Application of Suction-cup-attached VHF Transmitters to the Study of Beluga, *Delphinapterus leucas*, Surfacing Behavior in Cook Inlet, Alaska

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Introduction

Aerial surveys of belugas, *Delphinapterus leucas*, were conducted in Cook Inlet, Alaska, during June–July from 1993 to 2000 (Rugh et al., 2000) by the NMFS National Marine Mammal Laboratory (NMML), in cooperation with the Alaska Regional Office, the Alaska Beluga Whale Committee, and the Cook Inlet Marine Mammal Council (CIMMC). Counts from these surveys have been used to establish an abundance estimate for this stock (Hobbs et al., 2000a). Survey counts must be corrected for the fraction of whales that are not visible to aerial observers during the counting period, which varies from a few seconds to more than 20 sec during a systematic aerial pass (Hobbs et al., 2000b). The waters of upper Cook Inlet are extremely turbid, with typical Secchi disk readings of less than 20 cm (Moore et al., 2000; Shelden and Angliss[1]). Thus, submerged whales are not visible to aerial observers. Statistics on the dive interval (time between the midpoints of contiguous surfacings) and surfacing interval (the time a whale is visible at the surface per surfacing) are, therefore, necessary to determine this correction factor (Hobbs et al., 2000b).

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[1] Shelden, K. E. W., and R. P. Angliss. 1995. Characterization of beluga whale (*Delphinapterus leucas*) habitat through oceanographic sampling of the Susitna River delta in Cook Inlet, Alaska, 11–18 June 1994. Int. Whal. Comm. Unpubl. Doc. SC/47/SM13, 10 p.

ABSTRACT—Suction-cup-attached VHF radio transmitters were deployed on belugas, Delphinapterus leucas, *in Cook Inlet, Alaska, in 1994 and 1995 to characterize the whales' surfacing behavior. Data from video recordings were also used to characterize behavior of undisturbed whales and whales actively pursued for tagging. Statistics for dive intervals (time between the midpoints of contiguous surfacings) and surfacing intervals (time at the surface per surfacing) were estimated. Operations took place on the tidal delta of the Susitna and Little Susitna Rivers. During the 2-yr study, eight whales were successfully tagged, five tags remained attached for >60 min, and data from these were used in the analyses. Mean dive interval was 24.1 sec (interwhale SD=6.4 sec, n=5). The mean surfacing interval, as determined from the duration of signals received from the radio transmitters, was 1.8 sec (SD=0.3 sec, n=125) for one of the whales. Videotaped behaviors were categorized as "head-lifts" or "slow-rolls." Belugas were more likely to head-lift than to slow-roll during vessel approaches and tagging attempts when compared to undisturbed whales. In undisturbed groups, surfacing intervals determined from video records were significantly different between head-lifting ($\bar{x}$=1.02 sec, SD=0.38 sec, n=28) and slow-rolling whales ($\bar{x}$ =2.45 sec, SD=0.37 sec, n=106). Undisturbed juveniles exhibited shorter slow-roll surfacing intervals ($\bar{x}$=2.25 sec, SD=0.32 sec, n=36) than adults ($\bar{x}$=2.55 sec, SD=0.36 sec, n=70). We did not observe strong reactions by the belugas to the suction-cup tags. This tagging method shows promise for obtaining surfacing data for durations of several days.*

VHF radio-tagging studies were conducted in 1983 on belugas in Bristol Bay, Alaska (Frost et al., 1985), to obtain data on the diving characteristics of those whales. In that study, the instrument pack was pinned through the whales' dorsal ridge. Like the whales of upper Cook Inlet, the tagged Bristol Bay belugas were found around extensive tidal mud flats in extremely turbid water. Sergeant (1981) made shore-based measurements of durations of dives and surfacings of belugas in very turbid waters near the mouth of the Churchill River, Manitoba, Canada. Behavioral differences between the Bristol Bay, Churchill River, and Cook Inlet stocks, however, are not known. Further, the diving behavior of any particular stock may change seasonally and geographically. It is, therefore, important to obtain dive data that is representative of the whales being surveyed by the aerial observers.

To ensure that this occurred, the NMML conducted similar tagging studies on the whales at the Susitna River delta (Fig. 1) concurrently with the 1994 and 1995 aerial surveys. This is the region of Cook Inlet in which the majority of whales have been sighted during aerial surveys (Rugh et al., 2000). Our goal was to characterize the diving behavior of belugas found on the Susitna River delta, and to estimate dive interval and surfacing interval statistics to correct aerial survey abundance estimates. The transmitters were attached using suction-cup tags, also referred to as remora tags.

This type of tag has been used for the attachment of instrument packs onto wild cetaceans by several investigators, with a minimum amount of harassment to the animals and no permanent scarring. Although strong responses (including rapid swimming and energetic leaps from the water) to suction-cup tags by bottlenose dolphins, *Tursiops truncatus*, in Doubtful Sound, New Zealand, made this particular method unfeasible there (Schneider et al., 1998), tag attachment on killer whales, *Orcinus orca* (Baird,

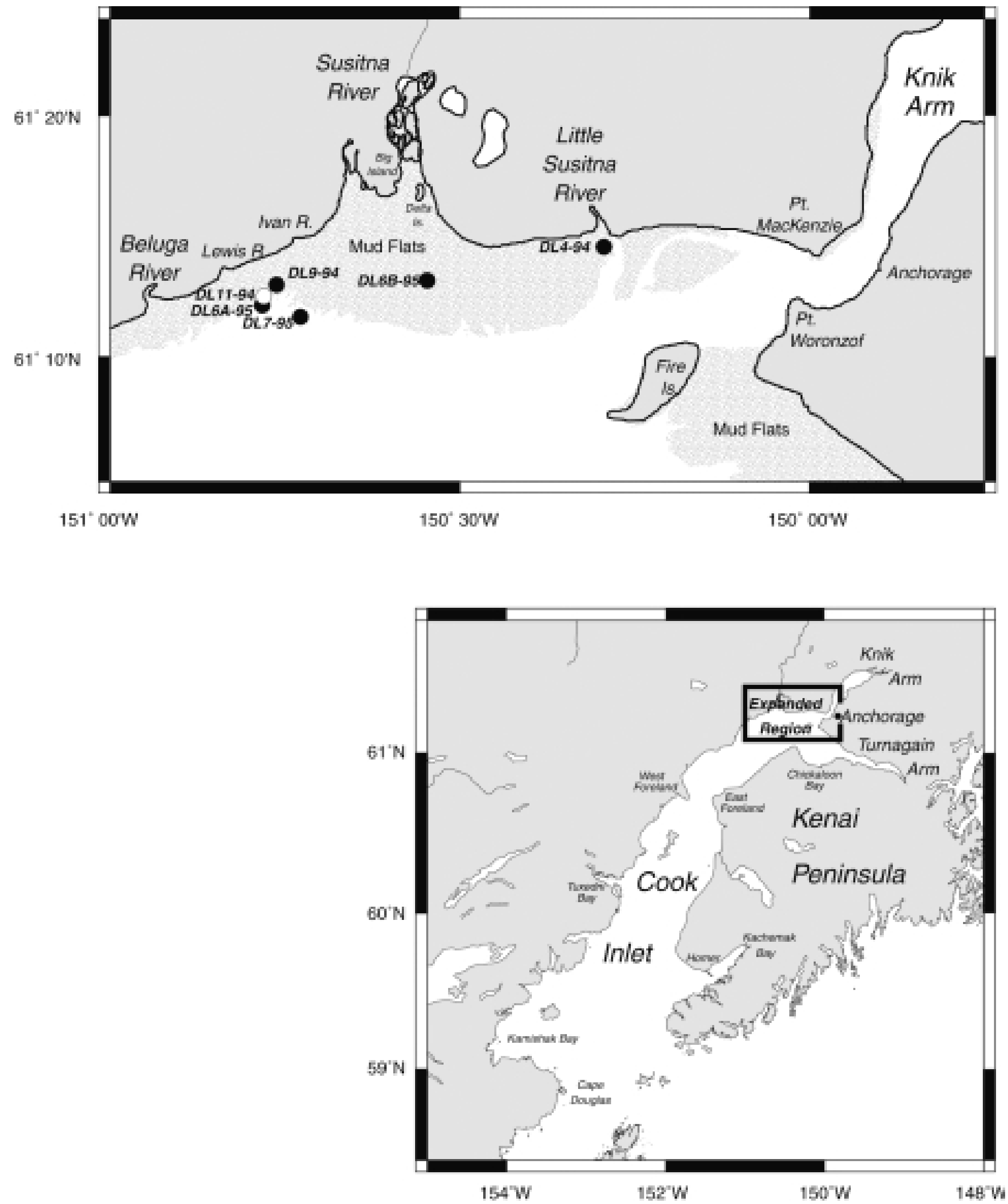

Figure 1.—The study site for tagging belugas in Cook Inlet, Alaska, in 1994 and 1995. Dots mark the tagging locations of five whales from which surfacing statistics were estimated. The circle marks the tagging location of the whale for which only video data were obtained (tag fell off after about 5 min).

1994; Baird and Goodyear[2]; Baird et al.[3]), and several baleen whale species (humpback whales, *Megaptera novaeangliae*: Goodyear, 1989; fin whales, *Balaenoptera physalus*: Giard et al.[4]; and gray whales, *Eschrichtius robustus*: Malcolm et al., 1996) resulted in little or no observable reactions. Low to moderate reactions by Dall's porpoise, *Phocoenoides dalli*, were observed during the first several minutes after tag deployment (Hanson and Baird, 1998; Hanson et al.[5]). While, for Hector's dolphins, *Cephalorhynchus hectori*, such reactions were observed 40 min after tag deployment (Stone et al., 1994, 1998). Suction-cup tags have been continuously deployed for as long as 80 h on humpback whales (Goodyear, 1989; Goodyear[6]), 78 h on fin whales (Giard and Michaud, 1997) and 31 h on killer whales (Baird, 1998).

Methods

The suction-cup tags used in this study were designed by Cetacean Research Technology[7], Seattle, Wash. (Fig. 2). Closed-cell foam (not shown in Fig. 2) was used to make the tags positively buoyant. Upon being released from the whale, the transmitter and tag could be recovered and reused. A water-soluble gelatinous plug placed into a small hole in the transmitter mount provided a time-release mechanism for the tags so the tag could be recovered the same day. Suction was broken when this plug dissolved. In a controlled laboratory environment, suction was maintained for 10–14 h when a gelatinous plug about 4 mm thick was used. The VHF radio transmitter (model 5A, Advanced Telemetry Systems, Inc., Isanti, Minn.) frequencies ranged between 164 and 168 MHz with a power output of 6 milliwatts (6 V × 1 mA). Pulses were transmitted at a rate of 400/min and had a nominal width of 20 ms. The high pulse rate was chosen so that the duration of surfacing intervals could be easily resolved. The total weight of the tag, including transmitter, suction cup, and floatation material, was about 185 g. Tags were deployed by using a telescoping (2.5–5 m long) aluminum pole (shown in Fig. 3a–f) equipped with plastic clips that lightly gripped the cylindrical housing of the transmitter. Once suction was made between the tag and the whale, the tag was easily released from the clips by pulling the pole away from the whale.

The suction-cup portions of the tags were tested on captive belugas at the Point Defiance Zoo, Tacoma, Wash., on 5 May 1994. Tags were placed just left of the dorsal ridge of two whales (a 900 kg male and a 450 kg female). The whales were then sent through their training ex-

[2] Baird, R. W., and J. D. Goodyear. 1993. An examination of killer whale diving behavior using a recoverable, suction-cup attached TDR/VHF tag. *In* Tenth Biennial Conf. Biol. Mar. Mammals, Galveston, Texas, 11–15 November (Soc. Mar. Mammal.), p. 25 (abstr.).

[3] Baird, R. W., L. M. Dill, and M. B. Hanson. 1998. Diving behaviour of killer whales. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 9 (abstr.).

[4] Giard, J., R. Michaud, and J. D. Goodyear. 1998. The days and nights of fin whales: a VHF tracking study of their behavior and use of habitat in the St. Lawrence Estuary, Canada. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 53 (abstr.).

[5] Hanson, M. B., R. W. Baird, and R. L. DeLong. 1998. Short-term movements and dive behavior of tagged Dall's porpoise in Haro Strait, Washington. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 59–60 (abstr.).

[6] Goodyear, J. D. 1981. "Remora" tag effects the first radio tracking of an Atlantic humpback. *In* Fourth Biennial Conf. Biol. Mar. Mammals, San Francisco, Calif., 14–18 December (Soc. Mar. Mammal. and European Cetacean Soc.), p. 46 (abstr.).

[7] Reference to trade names or commercial firms does not indicate endorsement by the National Marine Fisheries Service.

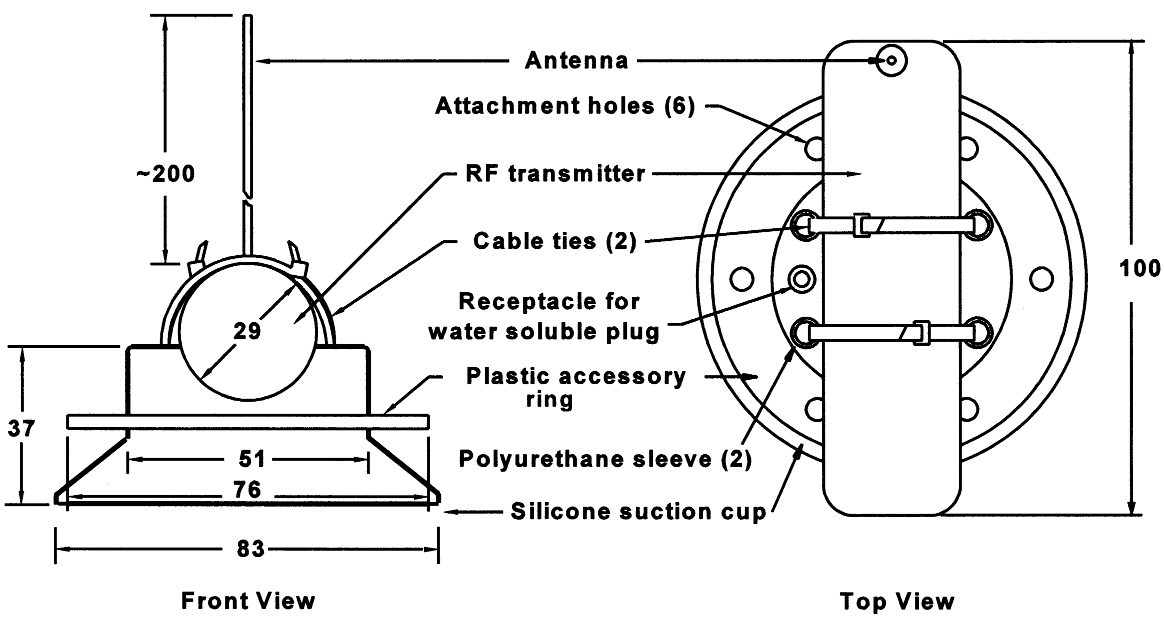

Figure 2.—Schematic of suction-cup tag and VHF transmitter. The closed-cell foam used for floatation is not shown. All dimensions are in millimeters.

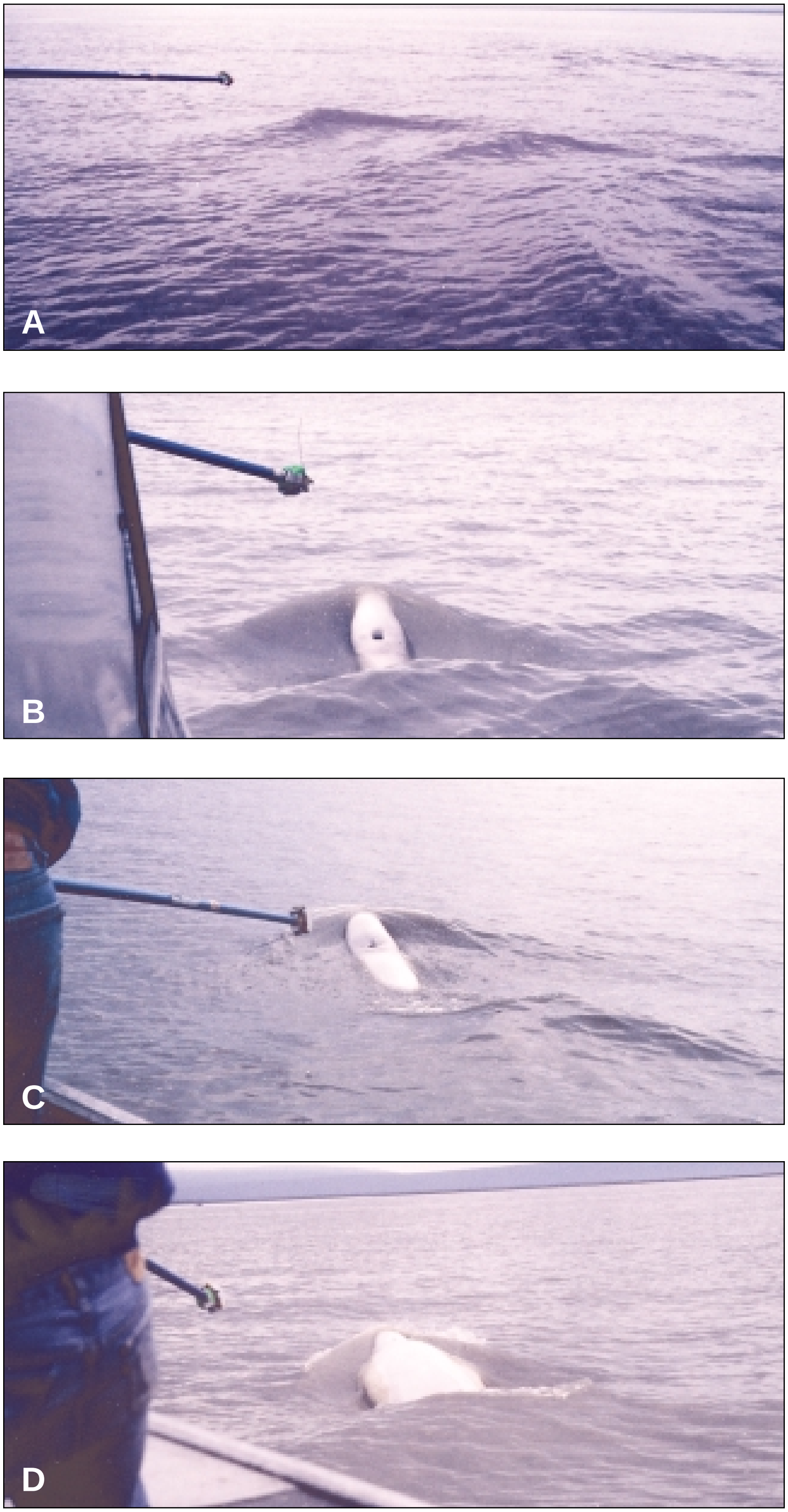

Figure 3.—Tagging belugas in Cook Inlet, Alaska. A. wakes generated by a beluga swimming rapidly in water <2 m deep (the first wake is created by the animals head, the second wake by the flukes). The tag deployment pole has the tag attached to the end. B. whale head appears in the first wake (blowhole visible). C. the whale's back appears and the animal begins to D. slow-roll, exposing its back. Photographs by Janice M. Waite.

ercises which included rapid swimming around the tank, rapid and extensive flexing of the back, and breaching. Both tags remained attached to the whales during the exercises and were removed by the trainer after being on the male for 2.25 h and the female for 1.75 h. Minimal tag slippage (~10 cm) was evident on the male. Examination of the belugas at the site of tag attachment revealed small depressions where the tag had been in contact with the skin. These indentations were no longer visible an hour after removal.

Small-boat surveys and tagging operations were conducted in the northeastern portion of Cook Inlet during 1–22 June 1994 and 3–7 August 1995. The focal region was the Susitna River delta located about 35 km west of Anchorage (Fig. 1). During both years, tagging operations were conducted from either a 5 m rigid-hulled inflatable boat or a 6 m aluminum boat.

The first three survey days (1–3 June) of the 1994 field study were spent developing tag deployment methods. On the fourth survey day, a local beluga hunter (D. Owens) joined the team and provided training in beluga pursuit techniques. Tagging was typically conducted just after low tide. Local beluga hunters have determined that it is easiest to track the whales when they are in water <2m deep. There, whales generate wakes and circular upwellings or "footprints" on the surface as their rostrum pushes through the water and flukes undulate rapidly (Fig. 3a).

Tagging bouts consisted of an approach on a group, isolation of an individual, and pursuit. A maximum of three tagging attempts were made on an individual. The pursuit vessel was driven rapidly toward the edge of the group,

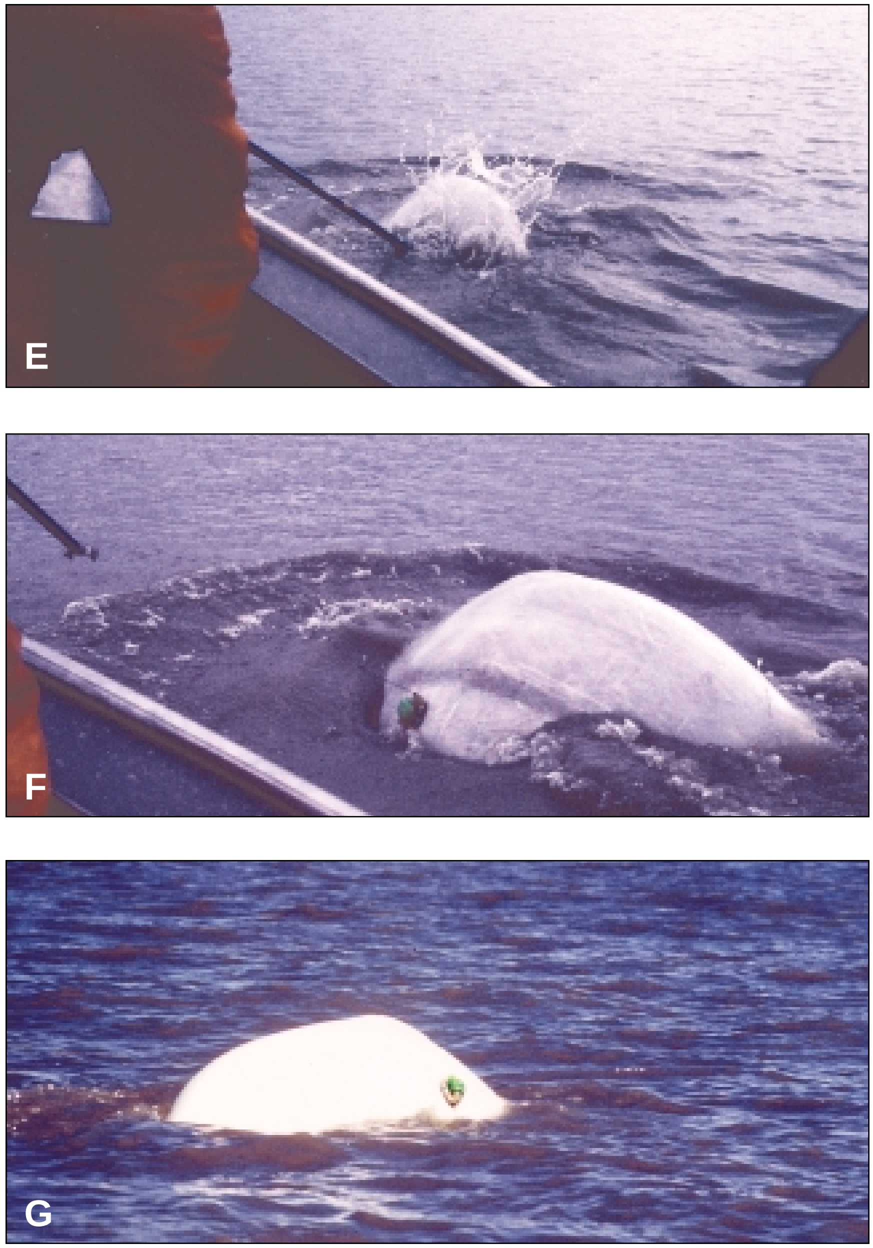

Figure 3 cont.—E. a member of the tagging team attempts to attach the tag. F. the tag is attached successfully, releasing from the pole as it is pulled away from the whale. G. tag attached to whale DL7-95. Photographs E, F by Janice M. Waite; photograph G by James A. Lerczak.

and a whale was chosen by its proximity to the vessel and its consistency in creating wakes. Isolation of an individual occurred within seconds and was either due to the individual moving away from the group or to the group distancing itself from the tagging operation. If it surfaced for a breath within 2 m of the boat, tag attachment was attempted by one or two members of the tagging crew positioned in the bow of the boat (Fig. 3e–f). Efforts were made to place the tag midway down the length of the whale and about 10–20 cm on either side of the dorsal ridge (Fig. 3g). Photographs and videotape were used to document tag location, whale size and coloration, tag placement, and to corroborate signals from the radio transmitter.

Radio-tag surfacing data were recorded by two methods. One of the tagging team members monitored the audio output of the radio receiver with a headset, while the rest of the team attempted to maintain visual contact with the beluga group containing the tagged whale. Initially, an observer announced surfacings to ensure that the audio monitor was interpreting the audio signal correctly. The time of each surfacing was recorded in real-time in a logbook. The audio signals from the receiver were simultaneously recorded on a standard audio cassette tape. Tagged whales were monitored from a distance of 0.5 to 2 km using a radio receiver and a whip antenna placed 2–4 m above the deck of the boat. When strong signals were received, the boat was allowed to drift with the engines off. If the signals were weak, the motor was restarted, and the boat was directed slowly toward the group until the signal strengthened. A hand-held directional antenna connected to a second radio receiver was used to aid in the relocation of a tagged whale and to find tags after they had fallen off a whale.

Blocks of data from the logbooks and tapes were used in the analyses if the surfacing signals could clearly be distinguished from the background noise. Blocks of time in which surfacing signals were low in intensity relative to background (probably because the boat was too far from the tagged whale) were not used. To reduce the bias towards shorter dive intervals, a minimum period of 10 min was chosen so that at least several long dives were included in a block. Within acceptable blocks of time, surfacings were designated as either definite or questionable. Signals from definite surfacings were high in intensity and long in duration (about 1–2 sec). Questionable surfacings were generally low in intensity and short in duration (<0.5 sec). Similar short, sporadic signals were occasionally heard during tests when the transmitter was known to be submerged. A dive interval was defined as the time from the middle of one surfacing to the middle of the next. The times of surfacings from audio tapes were digitized with a computer programmed to record computer times when a keyboard key was struck by a tape reviewer upon hearing a surfacing signal. Separate keys were used to distinguish definite from questionable surfacings. Surfacing intervals were measured using two keyboard keys to mark the beginning and end of the signal from each surfacing. For this, the tape playback speed was reduced to the lowest speed allowed by the tape deck to minimize the response time error of the tape reviewer with respect to the signal length. Tapes were digitized independently by two reviewers as a test of consistency.

The data collected in 1994 were analyzed using two criteria: with both definite and questionable surfacings included (Type A) or with only definite surfacings (Type B). In this way, the significance of the questionable surfacings could be assessed. Few questionable surfacings occurred in the data from 1995, and only time blocks with definite surfacings were used. We estimated the mean dive interval, μ, as the average of the mean dive intervals, μ_i, obtained from the N tagged whales. When μ is used in a correction of a count, it is necessary to estimate the inter-whale variance of the mean dive interval, σ_1^2, and the variance of the dive interval distribution of individual whales, σ_2^2. We assumed that individuals are independent in their diving behavior, and these variances were estimated by:

$$\sigma_1^2 = \frac{1}{N-1}\sum(\mu_i - \mu)^2$$
$$\sigma_2^2 = \frac{1}{N}\sum\sigma_i^2,$$

where σ_i^2 is the variance of the dive interval distribution of each tagged whale.

To assess the impact of the tagging bouts on subsequent dive intervals and to determine whether there was a trend in dive interval with time since tagging, data from whales tagged in 1995 were divided into at least two 30-min blocks after tagging, and the first 30 min were further subdivided into 10-min blocks. The mean and standard deviation of dive intervals were calculated separately for each of these blocks and for the period of time when the whales were followed to obtain photographs.

Video recorded surfacing behaviors collected prior to approaching beluga groups and during tagging pursuits were classified as "slow-rolls" or "head-lifts." During a slow-roll surfacing (Fig. 3d, f, g), the whale's head appeared then receded followed by the surfacing of the back, which first appeared as a thin line on the surface before arching high out of the water as the whale dove. The flukes were rarely observed breaking the surface. During a head-lift (Fig. 3b, c), only the head appeared above the surface then receded. In the analysis, whales observed slow-rolling were categorized as either juveniles or adults. These age classes were distinguished based on coloration, juveniles being uniformly gray and adults uniformly white. It was too difficult to determine the color of individuals displaying head-lift surfacing behaviors (i.e. the visual cue was small and video image resolution was poor during stop action). Therefore, head-lifts of juveniles and adults were pooled. To determine how regularly the head-lift behavior was exhibited by undisturbed whales, slowly panned video segments of undisturbed whales were used, and a random sample of surfacings were analyzed.

Results

Whale responses to our vessel activity followed a typical pattern during most of our tagging attempts. Once the vessel approached within about 10 m of a group, the whales moved away rapidly, creating wakes. During these initial rapid approaches on groups, before an individual whale was isolated for a tagging attempt, the fleeing whales were more likely to head-lift (92%) than slow-roll (8%; n=25 video recordings in 1994). The initial burst of speed by the whales at the start of each tagging bout lasted for only a short duration (<2 min). The whales then slowed and surfaced more frequently. At the termination of a tagging bout, whether or not a tag was attached, the whale that was isolated usually moved away from the vessel without slow-rolling at the surface until it was >10 m away from the vessel. The whale returned to the beluga group within about 15 min after the pursuit was terminated. Though not quantified, these behaviors were substantiated by field observations in both years.

An interesting behavior displayed by whales evading the tagging vessel was to rest at the bottom for several minutes, giving no cues to their location. Apparently, this evasion technique is most frequently used by older whales who have experience with hunters.[8] Whale DL6B-95 (Table 1) used this technique when we pursued it. On two occasions, we stopped the pursuit boat, cut the engines, and waited at the location where we thought the whale was resting. After about 2 min, the whale surfaced within 2–3 m of the vessel, and our pursuit continued.

Despite our presence, and the occasional presence of hunters in the area, the belugas never left the immediate survey area during the study. Whales in the vicinity of our tagging operations would move 300–500 m away during pursuits. Once the pursuit vessel stopped approaching, whales would return to within 100 m of the vessel within about 15 min. When boat engines were off, whales surfaced as close as 5 m and approached within 2 m or went under the vessels as evidenced by bubbles, "footprints" at the surface, or as indicated by the depth sounder. Prior to mid June, belugas were found in large clumped groups (>50) often surfacing in multiple directions. After mid June, the whales were more dispersed in groups ranging from 1–20 individuals. In August, the whales were dispersed for the duration of the tagging operations, consistent with previous observations of the dispersal of large groups by mid summer (Rugh et al., 2000).

Between 3 and 17 June 1994, a total of 93 individual belugas were isolated for tagging. Only 4 of the 93 attempts resulted in successful deployments of

[8] D. Owens (beluga hunter and CIMMC Chairman), Box 102456, Anchorage, AK 99510. Personal commun., July 1995.

Table 1.—Summary of six tagging events of belugas in Cook Inlet, Alaska, in 1994 and 1995.

Tagged beluga identification	Date and time of tag deployment	Location	Whale description	Tag position on whale	Time range of data collection (time after tagging) Beginning (min)	Ending (min)	Reason for termination of data collection
DL4-94	4 June 1994 14:05	lat. 61° 14.6′ N long. 150° 17.6′ W	Small, young adult; completely white	Dorsal surface of caudal area	148	412	Foul weather; tag still attached to whale. Tag found by local fisherman.
DL9-94	9 June 1994 15:55	lat. 61° 13.0′ N long. 150° 45.7′ W	Small, young adult; white with some gray mottling.	5 cm lateral to centerline of back; in line with dorsal ridge	10	132	Foul weather; tag still attached to whale. Tag was not recovered.
DL11-94	11 June 1994 12:48	lat. 61° 12.5′ N long. 150° 46.8′ W	Adult; white with slightly grayish mottling.	10 cm lateral to centerline of back; in line with dorsal ridge	0	5	Tag detached while whale was still in view of tagging vessel. Only video data collected.
DL6A-95	6 August 1995 09:14	lat. 61° 12.1′ N long. 150° 46.9′ W	Juvenile; uniformly light gray.	30-50 cm left of centerline of back; 15 cm forward of dorsal ridge	2	75	Whale swam out of range of receiver. Tag found floating in the delta 2.25 h after deployment.
DL6B-95	6 August 1995 13:13	lat. 61° 13.2′ N long. 150° 32.8′ W	Large adult; uniformly white.	30-50 cm left of centerline of back; in line with dorsal ridge	1	68	Tag detached from whale and was recovered within a few min after detachment.
DL7-95	7 August 1995 10:01	lat. 61° 11.7′ N long. 150° 43.7′ W	Large adult; uniformly white.	15 cm left of centerline of back; 15-30 cm forward of dorsal ridge	1	64	Whale swam out of range of receiver. Tag was not recovered.

tags. The successful attempts captured on videotape took an average of 5.5 min (SD=2.9 min, n=3). The reason for aborting was clear in 40 of the 47 recorded failed attempts. The greatest percentage of failures (38%) was due to the whale entering deep water (>2 m in depth). This resulted in the wake collapsing, leaving the tagging team with no visual cue of the whale's location.

The second highest failure rate (22%) was due to poor attachment of the tag. Tags would dislodge prematurely from the deployment pole after coming into contact with the whale at an improper angle or if the pole tip dipped into the water while underway. Other reasons included: aborting the attempt because the whale was too small or an adult was accompanied by a calf (10%); aborting the attempt after three unsuccessful approaches had been made (10%); unable to stay with a whale because it was too evasive (8%); the whale was lost in low contrast lighting (8%); or the wake of the boat was confused with the wake of the whale (5%).

Two of the four successfully deployed tags in 1994 stayed on long enough (>60 min) for surfacing data to be collected. A third tag remained attached for just over 5 min (whale DL11-94, Table 1). While no radio-transmitter data was collected from this tag, most surfacings were captured on video for the duration the tag was attached. Four whales were successfully tagged in 1995, and three radio-tags remained attached long enough for surfacing data to be collected (Table 1).

For whale DL4-94, radio contact was lost immediately after tag deployment; the tag was presumed lost, and other whale groups in the delta were pursued. After about 2.5 h, signals from DL4-94 were detected about 8.5 km to the west of the tag deployment location (Fig. 1). Surfacing data were then collected for 4.4 h using handwritten logbook entries (no audiotapes were recorded). Data collection was terminated because of foul weather, although the tag was still attached to the whale. The tag was discovered on the shore several days later by local fishermen. In contrast, data collection, using both logbook entries and tape recordings, commenced only 10 min or less after tag deployment for the other four whales. The locations of these tagging events are shown in Figure 1. Size and coloration were used as an indication of age of the tagged whales (Table 1).

For the dive interval analysis, logbook and tape-recorded records were combined to make as complete a time series as possible. Logbook data were used for periods common to both records. It was necessary to scale the dive and surfacing intervals obtained from the computer programs to account for differences in recording and playback tape speeds (even when the tape deck was run at normal speed, the playback time was shorter than the logbook time by 29 sec, on average, per 45 min of tape, or about 1%). This was accomplished by matching the surfacing times from the beginning and end of each tape side in the digitized record to the surfacing times from the logbook data to obtain the actual times for these surfacings.

The statistics μ, σ_1, and σ_2 were estimated to be 24.1 sec, 6.4 sec, and 26.6 sec, respectively (Table 2). These quantities were calculated using values from analysis Type B. Probability density histograms for dive intervals were calculated for each tagged whale and for each analysis type (Fig. 4a–f). Although much of the probability density is centered around the median dive interval, each distribution shows significant probability of long dive intervals (>2× median) which causes the means to be considerably higher than the medians.

For analysis Type B, the probability of long dive intervals increased and the mean of the dive interval distribution lengthened compared to analysis Type A (Table 2). This was quite evident for DL4-94. However, the results from the two analysis types were not very different for DL9-94, because there were few

Table 2.—Dive interval statistics for five beluga whales suction-cup tagged in Cook Inlet, Alaska in 1994 and 1995. Analysis Type A includes both definite and questionable surfacings; type B includes only definite surfacings. Logbook and tape-recorded data were combined into one time series and analyzed for all whales except DL4-94, which only had logbook data.

		Dive interval statistics					Percentile			
Whale ID and tagging date	Analysis type	Median (sec)	Mean (sec)	SD (sec)	Max (sec)	Min (sec)	97.5th	2.5th	Total time (min)	Sample size
DL4-94	A	18.0	26.8	24.7	182	4	102.5	8.0	204	460
4 June 1994	B	19.0	35.1	41.4	356	4	133.2	8.0	204	348
DL9-94	A	17.2	21.0	13.1	114.8	6.8	59.8	9.2	119	338
9 June 1994	B	17.1	23.2	20.2	164.2	6.8	88.8	9.0	118	304
DL6A-95 6 August 1995	B	14.0	20.1	21.1	151	4	80.7	6.0	37	109
DL6B-95 6 August 1995	B	14.0	19.2	15.5	131	6	62.7	7.0	53	166
DL7-95 7 August 1995	B	13.0	22.9	27.0	152	7	108.4	8.0	55	143

Table 3.—Dive interval statistics for three belugas suction-cup tagged in Cook Inlet, Alaska, in 1995 (stratified by time after tagging).

	Beluga identification								
	DL6A-95			DL6B-95			DL7-95		
Time category	Mean dive Interval (sec)	SD (sec)	*n*	Mean dive interval (sec)	SD (sec)	*n*	Mean dive interval (sec)	SD (sec)	*n*
All periods of time	20.1	21.1	109	19.2	15.5	166	22.9	27.0	143
During photo operations	14.9	10.1	60	16.6	15.1	41	32.9	40.0	38
After photo operations	26.6	28.2	49	20.0	15.6	125	19.3	19.4	105
1st 10 min after tagging event	17.1	7.9	28	12.1	4.6	11	28.8	31.6	16
2nd 10 min after tagging event	12.8	11.4	33	17.2	17.8	13	30.3	38.5	21
3rd 10 min after tagging event	23.6	28.0	28	19.2	14.6	30	26.9	36.4	23
2nd half hour after tagging event	31.7	28.9	20	19.1	12.6	92	18.5	17.8	81
After 1st hour				24.4	27.2	20			

questionable surfacings. Small secondary peaks at roughly 47.5 sec and 77.5 sec in the dive interval histograms of DL4-94 (Fig. 4a, b) may be the result of tag placement (on the tail stock rather than the dorsal ridge). The first secondary peak may correspond to two actual surfacings being interpreted as one, and the second may correspond to three actual surfacings being interpreted as one.

For whales tagged in 1995, there was no clear trend in the dive intervals as a function of time since the tagging event (Table 3). Two whales showed an apparent increase in dive interval, while the other showed a possible decrease. The variation from one whale to the next was as great as the variation from one time interval to the next for an individual. Further analysis is unwarranted because of the small sample size.

To measure the surfacing interval, we used 125 tape-recorded surfacings from whale DL9-94. Distributions of surfacing intervals as determined by two independent tape reviewers are shown in Figure 5a. The distribution from reviewer 1 is slightly narrower ($\bar{x}$ =1.88 sec, SD=0.28 sec) and has a significantly higher mean than the distribution from reviewer 2 ($\bar{x}$ =1.70 sec, SD=0.33 sec) (*t*-test=4.6, d.f.=239, P<0.001). The surface intervals measured by the two reviewers are well correlated (Fig. 5b). A linear fit to this curve has a slope of 0.954 (SD=0.063, r^2 =0.65, F=227, d.f.=122). Although the two reviewers were able to record a relative measure of the duration of surfacing intervals, interpretations of the onset and ending of the signals were different, leading to the slight differences in the distributions.

Using video recording of undisturbed beluga groups, surfacing intervals for each color category were compared for those whales exhibiting slow-roll behavior (Fig. 5c). Juvenile belugas (gray) averaged 2.25 sec at the surface (SD=0.32 sec, n=36) while adults (white) surfaced for an average of 2.55 sec (SD=0.36 sec, n=70). Adults spent significantly more time at the surface than juveniles (*t*-test =4.5, d.f.=79, P<0.001). This was also evident in video recordings of an adult/calf pair. Seven complete surfacings were captured for the adult and eight for the calf (all slow-rolls). The mean surfacing interval was 2.77 sec (SD=0.22 sec) for the adult and 1.42 sec (SD=0.33 sec) for the calf. Adult/calf surfacings were not always synchronized.

Color categories were combined and averaged in order to compare slow-roll behavior to head-lift behavior (Fig. 5c). As expected, the mean surfacing interval during a head-lift ($\bar{x}$=1.02 sec, SD=0.38 sec, n=28) was significantly less than the mean surfacing interval during a slow-roll ($\bar{x}$=2.45 sec, SD=0.37 sec, n=106) (*t*-test=17.9, d.f.=132, P<0.001). Only 24% (n=110) of the surfacings in undisturbed groups were head-lifts. This was considerably lower than the percentage observed for whales harassed during tagging bouts.

As stated earlier, belugas in groups fleeing from approaching tagging vessels were observed to head-lift (92%) more often than slow-roll (8%). During 27 video recorded tagging pursuits, 85%

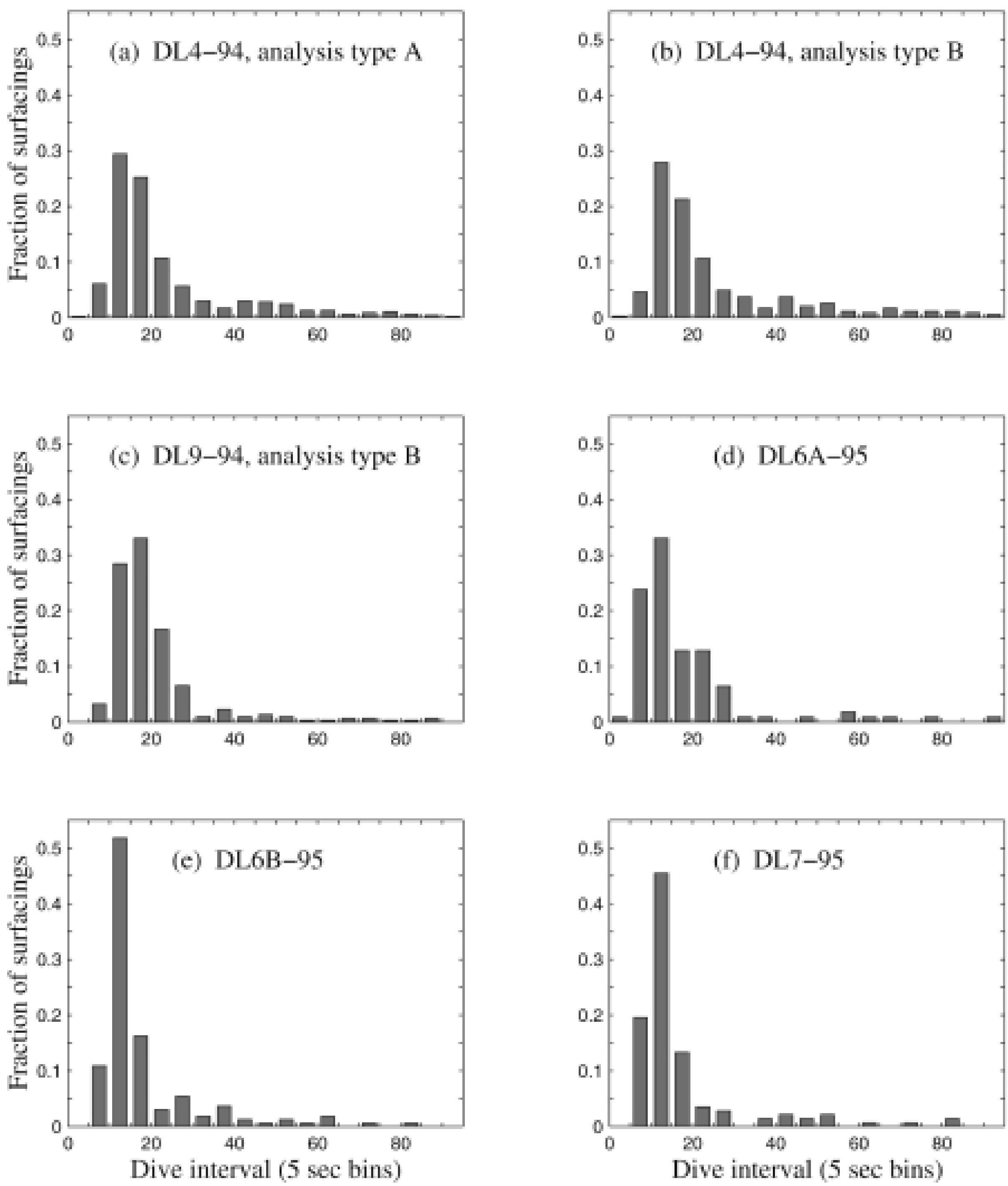

Figure 4.—Dive interval probability distributions for five tagged belugas (see Table 2 for distribution statistics). Distributions obtained from analysis types A (includes both questionable and definite surfacings) and B (definite surfacings only) are plotted for DL4-94 in (a) and (b), respectively. Only definite surfacings were used to obtain distributions for the other whales. The full extent of the long dive intervals are not shown in the plots so that the shapes of the distributions can be more easily compared.

of the whales isolated for tagging initially reacted by head-lifting on the first surfacing. Individuals isolated for tagging varied in their surfacing behavior during a chase sequence. Only 15% were observed to slow-roll thoughout the entire bout, while 59% exhibited only head-lift behavior. The remainder, 26%, exhibited almost equal preference

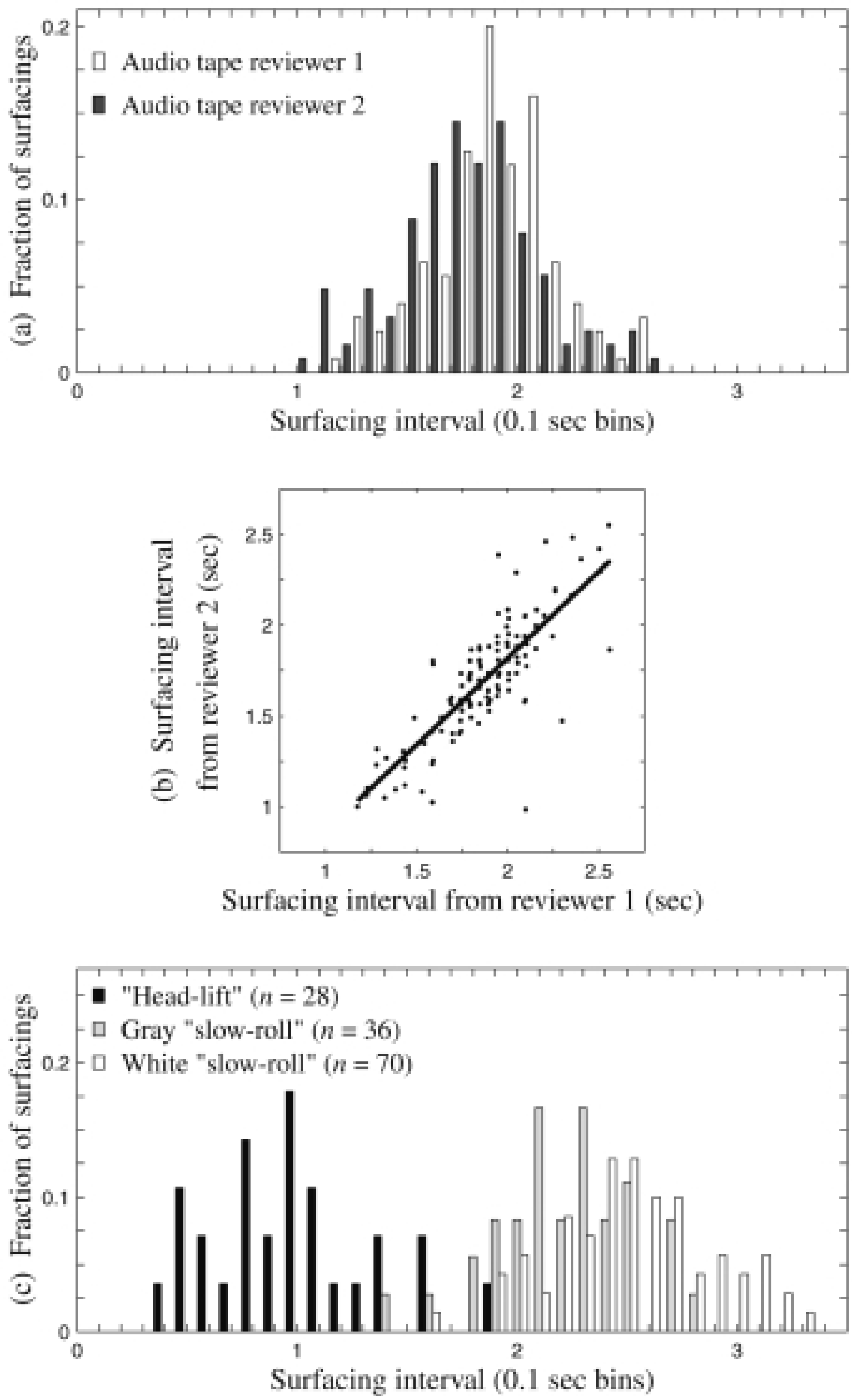

Figure 5.—Probability distributions of the surfacing intervals of belugas tagged in Cook Inlet, Alaska: a) comparing two independent reviews of 125 surfacings from audio tapes of radio-tag data from DL9-94; b) the correlation of surfacing intervals estimated by the two reviews, and c) probability distributions of the surfacing intervals for undisturbed whales segregated by age and size class (juveniles (gray) vs. adult (white)) and behavioral type (head-lift vs. slow-roll) analyzed from videotapes collected in 1994.

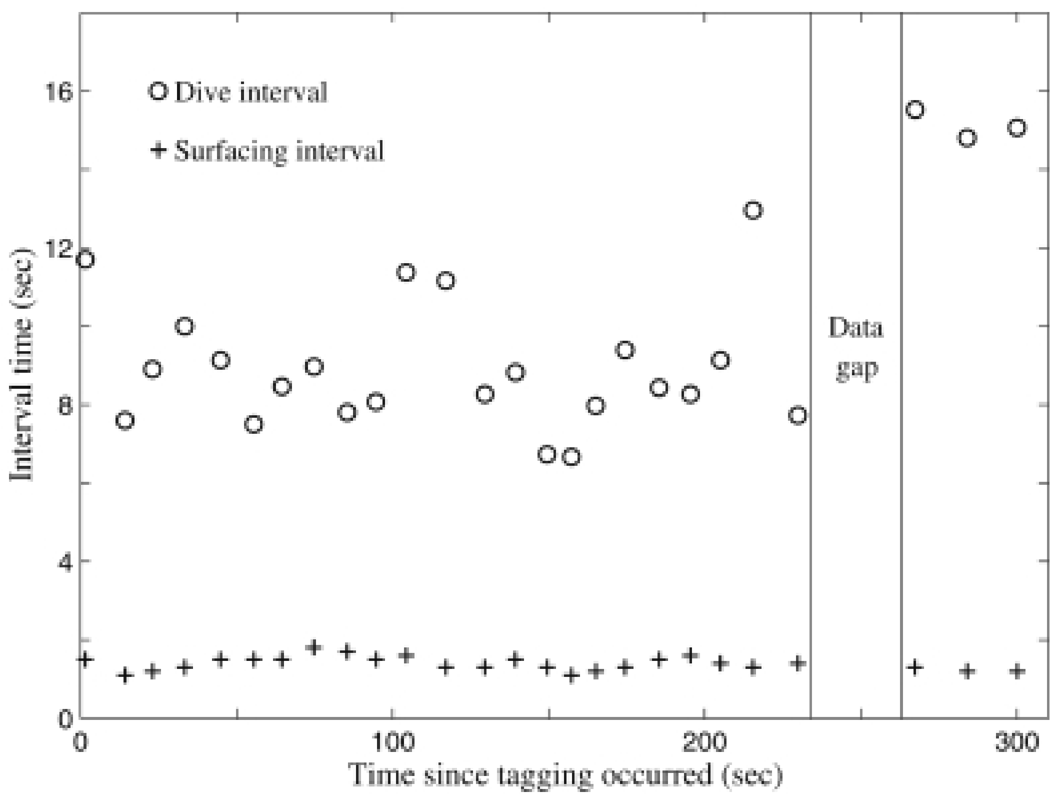

Figure 6.—Surfacing behavior of a beluga tagged on 11 June 1994 in Cook Inlet, Alaska. Data were obtained from videotape observations taken immediately after tag deployment. The break in the data at about 230 sec is due to a gap in the video record (although the surfacing was captured on the audio recording, precise timing could not be determined).

for the two types of surfacing behavior. Because the duration of a tagging bout averaged only 2.7 min, usually only 1–3 surfacings occurred before the bout was terminated.

Whale DL11-94 exhibited only head-lift behavior from the time it was tagged to the termination of video tracking (5.25 min). The mean dive interval was 10.3 sec (SD=2.5 sec, *n*=26). This was significantly less than the mean dive intervals of the five whales tagged for >60 min. The mean surfacing interval was 1.34 sec (SD=0.31 sec, *n*=28). Toward the end of the tracking period, the dive intervals appeared to increase and become more variable, while the surfacing intervals did not (Fig. 6).

Discussion

Based on our study, belugas appeared to recover quickly from disturbance. The whales displayed a strong fidelity for the study area and often approached the tagging vessel after the conclusion of a tagging bout. Head-lifting behavior appeared to be correlated with disturbance. Under similar environmental conditions, the fraction of surfacings that were head-lifts was considerably higher for pursued whales than for undisturbed whales. Tagged belugas did not display strong reactions to the tags (i.e. their reactions did not appear to differ from whales that were not pursued or tagged but fled during vessel operations). Unlike the bottlenose dolphins studied by Schneider et al. (1998), the tagged belugas made no apparent vigorous behaviors to remove the tags.

The mean dive intervals estimated in this study do not differ significantly from those estimated for the two whales tagged by Frost et al. (1985; 31 sec and 26 sec). Natural variability in the dive behavior of individual whales in a population is not unusual and probably accounts for much of the variability observed in the five belugas we tagged. These whales had a considerable range in size and age (Table 1). Seasonal variations in behavior may also account for some of the variability. Tagging operations in 1994 occurred in June, whereas operations in 1995 occurred in August.

Several factors related to tagging that may introduce biases in the observed surfacing behavior are listed below. Assessing their importance is difficult and beyond the scope of this paper. First, there was no apparent trend in dive behavior with time after tagging (Table 3). However, this does not definitively indicate that the tagged whales behaved “normally” and had recovered from the stress associated with the tagging pursuit before or during the period when data was being collected. Second, reactions to the presence of the tag that are not easily observed in the field may also bias the estimated surfacing behavior. Third, it is possible that, on occasion, only a faint signal or no signal at all was received when tagged whales surfaced.

When the whales tagged in 1995 were observed during photographic operations, nearly all surfacings (both headlifts and slow-rolls) observed visually were detected by the radio-tag monitor. These tags were located near the dorsal ridge of the whales (Table 1), a location that was very likely to come near the surface (especially during slow-rolls). The tag on DL4-94, however, was attached on the tail stock, an area less likely to come close to the surface. We believe nearly all slow-roll and headlift surfacings were detected using the radio tags when tags were placed near the dorsal ridge, but a careful study is necessary to confirm what fraction of surfacings were missed.

Even though transmitters provide a useful relative measure of the length of surfacing intervals, the duration of a transmitter's signal does not necessarily give the total time a whale is visible above the water. The whale's rostrum is probably exposed before the transmitter antenna breaks the surface, and the lower back and tail stock probably remain exposed after the antenna has resubmerged. This is confirmed by mean surfacing intervals from aerial (Hobbs et al., 2000b; $\bar{x}$=2.59 sec, SD=0.67 sec, n=155) and vessel video records (Fig. 5c), which were both higher than the mean time at the surface obtained from the radio-tag data. In this case, measurement of the time a surfacing whale is visible in video records is a much more direct and effective method than using radio-tag signals.

An unbiased sample of dive intervals for belugas in Cook Inlet is extremely difficult to obtain without the use of remotely sensed tags. Visual tracking of individual whales in a group is not possible because of the highly turbid water of the inlet, the irregular swimming patterns of the whales, the lack of obvious markings, and the large group sizes. Only short, continuous visual records of surfacings can be obtained before whales are either lost or confused with other whales. Such records are biased towards short dive times because whales are more likely to be lost during longer dives. With radio tags, long, continuous and unbiased dive records can be obtained.

The longest amount of time one of our tags remained on a whale was >6.9 h. Longer deployments are desirable in order to reduce the effect of stress associated with tagging the whale, and allow for studies of the temporal variability (e.g. at tidal and longer time scales) of diving behavior and of whale movements. An option for obtaining longer time series is to attach satellite packs onto the whales.

Capturing belugas and pinning instrument packs to their dorsal ridges has occurred successfully elsewhere (Frost et al., 1985; Martin and Smith, 1992; Heide-Jørgensen et al., 1998). On the Susitna River delta, attempts to capture and hold belugas for attaching satellite tags were unsuccessful in the 1995 and 1997 field seasons. However, satellite tags were successfully attached to one whale in 1999 and two whales in 2000. In addition, a suction-cup tag with a time-depth recorder (TDR) was attached to one of the whales in 2000 and remained on the whale for approximately 90 h. Satellite packs pinned through the dorsal ridge have remained attached to belugas for >3 months, and provide much more information about long-term whale movements and dive patterns than the radio transmitters used on our suction-cup tags.

This study is the first attempt to characterize the surfacing behavior of belugas in Cook Inlet. The sample size must be increased to better understand the range of behavior between individual whales and within different environmental conditions in the inlet. We believe that, with minor modifications to our attachment system, tag deployments as long as several days can be obtained (as has been shown with the suction-cup attached TDR deployed in 2000). Radio transmitters do not collect the detailed dive and whale movement information possible with satellite transmitters and TDR's. However, the cost of the tags used in our study is only one-tenth the typical cost of satellite tags. We believe that the methods employed in this study are a low-cost alternative for obtaining surfacing behavior data from a large sample of whales, which is required to estimate correction factors for the abundance of Cook Inlet belugas.

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