 62 km from Yakutat to Beluga Bay and the camp was set up on the morain on the opposite side of the bay to the 2005 camp site and primary observation post (Fig. 2 and see O'Corry-Crowe et al., 2006). Observations and photo-ID of whales were carried out from a number of locations on shore in Beluga Bay and nearby Haenke stream and Haenke Glacier (a.k.a. Black Glacier) overlooking the Turner Glacier (see Fig.s 2 and 3)

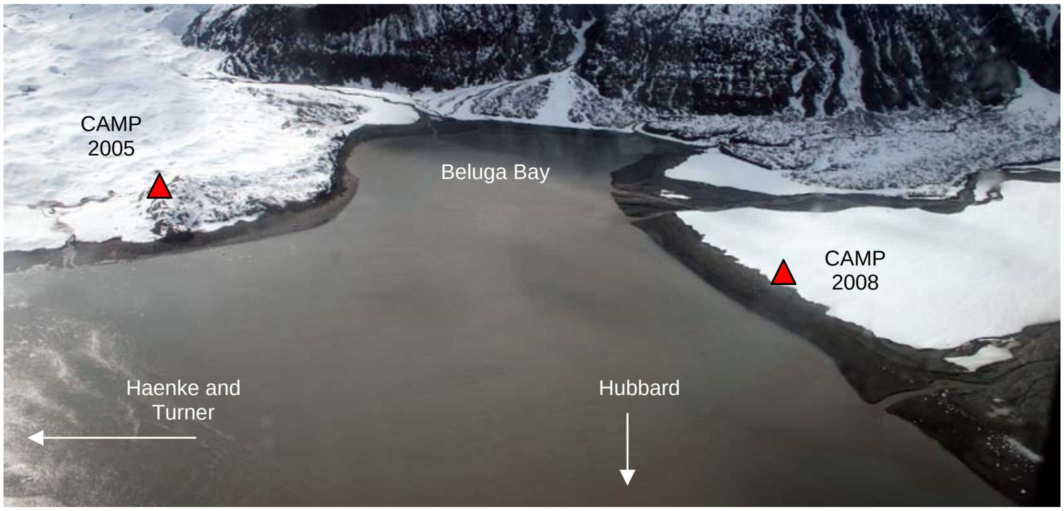


Fig. 2. Beluga Bay at the head of Disenchantment Bay in Yakutat Bay, and camp site locations in 2005 and 2008.

Observation posts were monitored daily by up to two teams of two observers which rotated after approximately 2 hours of effort. Most observations were conducted within and around Beluga Bay (Fig. 2).

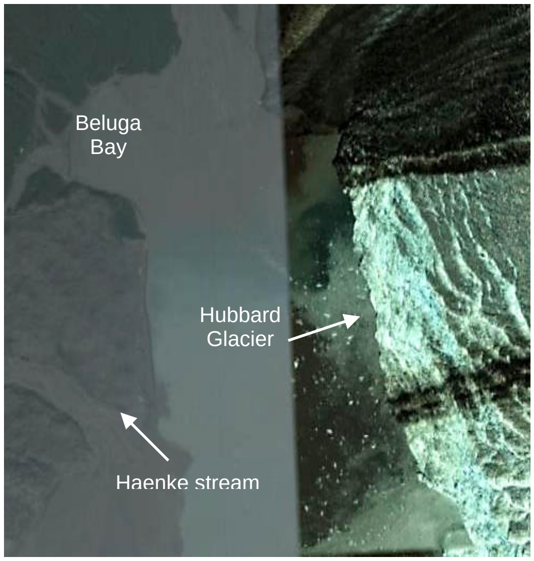


Fig. 3. Beluga Bay, Haenke stream and other Hubbard Glacier

Surveys for whales were carried out using 7X30 reticled Fuginon binoculars, 10X40 Nikon binoculars, or the naked eye. Each sighting was entered into a data sheet later transcribed into Excel. The data recorded included sighting time, location, number of whales, color composition, whether calves were present, behavior, photo# and whether there were any human activities being conducted nearby (e.g., acoustic logger deployment/recovery, biopsy sampling, cruise ships presence). Focal group sampling was applied whenever whale groups remained in sight. Behaviors were categorized into 6 categories (see results for details). When the whales were closer to shore, they were photographed using a Canon 20D or Nikon 80 digital camera with 300mm or 200mm zoom lens. The dorsal ridge, left and right flanks and when possible, tail stalk, of the individual was photographed for a photo-ID catalogue.

RESULTS

Habitat Use

A concerted effort, involving 40.28 hours of directed observations, was made to establish a more detailed account of beluga whale use of 2 of the 3 high-use areas identified in 2005: (A) Beluga Bay and (B) Haenke Stream. Visual surveys were primarily conducted at a number of shore-based locations from the camp site in Beluga Bay to Haenke Stream with some observations also carried out at the Black Glacier just south of Haenke Stream (Fig. 3). Systemic surveys were not possible at a third location used in 2005, Turner Glacier, because of major changes in the coastline resulting from an extensive surge of this glacier in the intervening years.

Apart from a 2-day hiatus in the middle of the field effort to re-provision camp and to re-calibrate acoustic recorders, visual scans of Beluga Bay to Haenke Stream were made on most days between May 10 and May 19, 2009. Detailed observation efforts were made on 7 days: May 10 -13, and May 16 -18, 2009 (Fig. 4). All observation effort occurred during daylight hours, the majority between 6:00 and 18:00 hours (Fig. 5).

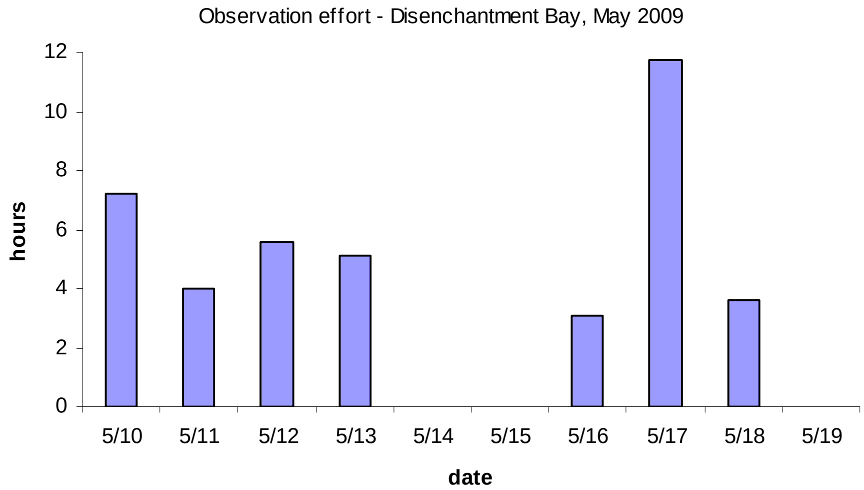


Fig. 4. Visual observation effort at three locations: Beluga Bay, Haenke Stream and the Black Glacier, in Disenchantment Bay, May 2008.

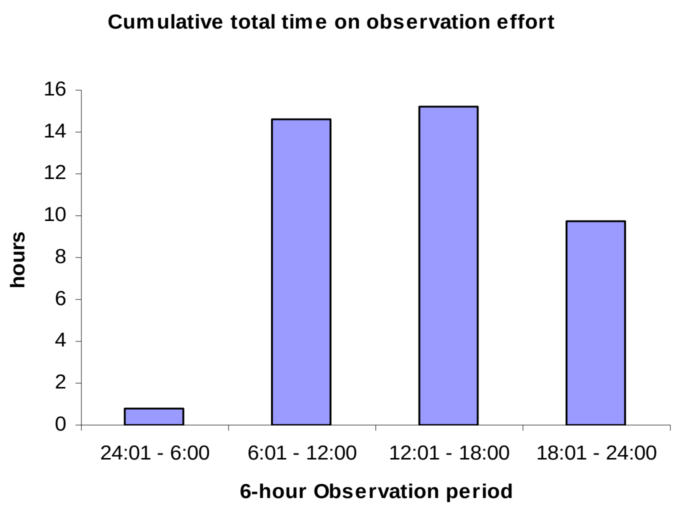


Fig. 5. Cumulative visual observation effort by time of day at three locations, Beluga Bay, Haenke Stream and the Black Glacier, in Disenchantment Bay, May 2008.

Whales were sighted on all days, and were observed for a total of 20.7 hours, just over 50% of the time on effort (i.e. 40.28 hours). It is important to note, however, that observation effort varied among days and that most of the effort was conducted in Beluga Bay. The following graph depicts whale presence in Beluga Bay in relation to observation effort (Fig. 6). A positive relationship was observed between the time spent each day searching for whales and the sighting frequency (r = 0.395). However, relatively little of the variation in the amount of time whales were observed each day could be explained by daily observation effort (r^2=0.156, Fig 7).

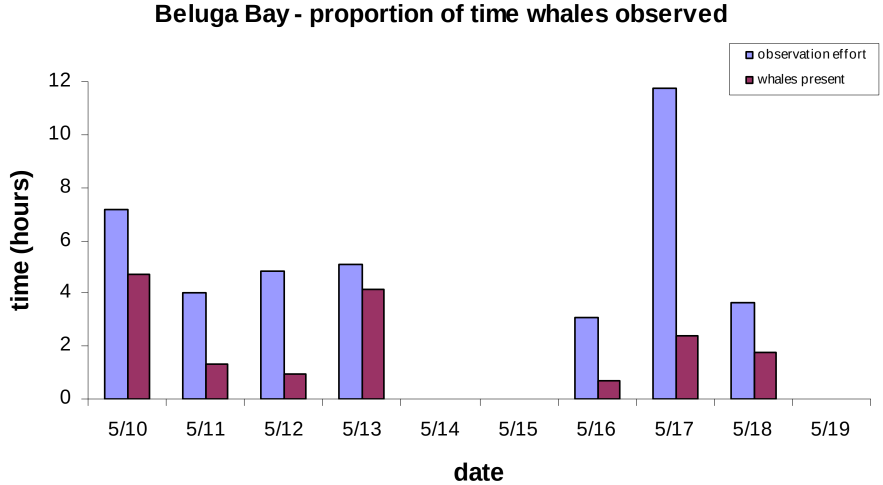


Fig. 6. The cumulative amount of time whales were sighted in relation to visual observation effort in Beluga Bay, May 2008.

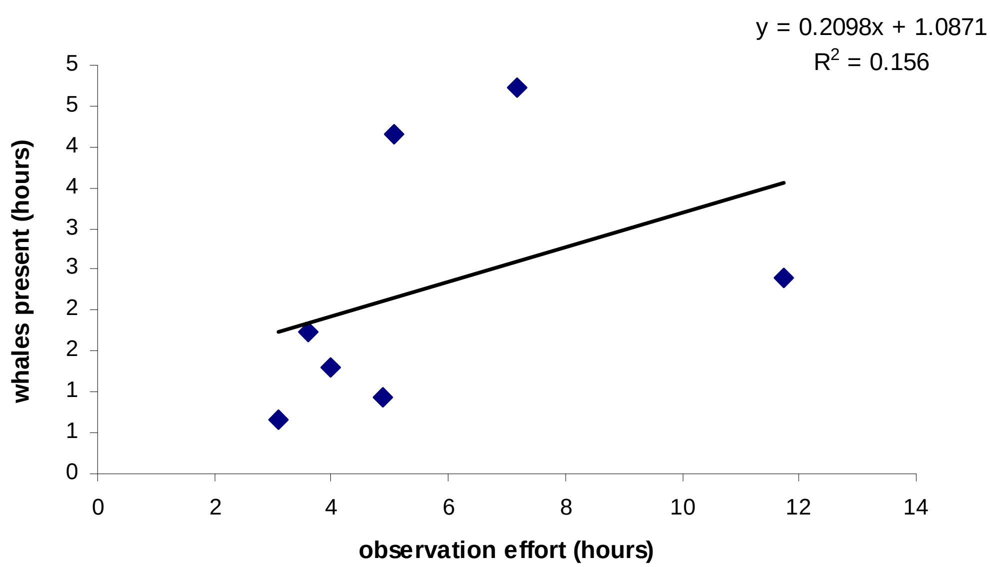


Fig. 7. The relationship between daily observation effort and beluga whale sighting rate in Beluga Bay over seven days in May 2008.

Forty four separate sightings were made ranging from opportunistic sightings of 2 minutes or less to extended observations of up to 224 min. The majority of sightings (n=25) were within Beluga Bay, but whales were also observed traveling between Beluga Bay and Haenke Stream (n=13 sightings), at Haenke Stream (n=5) and between the Black and Turner glaciers (n=1 sighting) (Fig 8.).

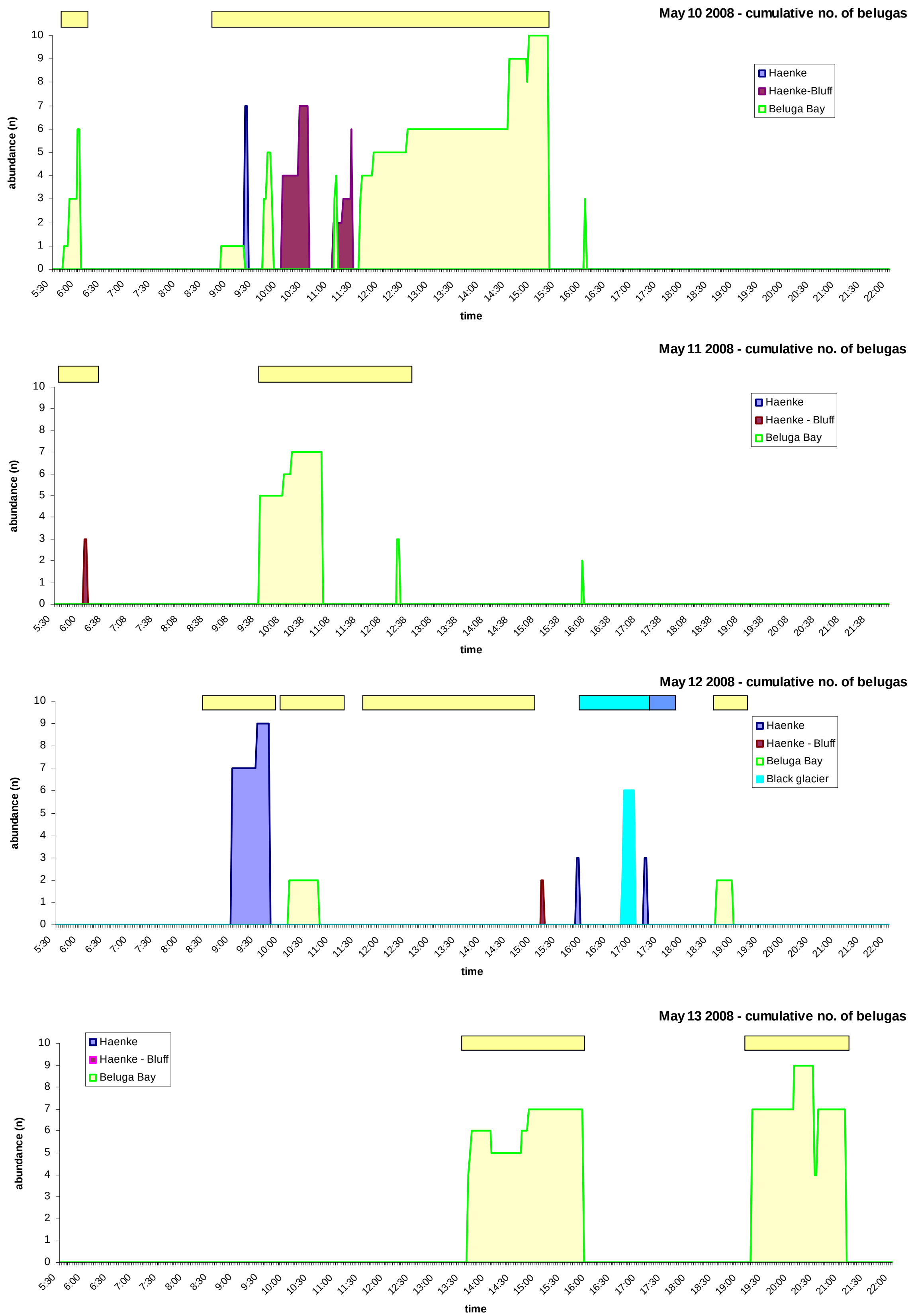
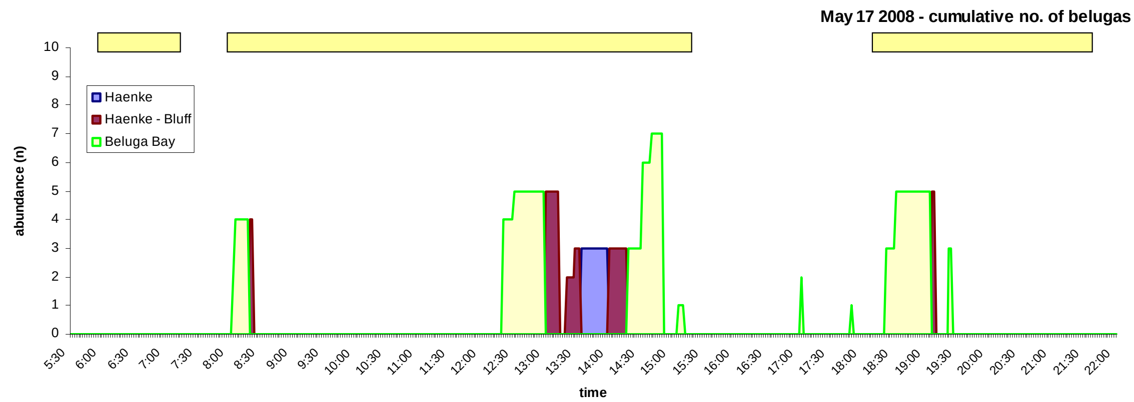


Fig. 8. Beluga whale abundance and habitat use in upper Disenchantment Bay.



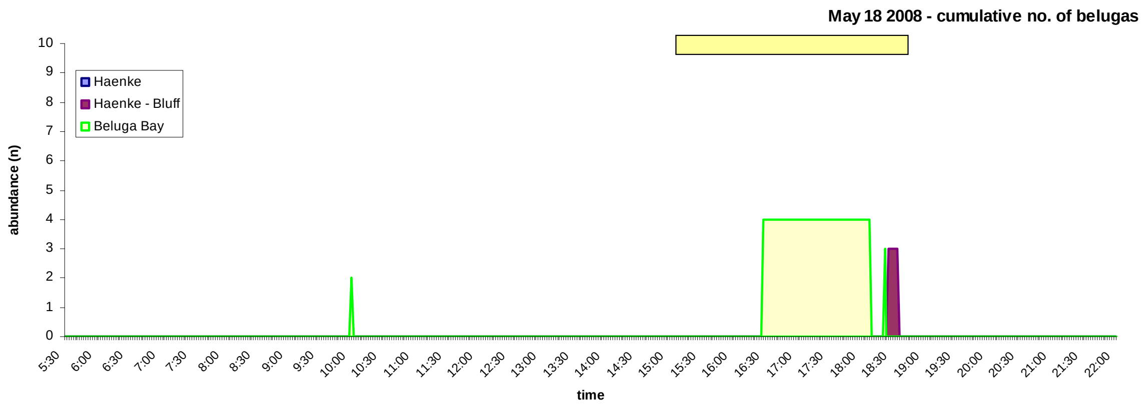


Fig. 8 continued. Beluga whale abundance and habitat use in upper Disenchantment Bay based on shore-based visual observations. Whale sightings were classified into 4 areas: (1) Beluga Bay (yellow), (2) Beluga Bay to Haenke Stream (wine) which extends from the bluff at the entrance to Beluga Bay to the stream, (3) Haenke Stream (blue) and (4) Black glacier (turquoise). The latter location allowed observations southwest across the face of Turner glacier. Abundance is given as cumulative estimates of the number of whales present. Time on effort is indicated by the bars across the top of each graph, the color corresponding to the geographic location of the observation post(s).

Fig. 9. Beluga whale calf, likely young-of-year, in Disenchantment Bay, Yakutat Bay, May, 2008.

Abundance, group size and composition

The maximum number of confirmed whales observed was 10. Most sightings, however, consisted of 3 to 7 whales (mean = 4.13, Fig. 10). Group composition varied from small, single sex groups of adults or adult-calf pairs to larger mixed-age and -sex groups, with the larger groups often consisting of two or more smaller sub-groups. Most of the lone whales were white adults while the maximum number of whales observed at one time comprised 2 adult-calf pairs (presumed mother-calf pairs), 3 large, white adults (likely males) and 3 grey animals of intermediate size. One of the calves was likely a young-of-the-year (Fig. 9). One grouping of three large white animals was consistently seen on most days. Presumably three adult males, one of which was heavily scarred, they were dubbed ‘los trés amigos’. These three white animals were rarely observed to interact with other whales. In many cases, estimated group size increased during the period of observation (see Fig. 8), which may be an artifact of the method (i.e., increasing sightability with time) or could reflect the arrival and fusion of sub-groups over the course of observation.

In some instances it was possible to track the movements of groups of whales between areas using the sequence of sightings, and group size and composition. On May 10 whales were observed moving between Beluga Bay and Haenke Stream (Fig. 8). On May 12, we tracked whales on foot moving between Haenke Stream and the face of the Turner Glacier and back. On three separate occasions on May 17 whales were observed in Beluga Bay followed by transiting to Haenke stream. In one instance whales were observed for long enough to record a return from Haenke back to Beluga Bay. Variable group size estimates over the course of these prolonged observations, however, indicate that we were probably missing some whales and/or that we were observing multiple groups that fused and split throughout the observation period.

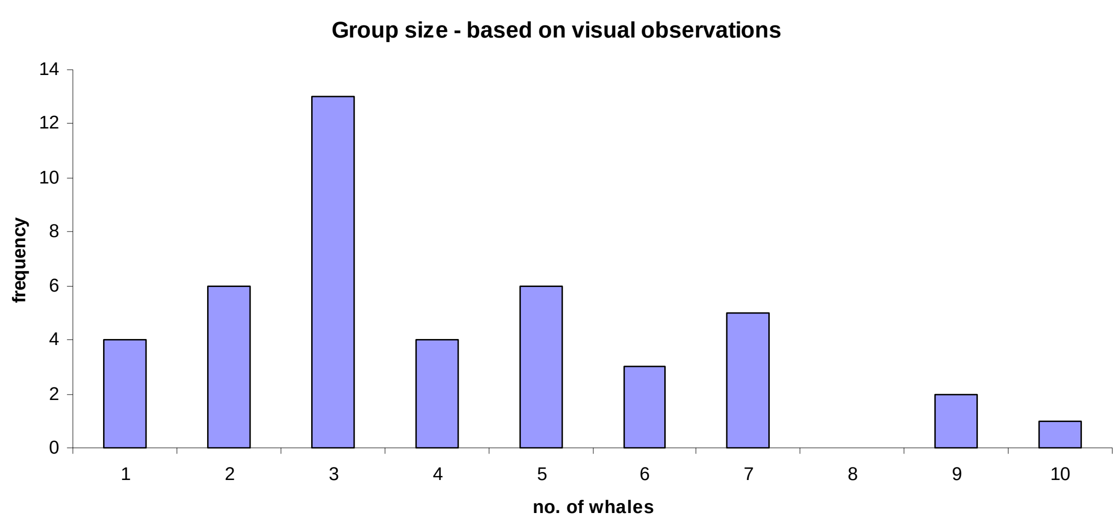


Fig. 10. The frequency of different group sizes observed in Beluga Bay over seven days in May 2009

Photo-Identification

A photo-identification catalogue was initiated during the field study to assess abundance, life history (age structure, survival, body condition, reproductive success), predation, habitat use, association patterns and behavior. A total of 960 digital SLR photographs of beluga whales were taken and are currently being screened for photo-matches using the procedure developed by Harbor Branch Oceanographic Institute's marine mammal program. Several whales displayed scars on the dorsal ridge and flanks that aid with identification, and a number of recognizable individual whales were observed on multiple occasions during the project. Figure 11 depicts a photo-match of a highly scarred individual photographed more than three days apart. Intra-specific interactions, molting, ice or human interactions (e.g., net, boat strike) were considered unlikely causes of deep scaring observed on at least one individual (Fig. 11). We provisionally concluded this whale's scars were characteristic of a predator interaction, likely killer whale.

(A). 13:23 hours, 5/10/2009 Beluga Bay

(B). 20:14 hours, 5/13/2009 Beluga Bay

Fig. 11. qualitative photo-match of an adult beluga whale (right side) observed in Beluga Bay on May 10th (A) and May 13th (B).

Environmental conditions greatly influenced photo quality, and hence match success. Taking photos from shore as opposed to boat follows minimized impacts on whale behavior and often resulted in the close approach of whales to the photographer.

Ethogram

Whale behavior was documented during visual observations and categorized into six broad classes (Table 1). These categories represent somewhat subjective interpretations of the likely function of these observed behaviors and thus should be treated with caution until further research can confirm their meaning.

Table 1. Types of beluga whale behavior observed in Upper Disenchantment Bay in May 2008 and their likely function.

Observed behavior	Interpretation	Code
Prolonged directed movements at moderate speed, regular surfacing at short intervals (<1min.)	Travel	T
Milling at surface, diving in same location, rapid movements at surface, rapid turning, dives up to 8 min.	Feeding	F
Slow movements at surface, non directional, often near others	Resting	R
Contact, spy-hops, splashing, fluke wave, sexual (i.e., penis) display	Socializing-Mating	S
Change in direction followed by directed movements away, few surfacings	Avoidance	A
Whale surfaces with head and dorsum covered in mud	Feeding/Molting	F/M

The meanings of many behaviors were ambiguous as they may have had more than one function. For example, whales observed moving in a directed manner may have been foraging as well as traveling between areas. Similarly, whales sometimes congregated in one area, performed dives of varying duration and interacted with each other (i.e., contact, bubble blasts, etc.), suggesting that they may have been involved in a number of activities including feeding and socializing. Avoidance behavior was not always obvious, the few times it was clearly observed was during the deployment of acoustic recorders. On these occasions this behavior was typically preceded by an approach to the scientist(s) (who were either in a raft or kayak or standing in water near shore) that suggested investigation of the unusual activity. One behavior that requires further research was the observation on two separate days in Beluga Bay of whales surfacing with much of their head and back covered in fine grain mud or silt (Fig. 12). This suggests either molting activity or possibly predation on benthic prey.

Preliminary analysis of the frequency of occurrence of the major behavioral categories revealed that almost half of the time whales were observed they were traveling (Fig. 13). Apart from a single instance of avoidance behavior almost all our observations (97.7%) in the area between the Bluff at the mouth of Beluga Bay and Haenke Stream involved whales in transit between these two areas. By contrast, behavior interpreted as likely to reflect feeding was regularly seen at Beluga Bay (23.17%) and at Haenke Stream (59.52%) where it was the most commonly observed activity. Behaviors interpreted as likely to represent resting, social interactions and in one instance potential sexual activity (i.e., contact and penis display), as was the aforementioned possible molting/benthic feeding behavior, were only observed in Beluga Bay.

Fig. 12. Beluga whale surfacing with fine grain silt and mud on back and flanks, Beluga Bay, upper Disenchantment Bay, May 2008.

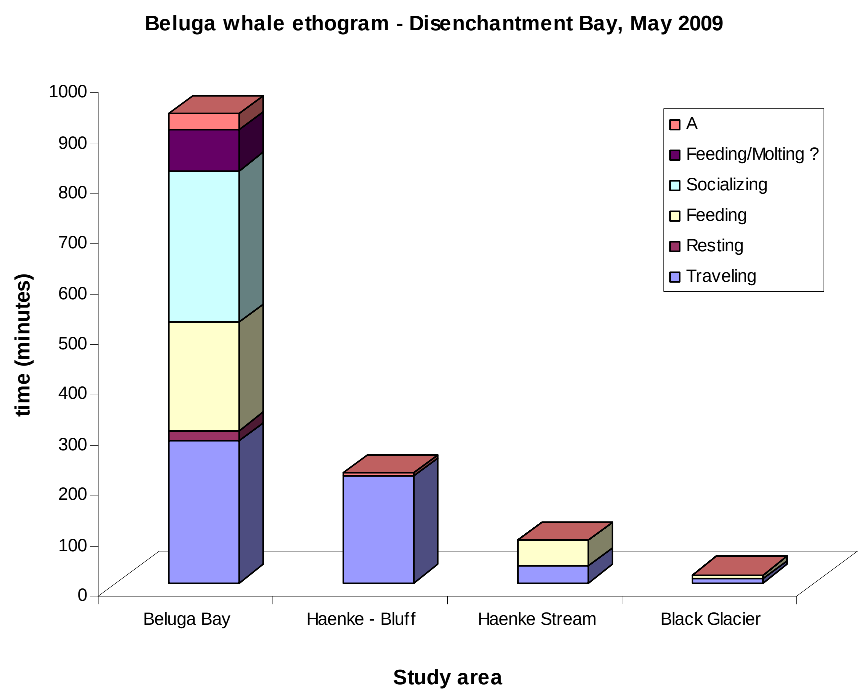
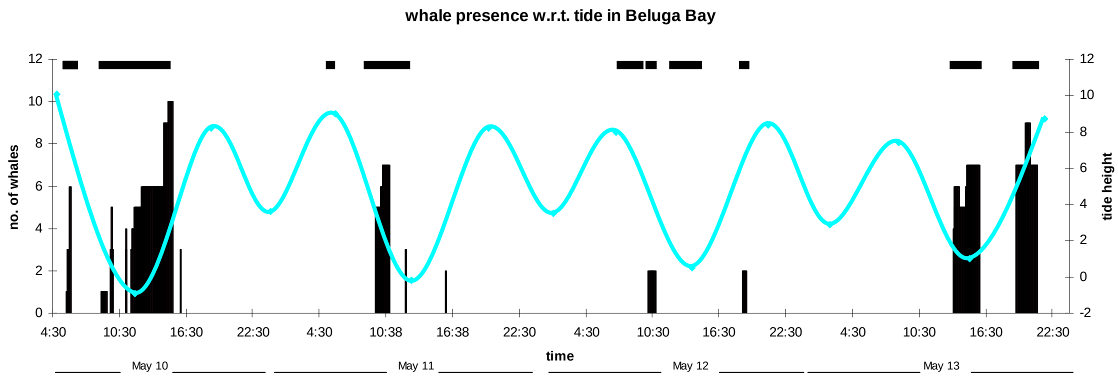


Fig. 13. Beluga whale ethogram, upper Disenchantment Bay, May 2008. Behavioral categories are described in Table 1.

Environmental variates – tide and time of day

Over the course of the field study, whales were observed in Beluga Bay at all phases of the tidal cycle. Plotting whale sightings against tide suggests that the majority of sightings occurred at or near low tide (Fig. 14). Observation effort, however, varied greatly throughout the course of the study (Fig. 6).

A.



B.

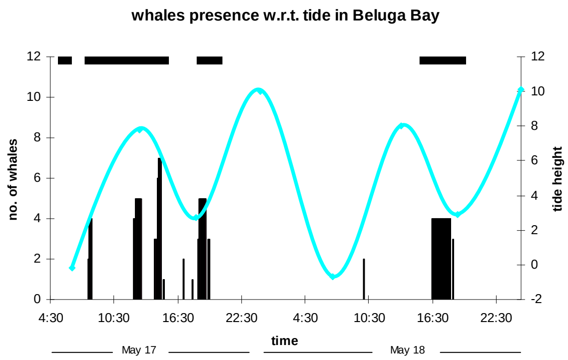


Fig. 14. Whale presence in Beluga Bay in upper Disenchantment Bay in relation to tide. The two graphs represent the two primary study periods: (A) May 10 -13 and (B) May 17-18. Tide height is indicated by the blue line. The black bars across the top of the graphs represent periods of visual observation effort.

In order to separate the effects of observation effort and tide on whale presence in Beluga Bay, we estimated the proportion of time whales were observed *when on effort* for different phases of the tidal cycle. The daily tidal cycles were divided into four phases: High, Falling, Low and Rising. Low and High tide phases were defined as two-hour periods centered on the predicted time of high and low tide, respectively from the Yakutat Bay Tide Tables. The Falling and Low tide phases were defined as the respective intervening time periods, and were typically of longer duration. Observation effort and the time whales were in view were then estimated for successive tide phases. Preliminary analysis suggest there may be an effect with the longest observed residence times in Beluga Bay occurring during low and falling tides and the shortest during high tide (G=14.59, P<0.005; Fig. 15b). It should be noted, however, that observation effort was also lowest during predicted high tides (Fig. 15a).

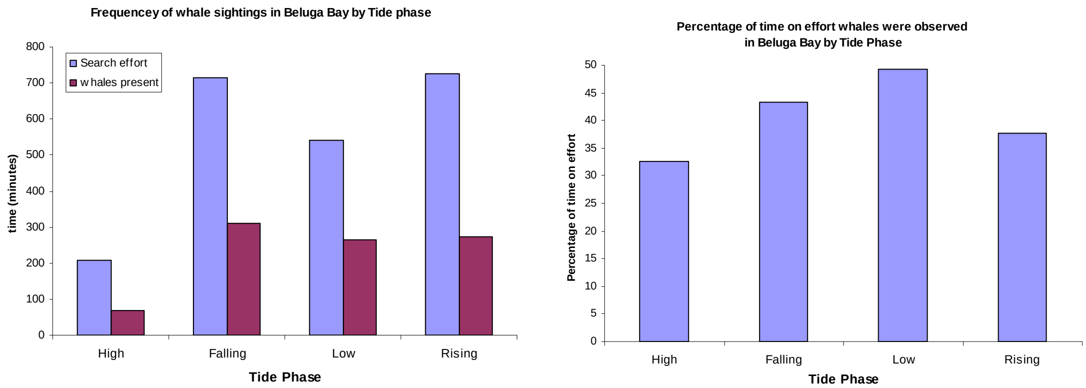


Fig. 15. Whale sightings in Beluga Bay in relation to tidal phase.

Time of day also seemed to affect sighting rate. Even when differences in sighting effort were taken into account, the highest sighting rate occurred, on average, during the six hour period from 12:00 to 18:00 hours ($G = 165.16$ $P < 0.001$; Fig 16).

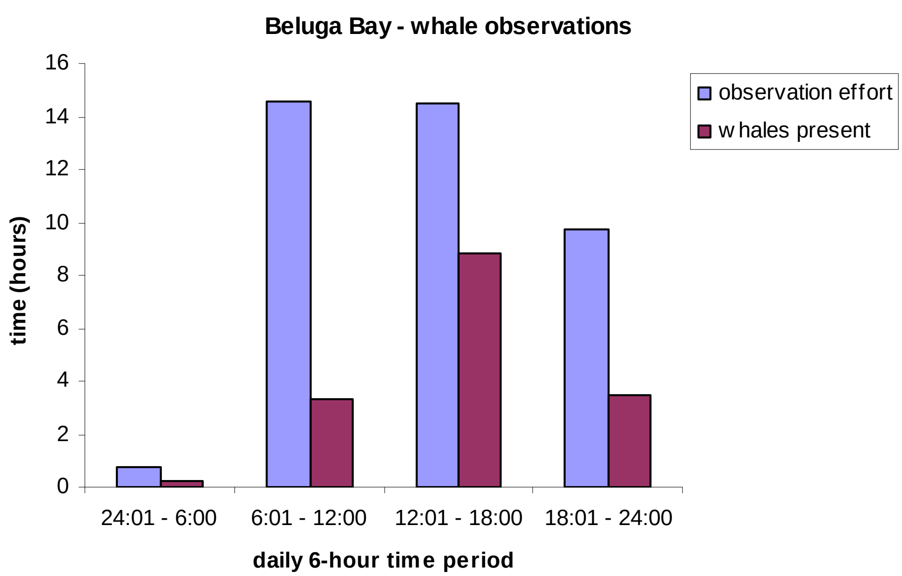


Fig. 16. Cumulative time whales were observed in relation to cumulative visual observation effort by time of day in Beluga Bay, May 2009.

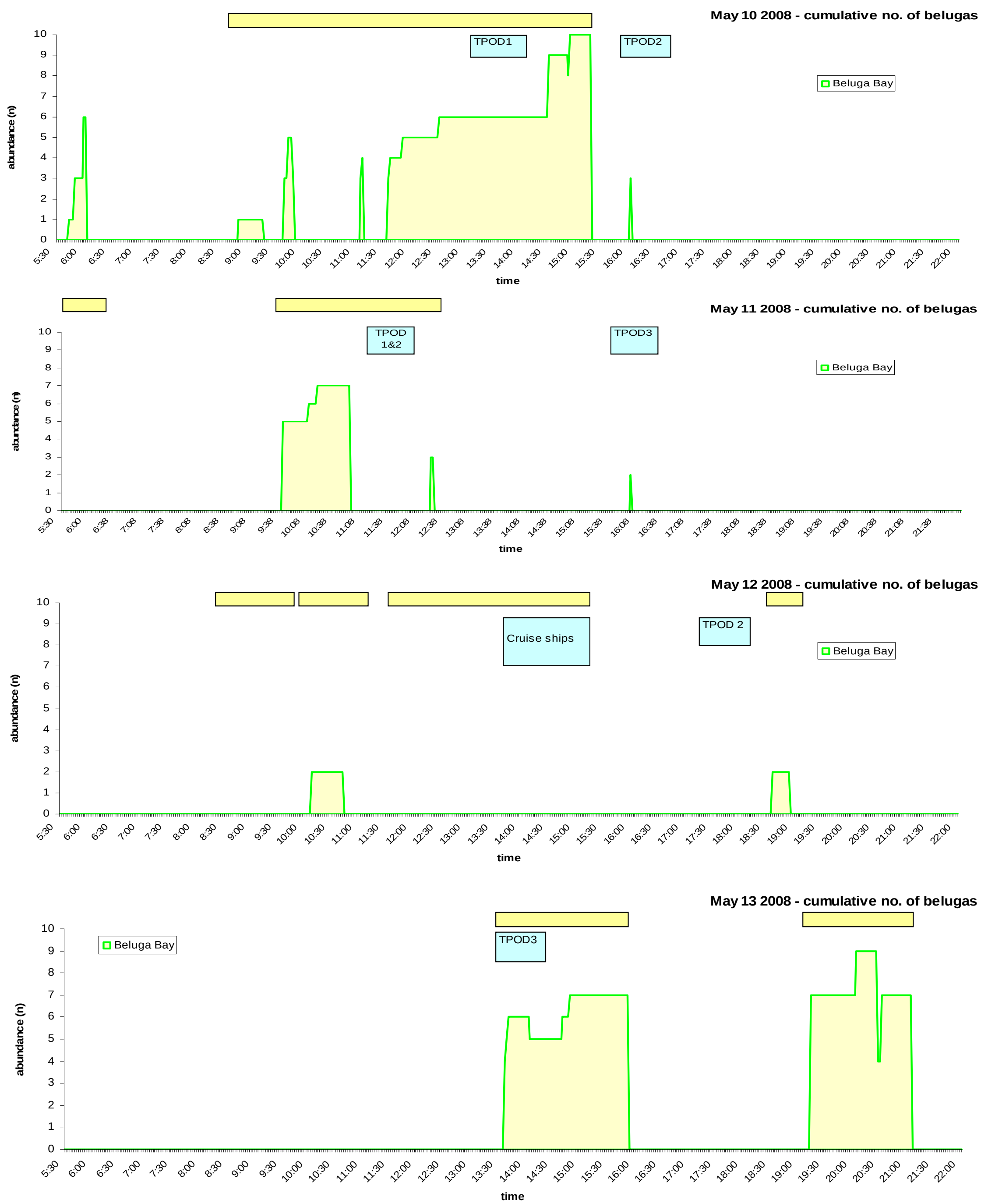


Fig. 17. Beluga whale abundance and habitat use in Beluga Bay based on shore-based visual observations in relation to human activities associated with the deployment/recovery of acoustic recorders and the collection of biopsy samples, and cruise ship presence in Disenchantment Bay. Blue shaded boxes span the time periods of the research activities in or on the water and when ships were near Hubbard and Turner glaciers. All other features as in Fig. 8.

Fig. 17. continued

Disturbance

The deployment and retrieval of acoustic recorders and mooring systems, tissue sample collection efforts, and cruise ship presence were monitored for potential impacts on whale presence in Beluga Bay. Detailed analyses of these data has yet to be completed. Initial qualitative assessments, however, suggest that research activities on the water in some instances had a temporary effect on whale presence (Fig. 17). This was also evident in the ethogram where behavior that was provisionally interpreted as avoidance behavior was documented (Fig. 13). In many instances whales remained in the area during the research activity or soon returned after the work was completed. On a number of occasions, whales approached scientists when in the water or on a small raft (the researchers that is, not the whales!), on one occasion within 2m of the vessel. Cruise ships were observed in upper Disenchantment Bay, close to Hubbard and Turner glaciers on only one occasion. Whales were not observed for a number of hours prior to our sighting of the ships. Unfortunately, visual observations were discontinued for a period just after the ship’s departure.

DISCUSSION

This part of the 2008 Yakutat beluga whale study further demonstrated the utility of shore-based observations in recording movements and habitat use of beluga whales in Disenchantment Bay. This approach was also successful in determining abundance, group size and composition and in documenting behavior. Furthermore, the field study successfully established a photo-identification based catalogue of individual whales and used photography in documenting predation pressure, and behavior.

Habitat Use

In 2005 a similar field effort was undertaken and revealed that the small embayment between the terminus of the Hubbard Glacier and the Haenke and Turner Glaciers, known since then as Beluga Bay, was an area of high use by a small group of beluga whales in early summer (O'Corry-Crowe, 2006). That study also identified two other locations in upper Disenchantment Bay where whales regularly occurred during the May 3 - May 19 study: Turner Glacier and a narrow strip along the shore between Beluga Bay and Turner.

Concentrating on Beluga Bay and the strip of coastline between it and Turner, the current investigation quantified habitat use for the first time, including diurnal patterns of habitat use, and revealed that whales spent a large portion of time in or near Beluga Bay each day between May 10 and May 19. Groups of whales were observed in the Bay on up to 8 separate occasions a day, spending from just a few minutes to over 3.7 hours there at a time. Across the period of the field study whales were sighted in Beluga Bay, on average, over 40% of the time spent on effort, although on some days this climbed to 65% and over 4.7 hours. Considering the limited amount of time spent each day scanning for whales (3.1 to 11.75 hours), the proportion of times whales were missed (yet to be quantified by comparison with the acoustic data), and the intermittent disturbance caused by our presence, whales likely use this habitat for 10 or more hours, on average, each day. This begs the question, why. The ethogram (see below for more discussion) suggests that the Bay has multiple uses, including a location for resting, socializing, feeding and possibly molting. Another, as yet un-quantified reason suggested by the scaring on some adults may be predator avoidance. The deep scars on the back, flanks and tail stalk of one individual were confirmed as likely killer whale, *Orcinus orca*, by Craig Matkin (North Gulf Oceanic Society, Homer, Alaska). Killer whales are known to regularly occur in mid and lower Yakutat Bay (W. Lucey, pers. obs.) but have not been observed within the glacial ice field in Disenchantment Bay. Beluga Bay may thus be an ideal retreat for beluga whales in not only lying deep within the extensive ice field but also in remaining relatively ice free itself much of the time. This latter attribute is presumably due to its geographic location and bathymetry relative to the Hubbard and Turner Glaciers.

Two other areas of localized use were the mouth of Haenke Stream and the coastal strip between this water course and Beluga Bay (Fig. 3). Although search effort was limited in these locations, our impression was that for much of the time that whales were not (in view) in Beluga Bay they were not present at these two locations either, indicating that they have a larger summer range. This was also the case in 2005 and was confirmed in 2008 by sightings of whales further south near Turner Glacier on the one day we ventured past the Black Glacier. Future observation-based research must, therefore, combine the larger search area of the 2005 study with the systematic sampling of the 2008 study. A complete picture of beluga whale movements and habitat use in Yakutat Bay and neighboring waters throughout the entire year is only possible through satellite-linked telemetry. Such studies should entail the remote deployment of satellite tags, either via projectile tags or jab-stick, as opposed to capture-based methods. Predator-prey studies need to be initiated including the continued documentation and examination of scars and the assessment of killer whale presence and ecology in Yakutat Bay. The latter should include acoustic surveys, sighting records, photo-ID, interviews and biopsy sampling, and ultimately telemetry.

Recommendation: Future research must combine the larger search area of the 2005 study with the systematic sampling of the 2008 study.

Generate more accurate estimates of habitat use by comparing acoustic detection rates to visual detection rates.

Initiate satellite-linked telemetry study to determine whale movements and habitat use within Yakutat Bay and neighboring waters.

Initiate a predator-prey study, focusing on killer whales, in Yakutat Bay. Methods to include: acoustic surveys, sighting records, photo-ID, interviews and biopsy sampling, and ultimately perhaps telemetry

Abundance, group size and composition

A total of ten whales were observed, two less than the maximum count in 2005. While no newborn calves were observed in the earlier field season, two calves, one likely less than one year old, were observed in 2008 (Fig. 9). That the triad of large white animals often remained in close proximity to each other and apart from other whales suggests that there may be some age and sex segregation. Similarly, much of the social interactions observed involved grey animals while lone whales tended to be white adults. These findings are the first look into beluga whale social structure in Yakutat Bay. A more complete analysis of social structure requires investigation of beluga whale interactions and long-term analyses of association patterns, group composition and genetic relationships (Whitehead et al. 2000). Fortunately, we have chosen the tools necessary, including visual and acoustic monitoring, photo-ID and genetic analysis.

The low number of the Yakutat whales is not clearly understood. The evidence of a likely killer whale attack suggests that predation is a factor. To fully address this, the life history of individual whales must be followed, the genetic component of fitness investigated and mortality factors quantified.

Abundance estimation and further elaboration of group composition will require genetic mark-recapture studies and biopsy sampling of known whales, and the estimation of age through long-term observations. Such methods employed in a longitudinal study are also required to estimate basic life-history parameters including reproductive success and survival, essential components in any analyses of population viability.

Recommendation: Future research must entail biopsy sampling of groups, preferably of photo-catalogued individuals.

Establish long-term observation of known individuals to resolve social structure and estimate life history parameters essential for effective management

Environmental variates

Any analysis of a relationship between habitat use and tide, or time of day or any other environmental variable, must take observation effort into account as well as how different environmental parameters co-vary. The preliminary results from 2008 suggest that tide had an effect and that there was some evidence of a diel pattern to whale use of the study area. Reasons for these observed patterns must remain speculative at this stage. Observation effort was limited, the number of environmental variables investigated was small, and the level of detail recorded on whale location within the study area was insufficient to assess the influence of environmental co-variates on whale behavior. Other physical parameters need to be investigated including ice cover and water temperature, more observation effort is required, and the utility of combining visual with acoustic monitoring (see Section I) must be further explored.

A fundamental understanding of any correlation or relationship between whale behavior and physical environmental variables also requires study of the biological relevance of these physical features. This includes how these features influence food availability, predation pressure and competition and thus foraging behavior, reproduction and survival.

Recommendation: Greater observation effort is required, more detailed data on whale location and behavior, and more environmental data should be recorded.

Studies on beluga whale foraging ecology, including diet, prey availability and foraging behavior (e.g., dive patterns) need to be undertaken

Photo-Identification

Photo-identification was tested as a potential field tool in 2005 but was not used in a systematic manner until this year. In 2005, several whales were observed with thin, linear scars on and near the dorsal ridge. Many appeared to be superficial scars and were considered to be due to rubbing on the substrate to remove dead skin. Similar scars were observed in 2008, especially on some of the larger grey animals. A new development in 2008 was the much deeper scaring on some of the large white individuals (Fig. 11). Criteria for assessing photo-matches are currently being developed. An extensive photo-catalogue has recently been established on beluga whales in Cook Inlet (McGuire and Kaplan, 2009). Continuous comparison of both catalogues is needed to monitor potential movements between both locales, while methods used in photo-matching should be compared and streamlined.

Recommendation: The photo-ID study should be continued and expanded. A second year of data is required to finalize criteria for photo matches.

Long-term photo-ID is required to estimate life-history parameters including survival and reproductive success, and predation pressure

Behaviour

The assessment of beluga whale behavior is still very much in the descriptive phase and the interpretation of behavior function will require further field observations in concert with coordinated investigations of acoustic behavior. The ethogram needs to be developed further, including more precise definitions of short-duration (i.e., event) and long-duration (i.e., state) behaviors. Intra- and inter-observer differences and other potential biases will also need to be identified and quantified (Mann 2000). Nevertheless, the 2008 field season yielded a lot of valuable data on whale behavior and produced the first ethogram we are aware of for this species in the North Pacific Ocean. The behavioral data along with information on habitat use confirm our earlier conclusions about the importance of the small bay between the Haenke/Turner and Hubbard glaciers, at least during the spring and summer. Beluga Bay appears to be the primary location for social interactions and resting behavior, but also seems to be an important foraging location and possible molting site. Similarly, the glacial stream at the foot of Haenke glacier appears to be an important foraging area. More observation effort needs to be placed at this location and at the Turner glacier which was only under observation on one occasion in 2008. This was because conditions were too hazardous for shore-based observations. On that one occasion whale behavior was consistent with foraging. This agrees with our 2005 data when more observations were made at this location.

Resolving the function of cetacean behaviors requires innovative methods of documenting behaviors beyond traditional visual observation techniques (Whitehead et al. 2000). The deployment of acoustic recorders at the same time visual observations were being conducted (see Section I), provided a unique opportunity to assess observed beluga behaviors in the context of acoustic behavior and vice versa. While analysis of this relationship has yet to be completed for the 2008 data, the field study successfully demonstrated that longitudinal studies of beluga whale behavior, employing a range of techniques, could be conducted in Alaska.

A picture is beginning to emerge of a number of diverse habitats visited daily by beluga whales in Disenchantment Bay in late spring - early summer. The findings to date enable us to generate a number of clear hypotheses about habitat importance and behavior that can now be tested including likely foraging, molting, resting and socializing areas and transit corridors.

Recommendations: Conduct surveys of prey availability and quality at several sites in Yakutat and Disenchantment Bay.

The beluga whale ethogram needs to be developed further. Visual observations should continue in conjunction with acoustic monitoring and photo-ID.

To understand social organization and the social context of habitat use and other activities, the type, frequency and patterning of behavioral interactions must be measured.

Preliminary comparison of acoustic and behavioral observations

In general, there was strong agreement between visual and acoustic detection of whale presence. No clicks were logged when whales were not observed in Beluga Bay or Haenke Stream (Section I, Fig.16), and the sequence of visual sightings between these two areas matched that of acoustic detections.

From a sampling standpoint, acoustic detection spanned a much longer time interval than visual observations. Acoustic detectors were deployed continuously at one or more locations for over 214 hours from May 10 to May 20, 2009 (Section I, Table 1) compared to a total of 40.28 hours of directed observations. The deployment and recovery of the acoustic recorders, however, did affect whale behavior. This was apparent from both visual observations and acoustic sampling. Total daily T-POD detections were often low on the day of deployment (Section I, Fig. 3). This was due in part to the limited amount of time the T-POD was in the water that day but is also possible evidence of avoidance behavior. The visual monitoring suggests that the effects of these activities, which sometimes involved wading into the water up to our chest as well as working from a small raft, were limited and short term. Whales either remained in the general vicinity or returned soon afterwards. The longer term effects of this work, however, must await further study in 2009.

Daily variation in click detections at each T-POD location also suggests changing patterns of habitat use by the belugas *within* the bay over time that was not systematically recorded by the visual observations. For example, the highest number of beluga clicks at the T-POD closest to the camp site (T-POD 1) was on May 15th, and the second highest was on May 14th (Section I, Fig. 3). These were the two days in the middle of the field project we had vacated the study area (and thus made no visual observations). This suggests potential localized disturbance by camp activities resulting in temporary avoidance behavior. Significantly perhaps, the number of clicks recorded at the T-POD in Beluga Bay furthest from our camp (T-POD 4) were lowest on these same 2 days. Notwithstanding the effects of the late deployment of T-POD 4 on May 14th, this suggests that the whales shifted their activity from this part of the Bay to the area close to camp. The pattern was reversed upon our return to camp on May 16th, potential further evidence of localized avoidance.

Any inference about whale presence, movements and abundance from T-PODs, however, must take the echolocation activity per whale into account, both the number of click trains and the pulse repetition frequency (i.e., clicks/sec.). This presumably is related to both behavior and environmental variables. For example, foraging or exploratory behavior will likely involve greater echolocation activity than when whales are at rest. Similarly, whales that pursue highly mobile prey may produce a higher click rate than whales foraging on more sedentary food sources. Thus, the high number of clicks recorded at T-POD1 (near camp) on May 15th might reflect exploration of the devise and mooring system rather than a shift in habitat use (see Section I).

Behavioral differences may also explain, in part, the apparent contrasting findings between acoustic and visual sampling on whale presence in relation to tide. In Beluga Bay, the number of clicks detected was highest during high tide (Section I, Fig. 8), while whales were observed more of the time, on average, at low tide (Section II, Fig.15). Other factors, as well as changes in click rate, may be at play here. The acoustic study revealed that the angle at which the TPOD rested in the water column was related to tide: close to vertical at high tide compared to near horizontal at low tide (Section 1, Fig. 7). If the angle influenced the detection field of the device, and thus the number of clicks detected per unit of time, this may contribute to observed correlations between the total number of clicks and tide. On the other hand, the low amount of time spent observing whales relative to acoustic monitoring, especially during periods of high tide, severely limited our ability to adequately test tidal influences with the visual data to date.

Clearly, these issues need to be resolved before click number, click frequency, or whale vocalizations in general, can be used as a proxy for whale presence, movements and abundance.

Recommendations: Repeat the field effort of 2008 in 2009 to: increase data quantity and statistical power, and to further investigate the potential impact of research activities on whale behavior.

Conduct more systematic visual observations in tandem with acoustic monitoring to describe and quantify beluga whale presence, abundance and behavior in relation to acoustic activity. Initiate this study with baseline visual data prior to deployment of acoustic loggers.

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Tess, bear dog extraordinaire

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