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Summer, Fall, and Early Winter Behavior of Beluga Whales, *Delphinapterus leucas,* Satellite-tagged in Cook Inlet, Alaska, in 1999 and 2000

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SUMMER, FALL, AND EARLY WINTER BEHAVIOR OF
BELUGA WHALES, *DELPHINAPTERUS LEUCAS*,
SATELLITE-TAGGED IN COOK INLET, ALASKA,
IN 1999 AND 2000

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ABSTRACT

The following report contains detailed information on the movement patterns of beluga whales that were satellite-tagged in 1999 and 2000 in Cook Inlet, Alaska. The seasonal movements and dive patterns of three whales CI-9901, CI-0001, and CI-0002 were analyzed, and movement data from the whales tagged in 2000 were referenced to in a subsequent paper by Hobbs et al. (2005). However, the detailed analyses of diving behavior and movement patterns of these individual whales were never made available until now.

The seasonal movements and dive patterns of three belugas in Cook Inlet, Alaska, were monitored between June and January 1999-2000 using satellite telemetry. One adult male whale was tagged on 30 May 1999 and tracked until 16 September 1999 (109 days), and one juvenile female and one adult male were tagged on 13 September 2000 and tracked until 2 (115 days) and 18 January 2001 (124 days), respectively. Whales remained in the inlet the entire time they were tracked. Mean dive depths across the entire tracking period ranged from 2.6 m (SD = 5.2) to 5.2 m (SD = 8.8). Mean dive durations ranged from 1.4 minutes (SD = 2.0) to 3.1 minutes (SD = 4.1). Overall mean time at surface (between 0 and 1 m) ranged from 23% to 70% and appeared to be related to season and location. Behavioral periods were identified for each whale (4-60 days) based on stationary movements in a particular part of the inlet and unique diving behavior during that time. Significant differences were found between diving behavior and tidal rate of change and direction, as well as whale location and average sea-ice concentration. Belugas in Cook Inlet display seasonal variation in dive behavior and movement patterns, both of which have implications for sightings rates, correction factors, and abundance estimates obtained for the population.

CONTENTS

INTRODUCTION

Beluga whales (*Delphinapterus leucas*) in Cook Inlet are the most geographically and genetically isolated of the five stocks recognized around Alaska (Ferrero et al. 2000, O'Corry-Crowe et al. 1997, Hill and DeMaster 1998). This isolation, in combination with their tendency toward site fidelity in summer (Rugh et al. 2000), makes them particularly vulnerable to both environmental and anthropogenic impacts (Hill 1996, Moore et al. 2000). Between 1994 and 1998, the Cook Inlet beluga population declined by nearly 50% to an estimated 347 whales (CV = 0.29) (Hobbs et al. 2000). The Native hunt of approximately 70 whales per annum in Cook Inlet (Mahoney and Shelden 2000), believed to be responsible for the decline, virtually ceased in 1999, and whale abundance was 367 (CV = 0.14) in 1999 and 435 (CV = 0.23) in 2000 (Hobbs et al. 2000), when the population was listed as depleted under the U.S. Marine Mammal Protection Act (Federal Register 65:34590-34597).

Belugas are seen in Cook Inlet all months of the year (Rugh et al. 2000), however, the distribution of whales outside of summer months is not well known and has been considered enigmatic (Huntington 2000). Aerial surveys have documented the distribution of belugas in Cook Inlet during June and July 1993-2000, when whales remain in dense groups in the northern part of Cook Inlet, concentrated near shallow, low-salinity river outflows presumably feeding on salmon and other fish runs (Rugh et al. 2000, Moore et al. 2000). Belugas are observed to remain in these dense groups through August. In autumn, belugas are believed to disperse south into the lower and middle part of Cook Inlet, where they remain throughout the winter. Surveys for belugas in February-March 1997 encountered small, scattered pods in the central part of the inlet (Hanson and Hubbard 1999), and numerous opportunistic sightings have been reported throughout the year. It has been suggested that belugas disperse into the Gulf of Alaska in winter (Calkins 1983, Hubbard et al. 1999), because fewer sightings are reported in the upper Inlet in winter months. Sporadic sightings outside of Cook Inlet have occurred in all seasons, however, these sightings of belugas are considered rare (< 30) relative to the survey effort (> 150,000 km) and many other cetacean sightings documented for the Gulf of Alaska and adjacent inside waters during the past 30 years (Laidre et al. 2000). Thus, the late fall and winter movements of the population remain unclear.

Information obtained on seasonal movement patterns from individual whales with satellite tags can be used to corroborate aerial surveys and opportunistic sightings. There has been only one study on the movements and diving behavior of belugas in Cook Inlet utilizing suction-cup attached VHF radio transmitters to characterize surfacing behavior and dive intervals (Lerczak et al. 2000). VHF technology provides general information on surfacing frequency and time spent below the surface. However, radio tags must be continuously monitored from close range to obtain detailed information on movements and dive behavior and less than 20 hours of data have been collected by this method. Satellite telemetry has proven to be a useful tool to monitor the movements and dive behavior of belugas in the high Arctic (Heide-Jørgensen et al. 1998; Martin and Smith 1992, 1999; Richard et al. 1998; Kingsley et al. 2001; Martin et al. 2001; Suydam et al. 2001). The decrease in tag size (mounted on the dorsal ridge) and increase in tag longevity (both battery life and attachment time) have facilitated the remote and continuous collection of data from individual whales for many months at a time.

Belugas are known to be exceptional divers and routinely reach depths of > 650 m in the Arctic Ocean (Heide-Jørgensen et al. 1998, Martin and Smith 1999, Martin et al. 1998, Shaffer et al. 1997). Such dives are assumed to represent foraging behavior (Martin and Smith 1992, 1999). It is important to note belugas in Cook Inlet are obviously limited by the depths of their surroundings, where the general depth of the inlet is approximately 73 m, and maximum depths are found as deep as 366 m at the entrance near the Barren Is. (Mulherin et al. 2001). The bottom topography of Cook Inlet is reported to be extremely rugged, with dramatic changes in depth and many relatively deep locations adjacent to shoals (Mulherin et al. 2001). Rapid changes in the tidal basin make it difficult to fully assess bottom contours. General depth classifications for specific regions may include undocumented pockets or channels with deeper water.

Ice cover in Cook Inlet is seasonal, forming in the fall (generally October) and disappearing completely in the spring. By December about half the Inlet area north of the Forelands is normally covered in pancake ice (up to 10 cm thick) and thin ice (30–70 cm thick) ranging in concentration primarily from open (10%) to close pack (70% to 80%) (Mulherin et al. 2001). The ice extent and thickness increase through late January and February, where maximums are reached in mid-February to early March. During colder winters the ice may extend into the lower inlet as far south as Anchor Point on the eastside and Cape Douglas on the west side (Mulherin et al. 2001).

In this study, satellite telemetry was used to monitor the movements and dive patterns of three belugas in Cook Inlet between June and January. This study used an individual-based approach to relate seasonal variation in movement patterns and associated changes in diving and surfacing behavior to physical and biological features in Cook Inlet, Alaska. The following report contains detailed information on the movement patterns of beluga whales that were satellite-tagged in 1999 and 2000 in Cook Inlet, Alaska. The seasonal movements and dive patterns of three whales CI-9901, CI-0001, and CI-0002 were analyzed, and movement data from the whales tagged in 2000 were referenced to in a subsequent paper by Hobbs et al. (2005). However, the detailed analyses of diving behavior and movement patterns of these individual whales were never made available until now.

MATERIALS AND METHODS

Three belugas were instrumented with SDR-ST-16 (Telonics, Mesa, AZ) satellite-linked radio transmitters (Wildlife Computers Ltd., Redmond, WA) in 1999 and 2000. One adult male (CI-9901) was instrumented on 31 May 1999 at the mouth of the Big Susitna River in upper Cook Inlet, and one juvenile female (CI-0002) and one adult male (CI-0001) were instrumented on 13 September 2000 in Knik Arm, in the vicinity of Eagle Bay (Fig. 1). Whales were captured using set nets deployed from a boat using a modified encirclement technique (Ferrero et al. 2000). All three tags contained a pressure transducer, conductivity sensor, four C-cell batteries, and a microprocessor cast in epoxy. The tag deployed in 1999 was glued to a flexible rubber saddle with holes for attachment via four threaded nylon pins secured with nylon nuts and washers. The tags deployed in 2000 incorporated three Monel cables into the epoxy casting, which were attached to both ends of three pins through the dorsal ridge of the whales with nylon nuts and washers.
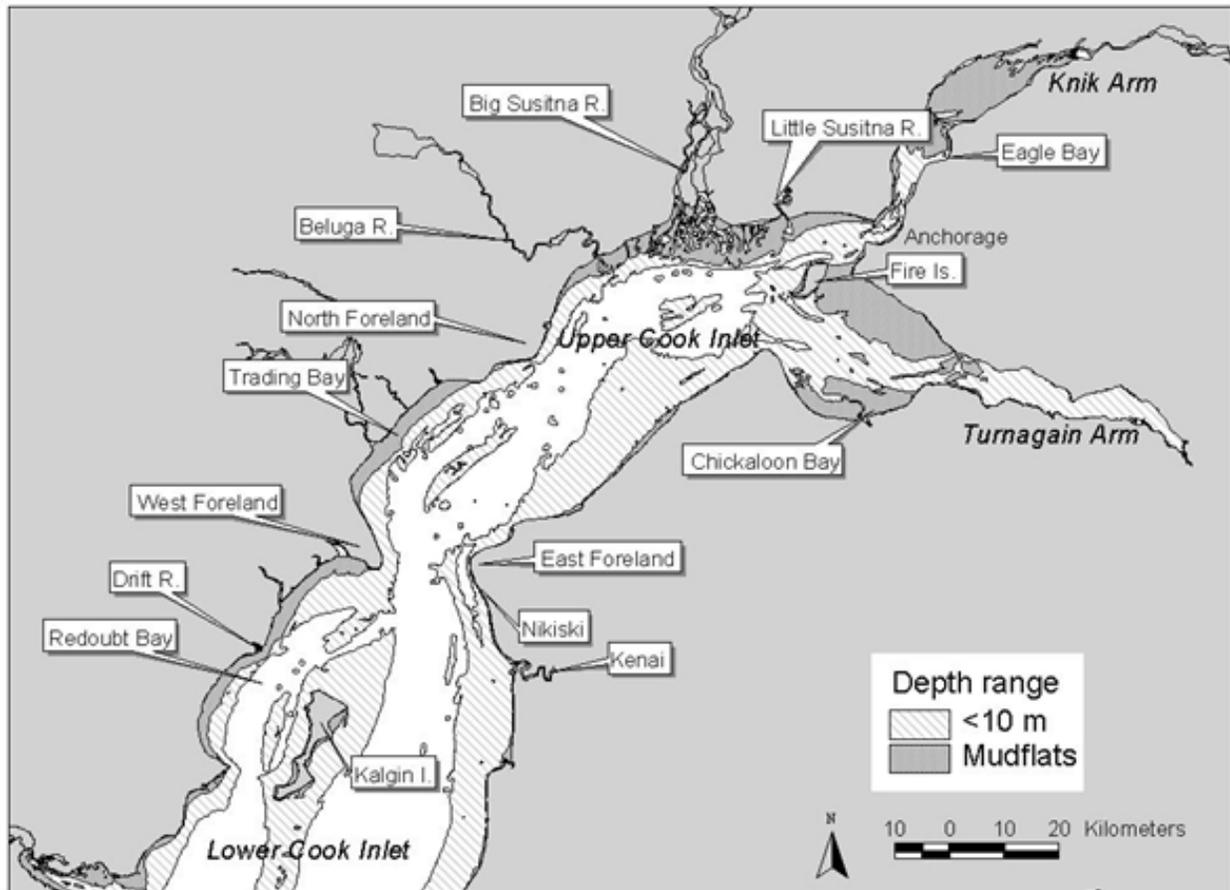
Figure 1. -- Map of localities mentioned in text. Dark shaded areas represent Cook Inlet mudflats, and hatched areas represent < 10 m in depth.

Tagged belugas were tracked using the ARGOS Data Location and Collection System. Tags transmitted ultra-high frequency messages, which were received by National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites. Locations were determined by Service ARGOS from the Doppler shift of the tag signal frequency that occurs during the satellite's pass overhead (Harris et al. 1990). ARGOS-acquired locations were coded based on predicted accuracy. Locations were assigned one of six location classes (LC 0-3, A, B, and Z). Location classes 1, 2 and 3 (LC 1-3) have a predicted standard error of 1.0, 0.35, and 0.15 km, respectively. Location classes 0, A, B, and Z have no predicted accuracy. Only location qualities LC 1-3 were used in this analysis. Distance and speeds were calculated assuming travel in a straight line between each good-quality ARGOS location.

All tags had pressure transducers that sampled the depth of the whale at a resolution of 1 m. Compressed information on dives was transmitted to the satellite, including the maximum depth in a 24-hour period, the number of dives in different maximum depth categories for four 6-hour sampling periods, the frequency of dives in 14 duration categories for each 6-hour period, and the amount of time spent in 14 depth categories. The 6 h periods, 0, 1, 2, and 3 were, respectively; 21:00-2:59:59 (local time), 03:00-08:59:59, 09:00-14:59:59, and 15:00-20:59:59. Maximum depth per dive and time spent at different depths were compiled and binned into depth categories of 0-1, 1-2, 2-3, 3-4, 4-5, 5-10, 10-25, 25-50, 50-75, 75-100, 100-150, 150-200, 200-245, and > 245 m. Time spent within a depth category with a duration of < 10 seconds may have been missed because depth data are sampled at 10-second intervals at those depths.

The shallow depth categories are at the resolution of the depth transducer, so careful interpretation is necessary. The analog signal from the depth transducer is converted to a digital 1 m resolution value in an arbitrary way. As an example, a reading of slightly over 1 m to slightly less than 2 m could be converted to either a digital value of 1 or 2 m. This is the translation of analog (smooth curve) to digital (steps) signals done by the A-to-D converter (an electronic chip). Which direction the signal gets converted is arbitrary and is not the same as rounding up or down. A reading of 2 m depth represents the true depth anywhere between 1 and 3 m. This is of concern for interpreting the 0-1 m depth bin, important in this study. Because time in the 0 m bin will represent a true depth as deep as 1 m, and depths in the 1 m bin could represent some of the time when the whale was at the surface, plus an arbitrary fraction of the time that the whale was between 0 and 1 m (Braun[1]). The depth bins are interpreted inclusive of the shallower bound and exclusive of the deeper bin bound. For bins below the surface, the average depth represented by these bins is (where S = shallow bin depth and D = deep bin depth) calculated as $(((S+D)/2)-0.5)$ and for bins that include the surface, the revised formula is $((0+D)/2)$.

The frequency of dives were compiled and binned into duration categories of 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-8, 8-10, 10-12, 12-15, 15-18, 18-21, 21-24, and > 24 minutes. For analysis comparing diel differences, temporal periods 2 and 3 (09:00-20:59.99 local time) were used as a proxy for daytime, and temporal periods 0 and 1 (21:00-08:59.99 local time) were used as a proxy for nighttime. The mean dive depth and mean dive duration across all 14 bins were

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[1]Braun, M. 2001. Wildlife Computers, 16150 NE 85th Street, # 226, Redmond, WA 98052. Pers. comm.

calculated using the mid-point of the corresponding depth and duration bins. The following was used to calculate mean dive depth:

$$meandepth_i = \frac{\sum_{j=1}^{14} middepth_j * dives_{ij}}{totaldives_i} \quad ,$$

where $meandepth_i$ = average dive depth for period i; $middepth_j$ = middle value of the depth category j; $dives_{ij}$ = number of dives in period i for depth category j and $totaldives_i$ = total number of dives in period i. The following was used to calculate mean dive duration:

$$meanduration_i = \frac{\sum_{j=1}^{14} midduration_j * dives_{ij}}{totaldives_i} \quad ,$$

where $meanduration_i$ = average dive duration for period i; $midduration_j$ = middle value of the duration category j in period i; $dives_{ij}$ = number of dives in period i for duration category j and $totaldives_i$ = total number of dives in period i. Variance for mean dive depth was approximated using the following formula:

$$Var \approx \frac{\sum_{i=1}^{14} n_b (middepth - \mu)^2}{\sum_{i-1}^{14} n_b} \quad ,$$

where n_b = the number of dives in bin b, μ = mean depth calculated for each individual whale, and $middepth$ = midpoint of a depth bin. Variance for mean dive duration was approximated using the following formula:

$$Var \approx \frac{\sum\limits_{i=1}^{14} n_b \, (midduration - \mu)^2}{\sum\limits_{i-1}^{14} n_b} \quad ,$$

where n_b = the number of dives in bin b, μ= mean dive duration calculated for the individual whale, and *midduration* = midpoint of duration bin. Time at depth was calculated as the fraction of total time spent in each depth bin. Percent of time at or near the surface was determined from binned dive data. Cumulative bins were examined for percent of time spent at depth by 1 m increments, ranging from 0-1 m to 0-6 m for each whale. Time at the surface was defined as the percentage of time spent at the 0-1 m bin.

Data from each whale were examined for changes in maximum dive depths for a 24-hour period, mean dive depths, durations (calculated over 6-hour periods), and surfacing behavior coinciding with a change in location. Shifts in whale movement patterns were typically associated with changes in dive behavior, and where this was the case, a shift defined the beginning of a new behavioral period.

Locations and diving behavior were examined relative to tidal cycles testing the null hypothesis that beluga diving behavior is not affected by tidal changes. Cook Inlet was divided into six tidal sectors in ArcView GIS with sector dividing lines equidistant between two adjacent tidal points: Anchorage (Knik Arm), Fire Island, Sunrise (Turnagain Arm), Nikiski, Seldovia, Drift River, and North Forelands (Fig. 1). Harmonic tidal stations were Anchorage, Nikiski, and Seldovia (on the southeast side of lower Cook Inlet). Predicted tides were obtained for Fire Island, Sunrise, East Foreland, Drift River, and North Foreland. ARGOS locations were assigned to one of six sectors, and tidal heights (to the nearest 5 minutes) were assigned to each ARGOS location using the tidal height at the closest tidal station or predicted tidal point (Tides and Currents Pro for Windows[TM] Version 2.5b). Tidal rate of change and direction of change were calculated from tidal heights at ten-minute intervals for the period each whale was tracked. Tides were classified as rising or falling based on tidal direction. High and low slack tide periods were identified by an average rate of change less than 60 cm/hour. High/low tides and rising/falling tides were compared to dive statistics (t-tests) for each whale in both individual 6-hour periods and behavioral periods.

Bi-weekly sea-ice concentration in Cook Inlet in December 2000-January 2001 was taken from the National Ice Center (NOAA). ArcView GIS was used to link sea-ice concentration to ARGOS locations summarized for whales tracked in fall and winter in 2-week periods. All locations found in sea ice-free areas were assigned a zero and included in the analysis. The standard level of significance was chosen to be 0.05.

RESULTS

Tag Performance

The three tags transmitted for 109 (CI-9901), 115 (CI-0002), and 124 (CI-0001) days providing 1,768, 2,525, and 3,346 locations, respectively (Tables 1 and 2). The number of good quality locations varied among tags and declined with days post-tagging for all three whales. The two whales tagged in 2000 provided a greater total number of locations than the whale tagged in 1999, however, a greater proportion of those locations were poor quality positions (Table 2).

Table 1. -- Information on whales tagged in Cook Inlet in 1999 and 2000. Duration is the number of days between the tagging event and the last good quality position.

Whale no.	Date tagged	Sex	Body length (cm)	Color	Period tracked	Number of 6-hour periods	Duration (days)
CI-9901	5/31/99	M	370	white	5/31/99-9/16/99	433	109
CI-0002	9/13/00	F	272	light gray	9/13/00-1/18/01	507	115
CI-0001	9/13/00	M	413	white	9/14/00-1/2/01	451	124

Table 2. -- Number of positions (relative to location quality) obtained from each tagged whale.

Tag #	Total locations	LC-1 (fair)	LC-2 (good)	LC-3 (high)	Poor quality
CI-9901	1768	33.8%	19.9%	7.0%	39.3%
CI-0002	2525	16.6%	4.6%	1.8%	77.0%
CI-0001	3346	24.7%	10.3%	3.7%	61.4%

Distribution and Movements

All whales tagged in 1999 and 2000 remained in Cook Inlet for the entire tracking period. Whale CI-9901 remained in upper Cook Inlet the entire time the juvenile male was tracked, traveling no more than 68 km from the tagging location (Fig. 2). Movements were directed between distinct areas or river mouths in upper Cook Inlet, and it was apparent when the whale was relatively stationary in one location for a period of time. The whale's movements were focused in four regions: the Little Susitna River, offshore upper inlet, Knik Arm, and Turnagain Arm. The beluga averaged 45.6 km/day (i.e., sum of distances between sequential positions) for the tracking period and total straight-line distance traveled was 4,972 km.

Movement patterns obtained from the two whales tagged in September 2000 were less defined than those collected during the summer of 1999. The movements of both whales were less focused in any particular area (i.e., river mouths) and were more broadly distributed spatially throughout the fall and early winter. The juvenile female (CI-0002) remained in Knik Arm for 2 weeks after the tag was deployed. From mid-October through January, CI-0002 ranged widely in the inlet, and traveled along the west coast and in the central part of the inlet, as far south as the southwest corner of Kalgin Island (Fig. 3).

The large male (CI-0001) moved immediately from Knik Arm to Turnagain Arm hours after the tag was deployed. This individual remained in Chickaloon Bay and Turnagain Arm for 6 weeks through 3 November 2000. For the remainder of the tracking period, the adult male spent time in upper Cook Inlet and moved between Knik Arm, the Little Susitna River, Turnagain Arm, and offshore waters north of East and West Foreland (Fig. 4). Whale CI-0002 traveled an average of 41.5 km per day with a total distance of 5,308 km while CI-0001 traveled an average of 66.8 km per day with a total distance calculated of 8,286 km.
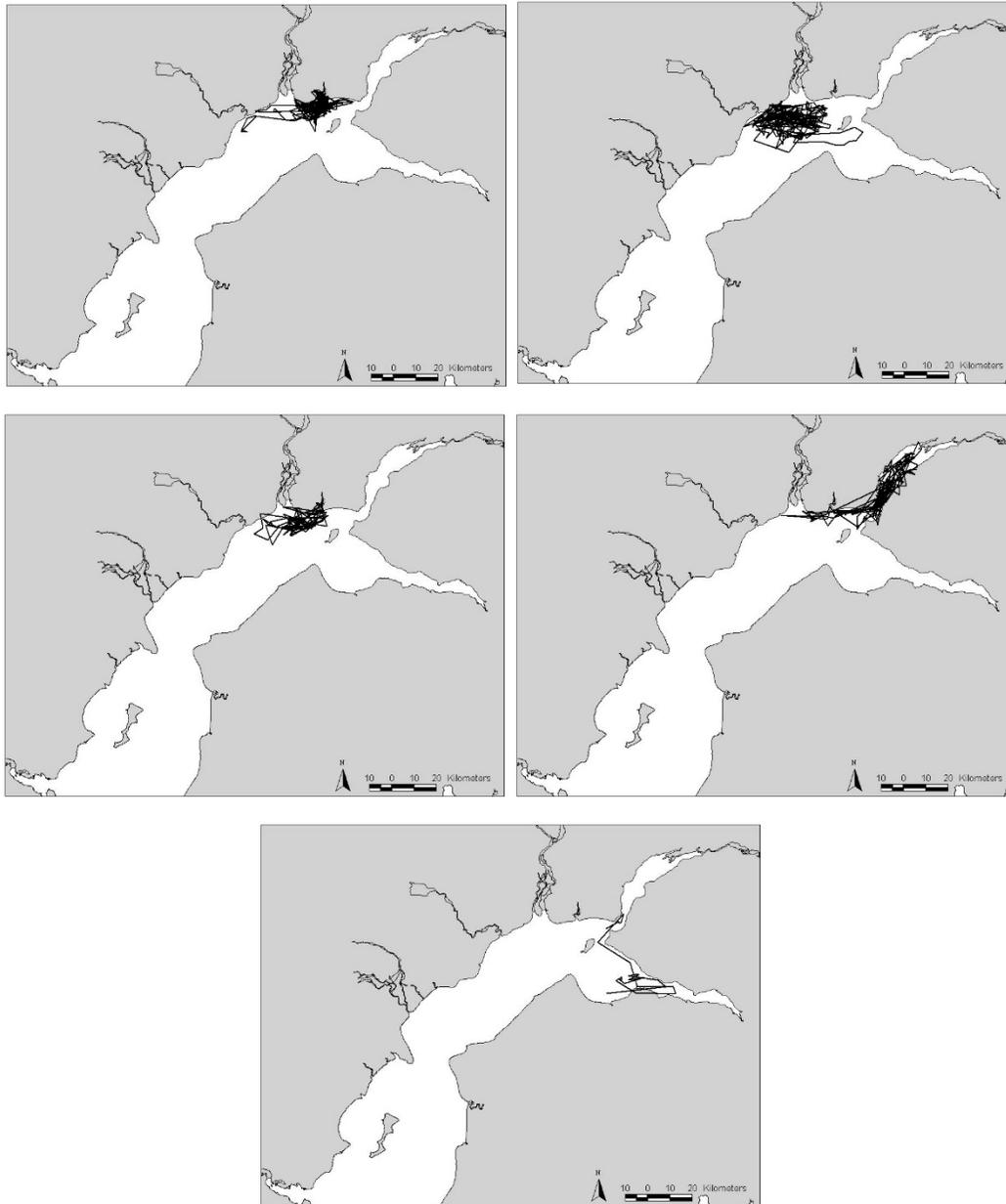
Figure 2. -- Movements of whale CI-9901 for each of five behavioral periods described in the text (Period 1 – upper left, Period 2 – upper right, Period 3 – middle left, Period 4 – middle right, and Period 5 – bottom panel).

Figure 3. -- Movements of whale CI-0002 for each of three behavioral periods described in the text (Period 1 – top panel, Period 2 – middle panel, and Period 3 – bottom panel).
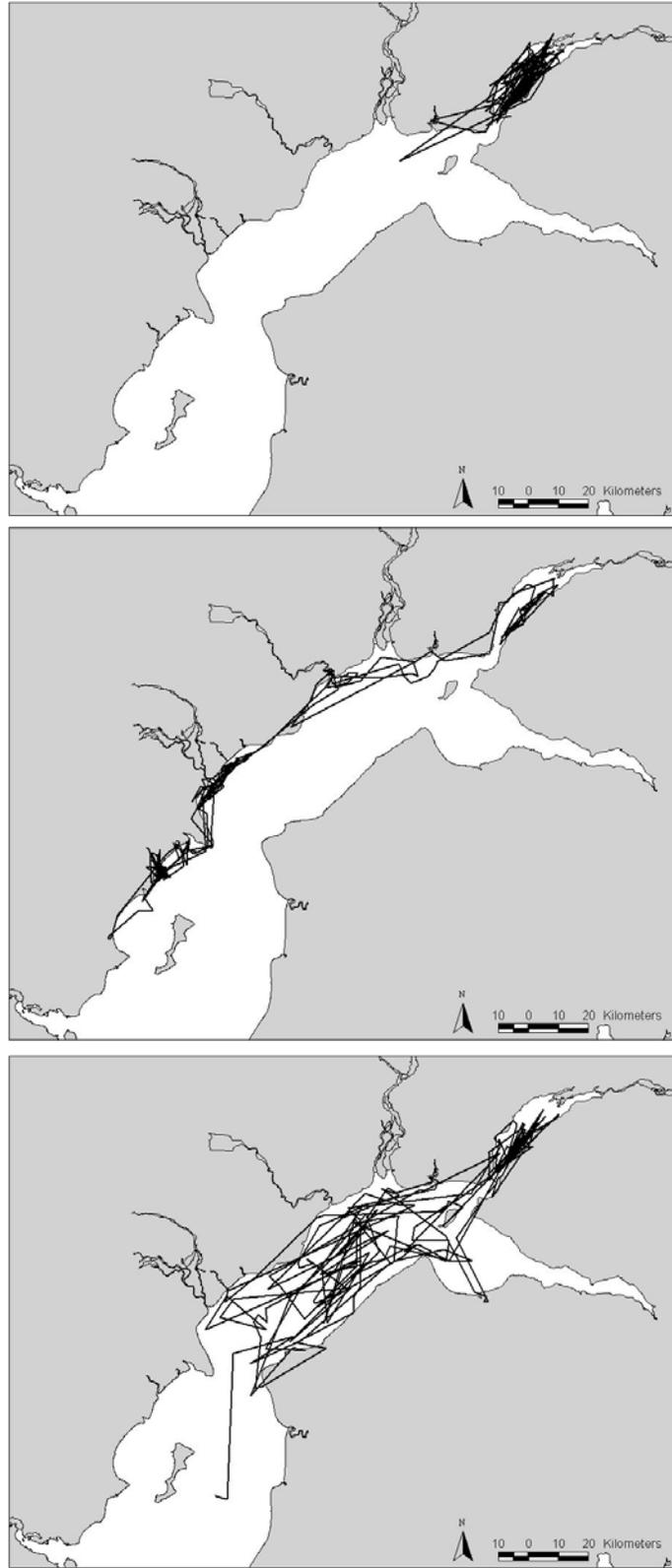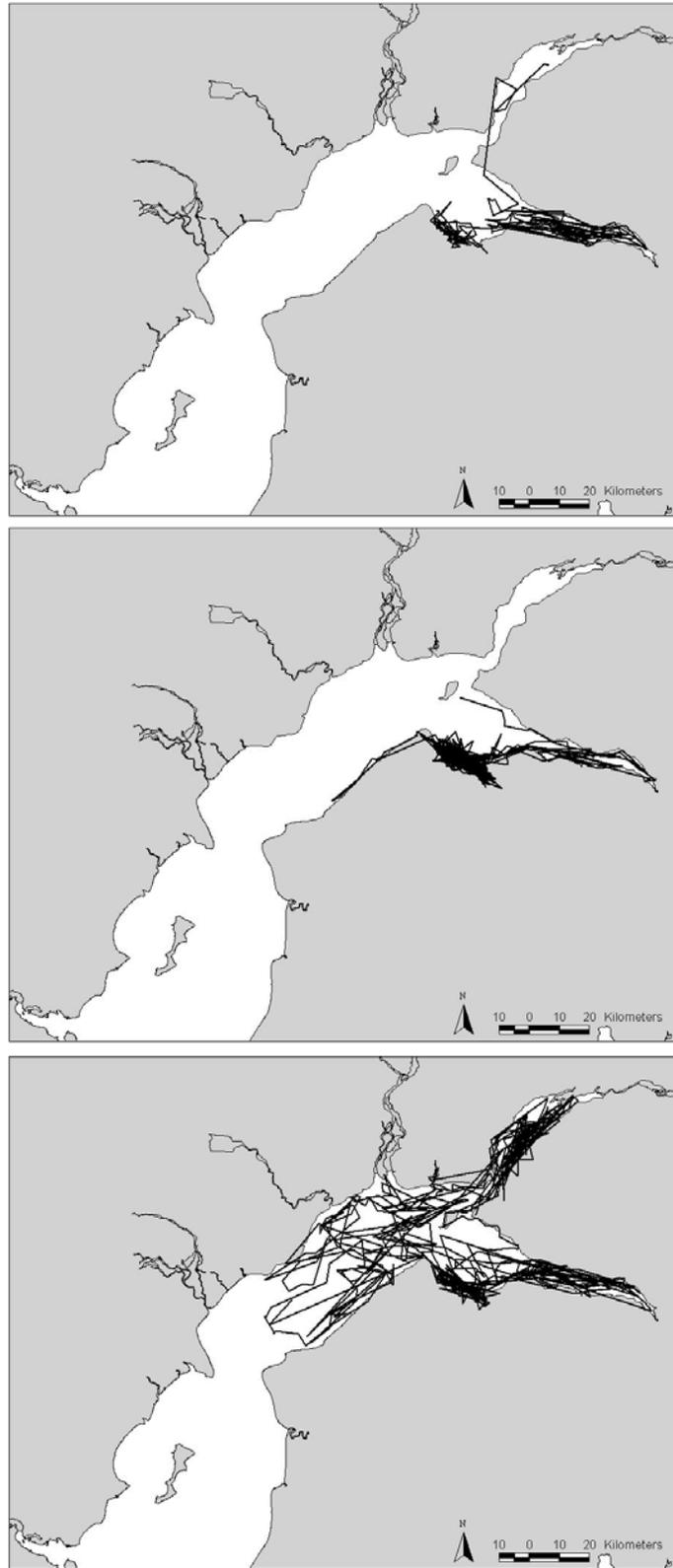
Figure 4. -- Movements of whale CI-0001 for each of three behavioral periods described in the text (Period 1 – top panel, Period 2 – middle panel, and Period 3 – bottom panel).

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Five behavioral periods were identified for CI-9901. The whale spent the first 2 weeks after tagging (31 May– 14 June) in and adjacent to the mouth of the Little Susitna River (Fig. 2, behavioral period 1). Between 15 June and 17 July, movements were less concentrated and more broadly distributed in the upper inlet (Fig. 2, behavioral period 2). Between 18 July and 17 August, the beluga again concentrated his movements in the Little Susitna River area (Fig. 2, behavioral period 3). Between 18 August and 12 September the whale moved to Knik Arm, spending time in the Eagle Bay area (Fig. 2, behavioral period 4). On 13 September, the whale left Knik Arm and moved south to Turnagain Arm, where the juvenile male remained for 3 days until contact with the tag was lost (Fig. 2, behavioral period 5). Similar behavioral periods were also described in Ferrero et al. (2000), however, changes in dive data were not incorporated in their study, therefore, dates defining periods are slightly different as presented here.

Three behavioral periods were identified for CI-0002. After tagging, the whale spent 2 weeks (13 September-4 October) in Knik Arm (Fig. 3, behavioral period 1). From 5 to 31 October, the whale moved along the northwest coast of the upper inlet between Knik Arm, the Susitna Delta, and Trading Bay (Fig. 3, behavioral period 2). Between 1 November and 18 January, the whale ranged widely in the upper and middle parts of the inlet (Fig. 3, behavioral period 3).

Three periods were identified for CI-0001. The whale spent 6 weeks in Turnagain arm and Chickaloon Bay. These 6 weeks were divided into two periods because of a sharp change in diving behavior after the first 3-weeks. During the first portion of this period (14 to 29 September), the whale's movements were concentrated in Turnagain Arm, a shallow tidal estuary, with forays into Chickaloon Bay and out to Point Possession (Fig. 4, behavioral period 1). Between 30 September and 3 November, the whale spent most of his time in Chickaloon Bay, a shallow water estuary, with shorter periods in Turnagain Arm and Knik Arm (Fig. 4, behavioral period 2). Between 4 November and 2 January, the whale ranged more widely in the upper inlet (Fig. 4, behavioral period 3).

Maximum Depths of Dives

The deepest dive measured was 112 m, recorded on 1 November 2000 from CI-0002. CI-9901 and CI-0001 had maximum dive depths of 64 m and 66 m, respectively. Maximum daily

dive records indicated whales in Cook Inlet sometimes spend several entire days at or near the surface, where maximum dive depths were recorded no more than 6 m for each of the whales on consecutive days.

Dive depths for CI-9901 varied substantially from June-September and were consistently related to the behavioral periods described for the movement patterns (Fig. 5). From 31 May through mid-June, when the whale was in the vicinity of the Little Susitna River, the whale did not dive below 8 m (behavioral period 1). From mid-June to mid-July, when the whale left the river mouth and moved widely in the upper inlet, maximum dive depths doubled ranging from 20 to 60 m (behavioral period 2). Starting in 18 July and continuing through 17 August, the whale moved back to the mouth of the Little Susitna River and there was an abrupt decrease in maximum daily dive depths (< 8 m) (behavioral period 3). From 18 August through mid-September, dive depths increased to a maximum of 64 m when the whale was traveling in (and between) Knik and Turnagain Arms (behavioral periods 4 and 5).
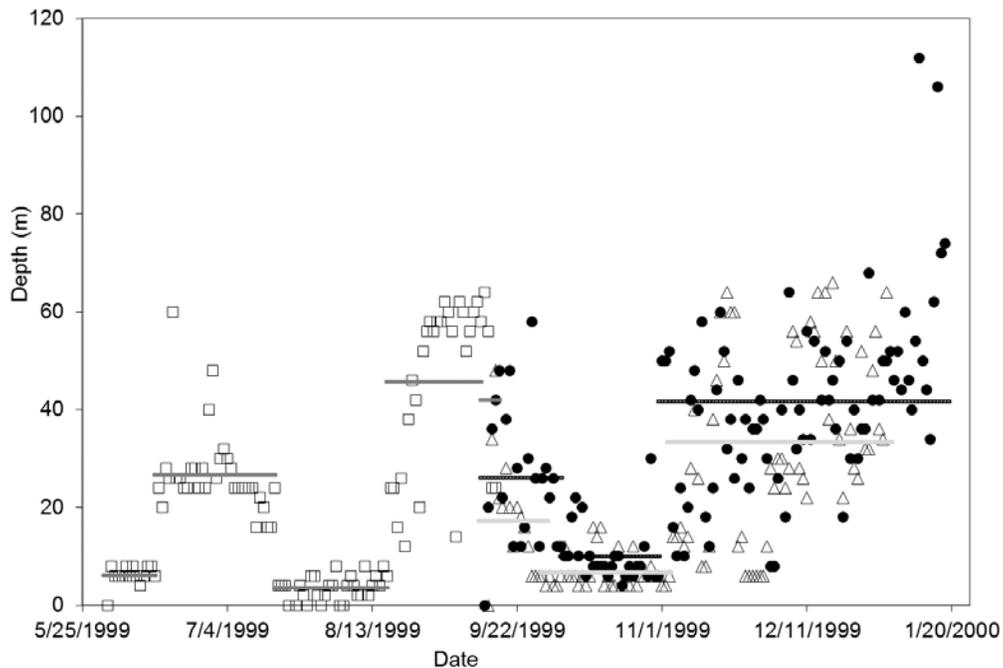

Figure 5. -- Maximum daily dive depths for three belugas tagged in Cook Inlet, with average depth for each behavioral period shown as a horizontal line. Mean values within each behavioral period are displayed with a dark gray line for CI-9901 (open squares) and black line for CI-0002 (black circles), and a light gray line for CI-0001 (open triangles).

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Dive depths for CI-0002 and CI-0001 were also related to shifts in movement patterns in the inlet. Whale CI-0002 dove to maximum depths of 58 m in Knik Arm for the first 3 weeks the juvenile female was tracked (behavioral period 1). CI-0002 later moved back and forth along the northwest coast of the upper inlet and decreased maximum daily depths to < 30 m (behavioral period 2). In early November, the whale changed behavior and ranged widely throughout the upper and middle inlet making deeper dives down to 112 m (behavioral period 3). Whale CI-0001 remained in Turnagain Arm for 6 weeks. When movements were more focused in the Arm (14 to 29 September) maximum daily dive depths were 48 m (behavioral period 1). When movements were more concentrated in Chickaloon Bay (30 September -3 November) daily maximum depths decreased to < 12 m (behavioral period 2). When the whale ranged more widely in the upper inlet (4 November to 2 January) maximum daily dive depths again increased to 66 m (behavioral period 3). Maximum dive depths for whales CI-0002 and CI-0001 demonstrated a significant linear increase over time (CI-0002, $P < 0.0005$; CI-0001, $P < 0.0005$) (Fig. 5) indicating a preference for deeper water habitats as fall progressed into winter.

Mean Depths of Dives

The mean dive depth across all periods for CI-9901 was 2.7 m (SD = 6.4), where 34,575 dives were recorded. This individual did not make dives deeper than 64 m for the entire period tracked. Most of the diving activity was directed between 0-2 m and 5-10 m. When periods were pooled, mean dive depths were significantly deeper at night (2.8 m, SD = 0.06) than day (2.6 m, SD = 0.05) (t-test, $P < 0.001$). Diving activity was most frequent ($n = 9,622$) during period 2 (09:00-14:59:59 local time).

The mean dive depth across all periods for CI-0002 was 5.2 m (SD = 8.8), where 52,312 dives were recorded. The deepest dives recorded for this individual were in the depth bin between 100 and 150 m. Most of the diving activity was directed between 0-3 m and 5-10 m. There was no significant difference between dive depths at night (5.1 m, SD = 0.3) and day (5.2 m, SD = 0.16) (t-test, $P = 0.15$). The greatest number of dives ($n = 13,526$) occurred during from 21:00-02:59:59 local time.

The mean dive depth across all periods for CI-0001 was 2.6 m (SD = 5.2), where 84,736 dives were recorded. The deepest dives were recorded in the depth bin between 50 and 75 m.

The diving activity for CI-0001 was concentrated between 0 and 4 m. Mean dive depths were slightly deeper at night (2.5 m, SD = 0.08) than during the day (2.6 m, SD = 0.04), however the relationship was not significant (t-test, $P = 0.15$). The greatest number of dives ($n = 21{,}667$) also occurred from 21:00-02:59:59 local time.

Histogram data corroborate the behavioral patterns observed in movements and maximum diving depths for all three whales (Table 3). In 1999, mean dive depths for CI-9901 for the first three behavioral periods were 1.1 (SD = 1.5) (Little Susitna River), 3.3 (SD = 5.7) (upper inlet), and 0.6 m (SD = 0.8) (Little Susitna River), respectively. During the time the whale occupied Knik Arm (behavioral period 4), the mean dive depth increased to 4.8 m (SD = 10.3) ($P < 0.001$), and when CI-9901 moved to Turnagain Arm (behavioral period 5), the mean depth was 3.9 m (SD = 5.9).

Table 3. -- Dive and movement statistics for behavioral periods for each whale tagged in Cook Inlet, Alaska, in 1999 and 2000. Approximated standard deviation is in parentheses for mean dive depth and mean dive duration.

Whale ID	Behavioral period ID	Behavioral period (dates)	Locality	Max depth (m)	Mean dive depth (m)	Mean dive duration (min)	Mean% time in 0-1 m depth
CI-9901	1	31 May-14 June	Susitna Delta	8	1.1 (1.5)	3.2 (3.1)	64%
	2	15 June-17 July	Broadly distributed in upper inlet	60	3.3 (5.7)	3.0 (3.1)	65%
	3	18 July-17 Aug	Susitna Delta	8	0.6 (0.8)	1.7 (1.7)	98%
	4	18 Aug-12 Sept	Knik Arm–Eagle Bay	62	4.8 (10.3)	3.8 (4.0)	61%
	5	13 Sept-16 Sept	Turnagain Arm	64	3.9 (5.9)	6.4 (5.8)	64%
CI-0002	1	13 Sept-4 Oct	Knik Arm–Eagle Bay	58	2.7 (3.8)	2.6 (3.3)	30%
	2	5 Oct-31 Oct	NW coast-upper inlet	30	1.6 (1.7)	1.8 (2.8)	45%
	3	1 Nov-18 Jan	Entire upper-middle inlet	112	8.4 (11.2)	4.0 (4.8)	16%
CI-0001	1	14 Sept-29 Sept	Turnagain Arm-Chickaloon Bay	48	2.0 (2.6)	1.3 (1.7)	38%
	2	30 Sept-3 Nov	Chickaloon Bay, & Turnagain Arm	12	1.2 (0.9)	1.0 (1.2)	57%
	3	4 Nov-2 Jan	Entire upper inlet	64	4.0 (7.3)	1.9 (2.5)	30%

In 2000, changes in mean dive depths were less extreme until both whales left the coastal areas in the upper inlet (Knik Arm, Turnagain Arm, Chickaloon Bay). When CI-0002 was in nearshore areas, mean dive depths were 2.7 (SD = 3.8) and 1.6 m (SD = 1.7) for behavioral periods 1 and 2, respectively. However, when the whale moved offshore, the mean dive depth increased to 8.4 m (SD = 11.2) ($P < 0.001$) (behavioral period 3). Similarly, when CI-0001 left Chickaloon Bay (where mean dive depths were 2.0 (SD = 2.6) and 1.2 m (SD = 0.9)) and traveled more extensively in the upper inlet, the mean dive depth increased to 4.0 m (SD = 7.3) ($P < 0.001$).

Duration of Dives

The overall mean dive duration for CI-9901 was 3.0 minutes (SD = 3.3). There was no correlation between time of day and dive duration (ANOVA, $P = 0.02$). Only 0.25% of the dives lasted > 24 minutes, the longest duration bin in which dive duration is recorded. Mean dive duration was lowest for this whale during behavioral period 3 when the whale was at the Little Susitna River (1.7 minutes, SD = 1.7) and highest during behavioral period 5 when the whale moved to Turnagain Arm (6.4 minutes, SD = 5.8).

The overall mean dive duration for CI-0002 was 3.1 minutes (SD = 4.1). There was no correlation between period and dive duration (ANOVA, $P = 0.015$); however, a higher number of dives were noted in the bin for 12-15 minutes duration between 21:00:00 and 2:59:59. Mean dive duration for CI-0002 remained relatively constant for the first two behavioral periods (2.6 minutes, SD = 3.3 and 1.8 minutes, SD = 2.8), and then significantly increased to 4.0 minutes (SD = 4.8) during behavioral period 3 ($P < 0.001$).

The overall mean dive duration for CI-0001 was 1.4 minutes (SD = 2.0). Very few dives lasted more than 18 minutes for this whale. Mean dive duration for CI-0001 followed the same pattern as CI-0002 for the three behavioral periods. However, the increase in duration in the late fall was not as high, 1.3 minutes (SD = 1.7), 1.0 minutes (SD = 1.2), 1.9 minutes (SD = 2.5) for behavioral periods 1-3, yet it was significant ($P < 0.001$) (Table 3). There was no correlation between period and dive duration for this individual (ANOVA, $P = 0.215$).

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Time at Depth

Over the entire tracking period, whale CI-9901 averaged 70% of the time between 0 and 1 m. Time spent close to the surface varied widely during the entire period CI-9901 was tracked. This whale spent approximately 65% of his time between 0 and 1 m in the first two behavioral periods. In the third behavioral period, time at these depths increased to 95-100% for approximately 4 weeks, and then declined again to 65% for the remainder of the tracking period (Table 3). CI-0002 and CI-0001 had overall mean surface times of 23% and 38%, respectively. Both CI-0002 and CI-0001 exhibited a large drop in overall time at or near the surface (0-6 m) in mid- to late November, which corresponded to the formation of ice in the inlet. In the late summer and early fall, time between 0 and 1 m for CI-0002 and CI-0001 was approximately 30-50% and later declined to 10-20% as the ice formed.

When time spent in depth bins between 0 and 6 m was examined, typical shallow water behavior could be characterized by the majority of the whales' time at depths < 4 m (September and October for CI-0002 and CI-0001) and the extreme case (< 1 m) in July and August (for CI-9901). Toward the end of the fall, deep-water behavior (mid-November to January for CI-0002 and CI-0001) could be characterized by the majority of time spent either above 2 m or below 5-6 m, with little time spent at intermediate depths (Fig. 6).
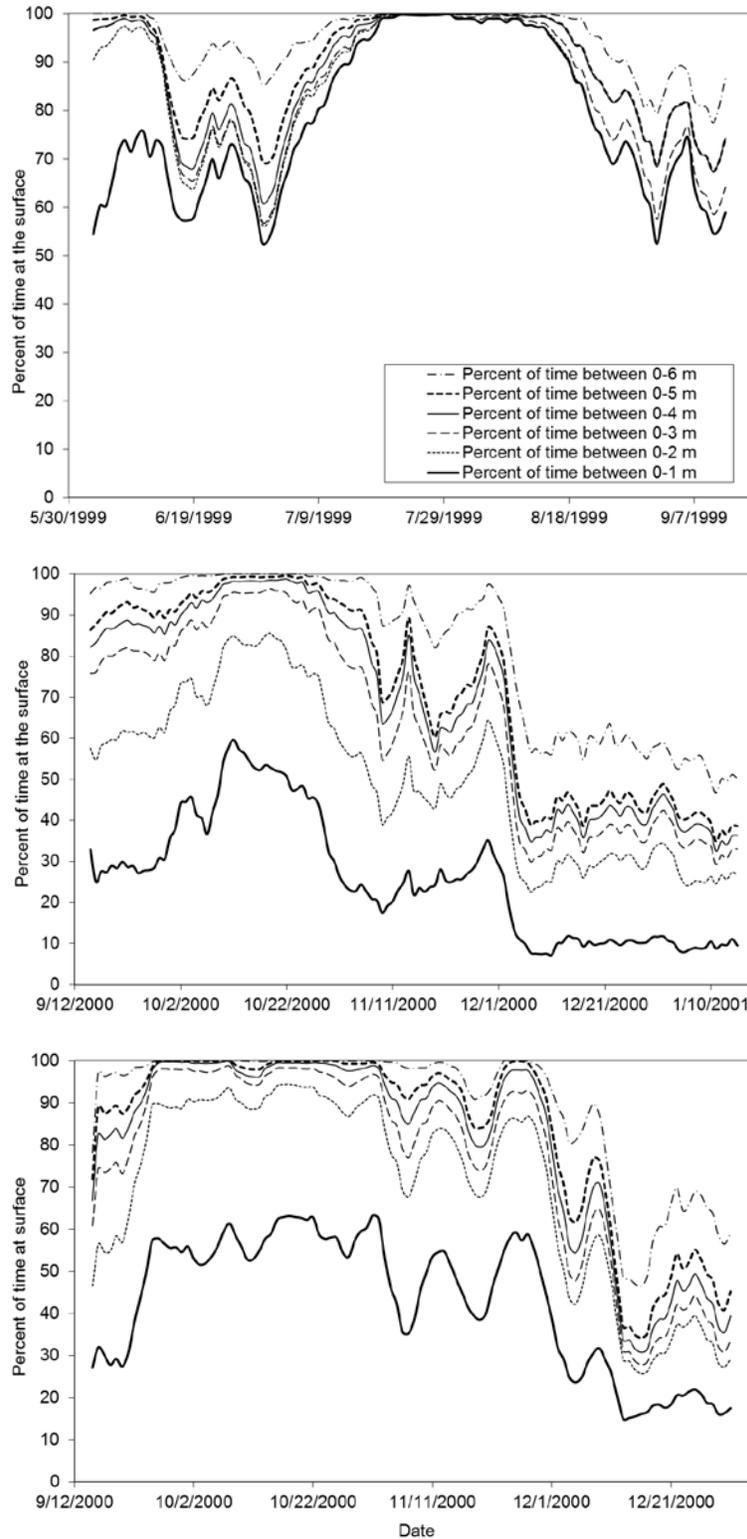
Figure 6. -- Percent of time spent at or near the 'surface', where surface was defined cumulatively between 0 and 6 m. Data are shown for CI-9901 (top), CI-0002 (middle), and CI-0001 (bottom). The dive data are presented as uniform smoothed daily averages during each period the whales were tracked.

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Surface Time

The fraction of time spent at the surface (reported here as fraction of a day) was also recorded for each whale, based on the percentage of time the saltwater switch was "dry" indicating that the tag was above the water line. Mean dry time for all whales corresponded with surfacing time obtained from the binned data. Dry time for CI-9901 was highly variable between June and September, ranging from 17% to 100% of the day at the surface (overall mean 64% (SD = 26.3)). It peaked 20-21 July (~100% of a day) and was 95% between 19 July and 20 August (SD = 6.8). This corresponds almost exactly with behavioral period 3 at the Little Susitna River. Dry time decreased again during periods 4 and 5 (61-64%).

Dry times recorded for the whales tagged in 2000 were relatively constant, slightly decreasing into the late fall and winter. Dry time was slightly higher for CI-0001 (mean 8.1%, SD = 6.0, range 2.6-45.4%) than CI-0002 (mean 4.2%, SD = 7.8, range 0.4-46.7%) throughout the period both whales were tracked, although this difference was not significant.

Movements and Tides

CI-9901 showed significant differences during behavioral period 2 (June 15– July 17), where dive depth, duration, and time at depth were all greater on the falling tide (depth $P = 0.004$, duration $P = 0.011$, time at depth $P = 0.005$). Significant differences were also found for CI-9901 for dive depth and time at depth on the high and low tide during behavioral period 3 (dive depth on high and low tide $P = 0.01$, time at depth on high and low tides $P = 0.04$) (Table 4).

Dive depths were shallower and durations where shorter for CI-0002 on the rising tide during period 1. This contrasts with period 2 and 3, where dive depths were deeper and durations were longer on the rising tide. Significant differences were found for this individual during period 3 for dive depth and time at depth (depth $P = 0.03$, time at depth $P = 0.02$). CI-0001 displayed greater dive depths, durations, and time at depth on falling tides during behavioral periods 1 and 3, and greater depths, duration, and time at depth on rising tides during period 2. However, there were no significant differences found for this whale ($P \geq 0.31$).

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Table 4. -- Dive statistics on rising and falling tides for belugas in Cook Inlet, Alaska. Mean and SD (in parentheses) are reported. Depth is reported in meters, and duration is reported in minutes. Behavioral periods where significant differences were found between rising and falling tides are shaded gray.

Whale ID	Behavioral period ID	Flood (rising) tide			Ebb (falling) tide		
		Dive depth	Dive duration	Time at depth	Dive depth	Dive duration	Time at depth
CI-9901	1	1.1 (0.4)	3.3 (0.7)	0.5 (0.3)	1.1 (0.5)	3.3 (0.8)	0.5 (0.3)
	2	2.5 (2.1)	2.7 (1.0)	1.5 (1.9)	4.9 (3.1)	3.5 (0.9)	3.5 (2.7)
	3	0.6 (0.2)	1.4 (0.6)	0.03 (0.1)	0.6 (0.3)	1.6 (0.6)	0.04 (0.2)
	4	6.5 (11.1)	4.8 (2.8)	3.8 (5.4)	6.6 (5.3)	4.3 (1.4)	5.8 (6.7)
	5	10.2 (6.7)	7.7 (2.2)	5.3 (4.1)	3.9 (1.8)	6.8 (1.5)	2.0 (0.7)
CI-0002	1	2.7 (1.0)	2.6 (0.6)	2.2 (2.0)	2.8 (1.5)	2.7 (1.0)	1.9 (1.4)
	2	1.9 (1.1)	2.1 (1.2)	1.0 (0.6)	1.7 (0.7)	2.1 (1.1)	1.0 (0.5)
	3	10.1 (6.8)	4.5 (1.8)	8.4 (6.6)	6.8 (5.0)	4.3 (1.6)	5.1 (4.3)
CI-0001	1	2.0 (1.2)	1.3 (0.7)	1.3 (1.0)	2.4 (1.1)	1.5 (0.6)	1.7 (1.0)
	2	1.2 (0.2)	1.0 (0.3)	0.5 (0.2)	1.2 (0.2)	1.0 (0.3)	0.6 (0.3)
	3	4.7 (4.1)	2.1 (1.1)	4.9 (5.2)	4.7 (3.9)	2.2 (1.0)	5.0 (5.1)

Movements and Sea Ice

The spatial distribution of sea-ice concentration in Cook Inlet in 2000-2001 was used to investigate whale's movements relative to average ice conditions. Three periods were examined for CI-0002 and CI-0001: 1-15 December, 16-31 December, and 1-16 January. The sea-ice concentration at locations for CI-0002 during the three temporal periods was 19% (SD = 20.0, range 0-60%), 3% (SD = 9.3, range 0-30%), and 28% (SD = 26.4, range 0-80%), respectively. The mean sea ice concentrations for the three temporal periods at locations for CI-0001 were 23% (SD = 16.5, range 0-60%), 12% (SD = 17.4, range 0-80%), and 49% (SD = 30.2, range 20-80%). CI-0002 was consistently found in areas of lower sea-ice concentration when compared to CI-0001; however, significant differences between sea-ice concentration at whale locations were only found during 16-31 December ($P = 0.007$).

DISCUSSION

Belugas routinely concentrate over the Susitna River Delta in early summer (Rugh et al. 2000). Alaska Natives report that the whales feed there on migrating fish, predominantly eulachon and salmon (Huntington 2000), which have been identified in stomach contents of harvested whales (Moore et al. 2000; NMFS[2]). The patterns and timing of eulachon and salmon runs seem to affect beluga feeding behavior and likely have the strongest influence on the movements of whales in Cook Inlet. When fish runs occur and are abundant, whales move to river mouths to feed. Later in the summer, prey species are more dispersed (Moulton 1997), which reduces dense group feeding behavior by the whales at river mouths (Moore et al. 2000). These sightings data and hypotheses were corroborated by the movements of the whales, especially CI-9901, which made small-scale, directed movements between river mouths or bays in the area. Behavioral periods 1, 3 and 4 in the Little Susitna River and Knik Arm may represent a shift in movements and associated diving and surfacing behavior relative to fish runs in these rivers or associated tributaries (Moore et al. 2000). It is difficult to make this quantitative link (relative to both spatial and temporal changes in fish runs in Cook Inlet) both because of the variable nature of salmon runs from drainage to drainage and changes in commercial and sport fishery patterns masking trends in salmon escapement (Moore et al. 2000).

The pattern observed for CI-9901 is similar to that observed in Lydersen et al. (2001) where belugas tagged in summer and fall near Svalbard spent > 60% of their time stationary either in front of glaciers with large outflows of freshwater or along specific areas of the coast. When whales moved from one place to another, they traveled in shallow water along the coast in a rapid and directed manner. During these stationary periods, the whales spent a larger proportion of time at the surface than when they were moving between different areas. Lydersen et al. (2001) suggested the freshwater areas in front of glaciers contain significant sources of prey, and beluga movements were simply a reflection of transport between other productive areas of interest.

The movements of the two whales tagged in 2000 (CI-0001 and CI-0002) are consistent with the hypothesis that belugas from the Cook Inlet population do not leave the inlet during the

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[2] NMFS unpublished data. July 2001. [Available from B. A. Mahoney, Alaska Regional Office, National Marine Fisheries Service, NOAA, 222 W 7th Ave, Box 43, Anchorage, Alaska, 99513, USA]

fall and winter period. The whales' range increased after early September and continued into the late fall. This may be due to both the formation of sea-ice in their primary areas of abundance and a decrease in the concentration of fish runs at the river mouths in the upper inlet. Most likely the dispersal into the middle inlet and the deeper dive depths in late fall and early winter represent a different foraging tactic, where whales find prey at or near the bottom in deeper water rather than at river mouths when seasonal salmon runs have ceased.

Similar stationary behavior during fall and winter months has been observed for beluga whales in Cumberland Sound, Baffin Island. In the fall and early winter, satellite-tagged whales stayed in open water areas of the sound, one tag lasting into January 2001. An aerial survey in March of 2001 confirmed whales were present in the same location that the tags stopped transmitting and it was concluded that the whales remained in Cumberland Sound through the winter (Richard[3]). These results, as well as the findings in Cook Inlet, indicate that there are some populations of belugas that do not make annual long-distance migrations between summering and wintering grounds (Martin and Smith 1999, Richard et al. 1998, Richard et al. 2001a,b; Suydam et al. 2001), and instead remain resident in a specific locality year-round.

The two adult male belugas exhibited similar maximum daily dive depths, as well as a similar range of mean dive depths across behavioral periods (Table 3). However, the trend and patterns observed from summer to winter varied, where dive depths were highly variable relative to location throughout the summer, yet dive depths increased linearly during the fall (Fig. 5). The increasing linear trend for dive depths observed for whales tagged in the fall is similar to that observed in other studies of beluga diving behavior in the Canadian high-Arctic (Heide-Jørgensen et al. 1998), where beginning in early October, whales reduce their time at the surface and dive to deeper depths.

The two adult belugas did not dive deeper than 66 m the entire time they were tracked. Dive depths and durations were significantly deeper (almost by twice) for the juvenile than those recorded for the adult male during the late fall/winter period (106-112 m) (Table 3, Fig. 5). It is surprising that the deepest dives were made by the juvenile, because other studies have reported juveniles exhibit significantly shallower diving behavior than larger adults (Heide-Jørgensen

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[3]Richard, P. 2002. Department of Fisheries and Oceans, 501 Crescent Street, Winnipeg, Canada, R3T 2N6. Pers. comm.

et al. 1998, Martin and Smith 1999), however, the depths available to beluga in Cook Inlet are much shallower than the depths available to whales in these other studies.

Maximum dive depths for the behavioral periods appear to be consistent with a dive to the bottom CI-9901 and CI-0002. Dives to 64 m were recorded infrequently for CI-9901 (only on 2-3 days) and are surprisingly deep for these otherwise shallow areas. It is possible there are small, deep regions in Knik and Turnagain Arms that whales utilize. Knik Arm is reported to be up to 36 m deep; however, tidal fluctuations are extreme and range up to 12 m, so the water could be as deep as 48 m at high tide). Maximum dive depths for CI-0002 occurred when the whale ranged between the North and East Forelands in the late fall. This region of the inlet is as much as 124 m deep (Mulherin et al. 2001); therefore, maximum dives are consistent with bottom depths in this region. The deepest dive recorded for CI-0001 was 66 m. This whale had access to much deeper water when travelling farther into the middle inlet (behavioral period 3) but did not appear to dive to the bottom in those areas.

Cook Inlet is a semi-enclosed tidal estuary, which receives enormous amounts of glacial sediment from adjacent rivers. The inlet also has an extremely large tidal fluctuation, which redistributes sediments daily and creates opaque, turbid water. Because of these physical features, belugas cannot be seen underwater at depths typical for belugas in other areas with relatively clear water (5-7 m), such as the high Arctic. Therefore, correction factors for availability bias developed for other beluga populations are not relevant for Cook Inlet. Currently, the correction factor estimate for Cook Inlet is derived from annual aerial counts which are corrected to account for 1) the fraction of animals below the surface at the time of the survey, 2) the fraction of belugas at the surface that were missed by observers during counts, and 3) the fraction of beluga in groups missed by the observers (Hobbs et al. 2000). The correction factor for whales below the surface is determined from dive or surfacing data, where the proportion of time the animal spends below the surface is calculated based on typical dive profiles or surface activity. Aerial surveys for distribution and abundance of belugas in Cook Inlet are conducted during the first 2 weeks of June (Rugh et al. 2000). The correction factor applied to the raw counts for these data is based on dive interval data (maximum 10 hour longevity) from two belugas tagged with suction-cup attached VHF transmitters in June 1994 and three belugas tagged in August 1995 (Hobbs et al. 2000).

Satellite tags provided a much longer time series for time at surface than the suction-cup attached VHF tags. The two types of at surface data are reported: 1) the fraction of time in the 0-1 m depth bin, which is the total time the tag reported depths at or above 0 m (Fig. 6), and 2) the fraction of "daily dry time" or time at the surface when the tag itself was above the water. For all three whales, the total time the tag was "dry" was less than the total time spent in bin 1, which is consistent with the definitions of the two data types. Neither of these two data types are appropriate for calculating a correction factor for whales missed below the water during aerial surveys of Cook Inlet because neither is a measure of the amount of time a whale is visible at the surface. However, these data do indicate qualitative changes in the correction factor assuming a whale at <1 m depth would typically break the surface and be seen by observers in an aircraft.

Our results suggest that surface behavior in Cook Inlet is correlated with time of year and locality. The highly variable surfacing behavior exhibited by CI-9901, including the extreme amount of time at the surface in July, is thought provoking. If representative, these data indicate that the proportion of time spent near the surface (where whales can be counted) varies seasonally, which would significantly affect aerial counts of these whales. Indeed, aerial counts are consistently higher in June and July than in any other month (Rugh et al. 2000). Considering how belugas are found in large, dense groups in the upper inlet during summer (Rugh et al. 2000), it is not unreasonable to assume that the behavior of a tagged individual may be representative of an entire group.

The cohesion of beluga groups in Cook Inlet during early summer means that the whales are aware of each other and behaving in common. This has been especially notable in aerial observations during the past 10 years when beluga groups move together away from shallow water during a falling tide and travel together up narrow channels during a flooding tide (Rugh[4]). At times the whales are in such shallow water that their wakes are continuously visible, sometimes even exposing most of their backs throughout a series of fluke strokes. This would mean a tag mounted on the back of a whale could indicate that it was at the surface throughout this period. Because the whales are taking advantage of shallow mudflats to find fish, this near-surface behavior may persist for days or weeks, as evidenced in Figure 6.

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[4] Rugh, D. 2002. National Marine Mammal Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, USA. Pers. comm.

The binned dive data, when examined for time spent at or near the surface (Fig. 6), were consistent with that found for other beluga populations. Heide-Jørgensen et al. (2001) reported that belugas in the high Arctic spend 100% of their time in water depths 0-6 m in July in estuarine areas where whale congregate in large groups. This is similar to our results for CI-9901, which spent >90% of his time at these depths in all behavior periods. Martin et al. (2001) examined dive behavior of belugas in the shallow waters of Hudson Bay, Canada, and found that whales spend up to 100% of their time at depths < 4 m in this area. Martin and Smith (1992) also reported time at or near the surface varies dramatically, and noted extreme surfacing behavior for a beluga in Cunningham Inlet, Canada, where the whale spent 5 consecutive days in extreme shallow water, rarely diving more than a few meters.

In late fall, Heide-Jørgensen et al. (2001) reported that surfacing time declined to approximately 20% when whales moved offshore in the fall, similar to our results for CI-0002 and CI-0001. Both whales tracked into the winter months showed a sharp decline in surfacing time, both when the surface was considered to be between 0 and 1 m and when the tag was dry. This decline was observed even when the whales occupied different areas of the inlet. A decline in surfacing time can be explained by multiple factors. For example, sea ice may cause whales to make shorter visits to the surface just for breathing, as noted in Heide-Jørgensen et al. (2001). Alternatively, if whales do remain at the surface to rest, it is possible they only expose their blowhole and the top portion of their back, leaving the tag below the waterline. In addition, if whales are foraging on more dispersed bottom dwelling prey, rather than shallow water fish runs, it would require they spend more time below the surface diving and searching.

This extreme decline in surfacing time, in combination with the dispersal into the middle of the inlet away from the most populated area in Cook Inlet (Anchorage and vicinity), may help explain why fewer whales are seen during aerial surveys in fall and winter. For example, Hansen and Hubbard (1999) counted 160 belugas including re-sightings in winter 1999 (when whales appear to spend less time at the surface), yet Rugh et al. (2000) counted 217 belugas without re-sightings in June of that same year. There is some speculation that whales in Cook Inlet disperse into the Gulf of Alaska during the late fall and winter months, primarily because whales are not seen as frequently and in as large groups as the spring and summer. However, Laidre et al. (2000) reported less than 30 sightings of beluga whales outside Cook Inlet in the Gulf of Alaska

between 1975 and 2000, despite hundreds of thousands of kilometers of marine mammal survey effort in the area.

Tidal fluctuations in Cook Inlet (9 m) are among the most extreme in the world (second only to Canada's Bay of Fundy), and the tidal range produces extreme tidal currents ranging from 4 to 8 knots (Mulherin et al. 2001). Tides have been documented to influence beluga movements in other areas (Kleinenberg et al. 1964, Caron and Smith 1990). Belugas in Cook Inlet have been observed moving into the upper reaches of the inlet during flood tide and departing during ebb tide (Moore et al. 2000). Our results indicate that significant differences in dive depths, durations, and time at depths occurred for two of the whales on rising and falling tides when whales were farther away from shore (or river mouths) and more dispersed in the mid-inlet. It is possible that tidal currents (not analyzed in this study) influenced by rising and falling tides may have more of an effect on behavior when whales are farther offshore in deeper water, perhaps affecting the distribution, or ease of detection and capture of prey. Variability in the temporal reception of ARGOS locations, the positional error, the small areas of interest relative to tidal fluctuation, and the summarization of dive data into a 6-hour period confound more detailed examination of a relation between observed behavioral changes in diving and tidal fluctuations.

Mean sea-ice concentration analyses indicate that CI-0002 was located in areas that typically had a lower concentration of sea ice (farther south in the inlet and farther offshore) than CI-0001. Moore et al. (2000) found belugas in the Alaska high-Arctic selected a range of sea-ice concentrations, from 10% ice cover to 100% ice cover, depending on the season and behavior. It has been well documented that belugas can tolerate extreme concentrations of sea ice, where satellite-tagged belugas traveled from the northwest coast of Alaska to a latitude of 80°N through sea ice concentrations as high as ~100% (Suydam et al. 2001). The winter of 2000-2001 was reported to be a light ice year in Cook Inlet (Page[5]), therefore, sea-ice concentrations correlated to ARGOS locations may not reflect the typical ice conditions whales encounter during those months in other years.

Belugas in Cook Inlet appear to display variation in movement patterns and dive behavior in different months and different localities within the inlet. This variation has implications for

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[5]Page, R. 2001. National Weather Service, Anchorage Weather Forecast Office, 6930 Sand Lake Road, Anchorage, AK, 99502. Pers. comm.

sightings rates, correction factors, and abundance estimates obtained for the population. Clearly, generalizing on results from three animals can be misleading, and larger sample sizes are necessary to confirm that the observed behavioral changes are representative of the population, particularly from May through August. However, the results of this study indicate that this variation, as well as responses to temporal and spatial changes in prey distribution and sea-ice formation, should be incorporated into future research on beluga whales in Cook Inlet.

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