Surveying Killer Whale Abundance and Distribution In the Gulf of Alaska and Aleutian Islands

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A group of resident-type killer whales seen on the southwest side of Adak Island. Photo by Robert Pitman.

Introduction

The documented declines of Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), and sea otters (*Enhydra lutris*) in the western Gulf of Alaska and Bering Sea have generated a range of hypotheses regarding possible causes. One recent hypothesis suggests that killer whale (*Orcinus orca*) predation may be responsible for these declines, with prey shifting over time as killer whales sequentially deplete populations of available prey species. Evaluation and testing of this hypothesis requires empirical data on the abundance, distribution, and feeding ecology of killer whales in this area.

Three forms of killer whales, termed "resident," "transient," and "offshore" have been described in the coastal waters of the Northeast Pacific Ocean. These terms were originally designated by killer whale researchers to describe the whales' patterns of occurrence, particularly in British Columbia and Washington. "Residents" were generally in inland waters all summer, whereas "transients" only appeared occasionally, and "offshore" whales were seen only in outer coast waters. As studies have increased over larger geographical and temporal scales, it has become apparent that these terms do not fully depict the ranging patterns of these three ecotypes. However, recent research continues to confirm that the three terms do refer to very distinct types of killer whales that can be distinguished based on genetics, acoustics, and morphology. Research also shows the terms apply to distinct types of feeding ecology. Resident killer whales are known to be primarily fish-eaters, in contrast to transients that feed primarily on marine mammals. Relatively few feeding observations have been made for the offshore type, but initial data suggest they also eat fish.

Although killer whale population size and stock structure is well documented for the waters of southeastern Alaska and Prince William Sound, relatively little abundance and genetic data exist for killer whales in Alaskan waters west of Kodiak Island. Thus, in 2001, the National Marine Mammal Laboratory's Cetacean Assessment and Ecology Program (CAEP) initiated a 3-year study with an aim of providing comprehensive baseline information on killer whales in the waters of the Gulf of Alaska and Aleutian Islands. Specific research objectives included estimating killer whale abundance in coastal waters between the Kenai Fjords region of southcentral Alaska to the central Aleutian Islands using line-transect and mark-recapture techniques, examining distribution and movement patterns of killer whale groups, and determining the ecotype of killer whale groups using this area. Here we report on the methodology used in these surveys and present preliminary results.

Field Methods

Ship-based surveys were conducted over three summer field seasons, each 6 weeks in duration. Survey dates were 17 July - 25 August in 2001; 10 July - 21 August in 2002; and 3 July - 14 August in 2003. Large charter vessels were used as sighting platforms, with a small skiff deployed from the vessels for close approaches to whales. A stable sighting platform is important for cetacean surveys, as too much motion makes it difficult to search through binoculars. Additionally, searching is aided from being on a platform that is high above water; not only can a greater area be searched, but a larger portion of an animal's body is visible. In 2001, the *Aleutian Mariner* was used, and in 2002 and 2003, the *Coastal Pilot* was used. The *Aleutian Mariner* is 38 m long and has an outside observation platform 3.8 m above the water. The *Coastal Pilot* is 53 m long and has a bridge height of 7.5 m. Assuming an average eye height of 1.7 m, the observation heights were 5.5 m above sea level on the *Aleutian Mariner* and 9.2 m above sea level on the *Coastal Pilot*.

The survey was designed to estimate the abundance of killer whales within a substantial portion of the known haul-out range of the western stock of Steller sea lions in U.S. waters. Given the focus on the possible predation of Steller sea lions by killer whales, the highest priority was to estimate the abundance of transient killer whales. In summer, Steller sea lions are thought to forage primarily in relatively close proximity to their rookeries and haulouts. Therefore, the killer whale survey was designed to include a 20 nautical mile (nmi) area around Steller sea lion rookeries and major haulouts. This was accomplished by surveying an area that had an offshore boundary approximately 30 nmi from the main coastline and major islands, with some extensions to accommodate locations further offshore

The survey track was a randomly placed sawtooth (zig-zag) pattern inside a rectangle, where the offshore boundary of the rectangle was drawn to parallel the major axis of the coastline (Fig. 1). This design ensured that the tracklines randomly sampled the study area. Multiple rectangles were established, with each rectangle designated as a stratum in a stratified survey design. The eastern boundary of the study area coincided with the eastern border of the western stock of Steller sea lions, along the coastline of the Kenai Peninsula. The western boundary of the study area was defined as the western side of Seguam Pass in the central Aleutian Islands in 2001 and was then moved farther west to Tanaga Pass in 2002 and 2003. Breakpoints for establishing the ends of the strata were established at various locations in order to

The charter vessel *Coastal Pilot* used on the surveys in 2002 and 2003. Photo by John Brandon.

accommodate changes in the orientation of the coastline, the need to extend the study area farther offshore to include various islaand groups, and to align with the major areas already used for examining trends in abundance of the western stock of Steller sea lions.

Four of six designated Steller sea lion areas (central Gulf of Alaska, western Gulf of Alaska, eastern Aleutian Islands, and central Aleutian Islands (as far west as Seguam Pass)) were surveyed (Fig. 1). Logistics and available ship time have precluded extending the survey farther west. Fourteen strata were designated in 2001, and 16 were designated in 2002 and 2003 to include the extension of the study area to the west in those years. The total area surveyed was 177,656 km^2 in 2001 and 221,083 km^2 in 2002 and 2003. Effort per unit area (the length of the transect lines divided by the area inside each stratum) was kept constant across all strata. This provides the greatest flexibility in analysis, as a constant search effort allows all strata to be pooled for analysis, if desired, while still allowing abundance and density in individual strata to be considered. A random number generator was used to position the transect lines in each stratum.

John Durban and John Brandon track a group of Baird's beaked whales on the north side of Tanaga Island, with Tanaga volcano in the background. Photo by Paul Wade.

Line-Transect Methodology

Sighting data were collected from high points on the decks of the *Aleutian Mariner* (in 2001) and the *Coastal Pilot* (in 2002 and 2003). During line-transect surveys, sighting data were collected by three observers. Starboard and port observers were stationed outside on the observation platform and the data recorder was positioned inside, at a computer station, on the bridge. Starboard and port observers used 7 x 50 Fujinon reticle binoculars to search from the ship's bow to the beam of the ship. The data recorder searched the trackline while scanning through the viewing areas of the two primary observers. Each observer and the data recorder had an angle board (pelorus) to determine the horizontal angle to the cetacean groups. When a sighting occurred, the observer alerted the recorder and then determined the horizontal angle and number of reticules from the horizon to the position where the sighting was first noted. Additional information collected included sighting cue, course and speed, species identity, and the best, low, and high estimates of group size. The computer program WINCRUZ was used to record all sighting and environmental data (e.g., cloud cover, wind strength and direction, and Beaufort sea state). The computer was interfaced to a portable Garmin GPS to gather positional and navigational information.

Six observers rotated through the three positions, resulting in 2 hours of "on effort" by each observer followed by a 2-hour rest period. The order in which individual observers rotated through the schedule each day was randomized. Survey effort began approximately 30 minutes after sunrise and ended 30 minutes before sunset. On-effort search was abandoned when the weather and visibility conditions were poor or the sea state was above Beaufort 5. Under unacceptable weather conditions, the recorder stayed on watch at the bridge to record "off-effort" sightings and environmental data. When sighting conditions were good, the observer teams also maintained a marine mammal watch while transiting between line-transect legs. Although this effort will not be used in any line-transect analysis, line-transect protocol was maintained in order to search for killer whales, so the data could be used in a mark-recapture analysis. Furthermore, perpendicular distance information from transit legs could potentially be included in estimating the detection function for line-transect analysis. Most of the survey was done in passing mode, meaning that the observers did not go off effort when sightings were made of species such as Dall's porpoise (*Phocoenoides dalli*). For all killer whale sightings and, if time allowed, for sightings of other species of interest, such as humpback (*Megaptera novaeangliae*), fin (*Balaenoptera physalus*), and sperm whales (*Physeter macrocephalus*), closing mode was used, where the observers would go off-effort (stop searching widely) and focus their attention on the detected whales. Usually the whales would be closely approached after going off-effort to confirm species identification. Killer whale groups were approached to estimate group size and to conduct photo-identification and biopsy data collection. When resuming effort, the survey would recommence on a convergent course with the trackline.

Photo-Identification and Biopsy Sampling

When killer whales were encountered, the line-transect survey was temporarily suspended in order to collect photographs of the killer whales' dorsal fins and adjacent saddle patch pigmentation to identify individual whales. When conditions permitted, a small boat (19-ft or 22-ft rigid-hull inflatable) was launched to allow for closer approaches to the whales. Tissue samples were collected using remote biopsy techniques and, when possible, acoustic recordings of killer whale calls were collected using a hydrophone and DAT recorder. When time permitted, photographs and tissue samples were collected from other cetacean species and, if conditions were favorable, acoustic recordings were also collected.

Ecotype Determination

A preliminary assessment of killer whale ecotype (resident, transient, or offshore) was made in the field during each encounter using morphology, group size, and behavior. A further determination of ecotype was made post-cruise, from photographs, by two experienced CAEP killer whale biologists. Morphology has long been used to make a preliminary determination of ecotype. Photographs from each encounter were examined independently by the two biologists. They used morphological features that have been established previously from long-term killer whales studies, primarily dorsal fin shape and saddle patch shape and position. Examples of identification photographs from each ecotype showing these differences are shown on page 7.

All whales photographed during an encounter were examined. Typically, some portion of a group showed obvious morphological characteristics that distinguished the ecotype, and the whole group could be classified based on the presence of those characteristics. However, a small number of groups either were not photographed or the photographs were of such poor quality that the ecotype was uncertain. These groups were classified as having an "unknown" ecotype. The field and photographic ecotype determinations were then confirmed for groups that had been biopsy sampled and genetically assigned to ecotype based on mitochondrial DNA sequence variation. Previous killer whale studies have also established that killer whale ecotype can be unambiguously determined from acoustic calls. Where

John Durban collects a biopsy sample using a pneumatic rifle that projects a lightweight dart (right, arrow). The dart rebounds from the whale and floats, retaining a small sample of epidermal tissue and subcutaneous blubber that are used in genetic and other studies. Photos by Lori Mazzuca (left) and John Brandon (right).

Table 1. Total on-effort tracklines for the 2001-03 dedicated killer whale surveys conducted by the Cetacean Assessment and Ecology Program.

	2001		2002		2003	
Beaufort	Effort (nmi)	%	Effort (nmi)	%	Effort (nmi)	%
0	93.6	4.8	77.5	3.5	124.1	5.7
1	298.9	15.4	434.0	19.6	319.8	14.7
2	479.1	24.7	697.1	31.5	419.7	19.3
3	505.0	26.1	557.2	25.2	560.0	25.8
4	478.0	24.7	238.5	10.8	386.0	17.8
5	82.4	4.3	206.3	9.3	363.6	16.7
Total	1,937.0	100.0	2,210.6	100.0	2,173.2	100.0

available, these data were also used to verify the photographically determined ecotypes. In addition, because groups only associate with other groups of similar ecotype, it was possible to use association to verify or even classify a group's ecotype. For instance, if a group that has been classified as transient by morphology and genetics is seen associating with another group that either does not have strong distinguishing morphological features or has not been biopsy sampled, that group can be classified as transient based on association with the known transient group.

Survey Results

A total of 6,321 nmi was surveyed "on effort" under acceptable conditions (Beaufort 0-5) during the surveys in 2001-2003 (Table 1). More effort was accomplished in 2002 and 2003 than in 2001 due to better overall weather and a more stable vessel. The most favorable conditions occurred in 2002 (Table 1). In total, 1,738 cetacean sightings were recorded (Table 3), including 59 groups of killer whales (Figs. 2-3). Killer whale groups ranged in size from 2 to 90 whales, with a median estimated group size of 12. Photographs were obtained from 55 of the encounters, and 61 tissue samples were collected from 33 of the encounters using remote biopsy techniques. Based on the analyses of these photographic and genetic data, and from observations during the encounters, all three distinct killer whale ecotypes were identified.

The three methods of ecotype determinations (field observation, post-field photographic analysis, and genetic analysis) were in agreement for every encounter that had the appropriate data (Table 2), indicating the reliability of each assignment method. Ecotype determination for the subset of encounters with acoustic recordings in 2001-02 were also in agreement with the other methods (2003 acoustic data have not yet been analyzed). Of the 59 killer whale encounters over the 3-year study, 39 were resident (66%), 14 were transient (24%), 2 were offshore (3%) and 4 were unknown (7%). These percentages differed by year. In 2001, a higher percentage of encounters were transient killer whales (37%), compared to 2002 and 2003 (19% and 17%, respectively). The mean group size was 22 whales (min=4, max=90) for residents, 5 (min=2, max=13) for transients, and 50 (min=40, max=60) for offshores. The four groups with unknown ecotypes had an average group size of 6 (min=3, max=15).

Other odontocete (toothed-whale) species seen included 592 sightings of Dall's porpoise, 19 sightings of harbor porpoise (*Phocoena phocoena*), 37 sightings of sperm whale , and 8 sightings of Baird's beaked whale (*Berardius bairdii*). In 2002, a sighting was made on the south side of Unalaska Island of two unidentified beaked whales, suspected of being Stejneger's beaked whale (*Mesoplodon stejnegeri*). The whales were not close enough to the ship to confirm the identity of the species, but the only other likely species would be Cuvier's beaked whale (*Ziphius cavirostris*); the whales were not Baird's beaked whales. Mysticete (baleen whale) species seen included 407 sightings of humpback whale , 276 sightings of fin whale, 96 sightings of minke whale (*Balaenoptera acutorostrata*), and 22 sightings of gray whales (*Eschrictius robustus*). No blue (*Balaenoptera musculus*) or sei whales (*Balaenoptera borealis*) were seen, though they are known from Alaska waters from whale harvest data.

When time and conditions permitted, photographs for individual identification were also taken of cetacean species other than killer whales (Table 3), notably humpback, sperm, fin and Baird's beaked whales. Humpback whales in particular have long been the subject of photo-identification studies in the North Pacific. Biopsy samples were also collected from other cetacean species, with a total of 31 samples from humpback whales, 14 from fin whales, 9 from Baird's beaked whales, 8 from sperm whales, and 3 from gray whales. These will be used for population genetic analyses. Extremely rare acoustic recordings were also made during two encounters with Baird's beaked whales. The sightings data from these surveys have been used to make line-transect abundance estimates of humpback, fin, and minke whales; these preliminary estimates were reported to the Scientific Committee of the International Whaling Commission in June 2003 (IWC document SC/55/O9 available from the NMML library).

Distribution and Movements

Killer whales were detected throughout the study area (Figs. 2-3). It is notable that both resident and transient type whales were seen in Amchitka Pass at the far western extreme of the study area; this is the farthest west that both ecotypes have been seen in U.S. waters (on-going studies suggest that both ecotypes are present in Russian waters as well). Seguam Pass, as well as the waters around Umnak and Unalaska Islands in the eastern Aleutians appear to be areas with overall high killer whale densities in addition to relatively frequent sightings around Kodiak Island. The different ecotypes appear to have some differences in their distribution pattern. Transient killer whales were seen throughout the study area, but appear to be more frequently seen in the central part of the area, from the Shumagin Islands through the eastern Aleutian Islands (Fig. 2). When encounters from the other NOAA surveys are added (discussed below), a similar pattern is seen. In particular, several additional encounters with transients have been made in the Unimak Pass area. One of these encounters, from the Aleutian Passes cruise in 2002 on the *Alpha Helix* was particularly interesting, as it was a large group of transient killer whales (~30 whales) that were feeding on a gray whale carcass in early June. Gray whales, along with other species of baleen whale, migrate seasonally through Unimak Pass, so this may be an important seasonal resource for transients. No encounters with transients were made between the Shumagin Islands and the east side of Kodiak Island (Fig. 2).

Resident type killer whales were particularly abundant around Umnak and Unalaska Islands in the eastern Aleutians, and around all sides of Kodiak Island (Fig. 3). Seguam Pass in the Aleutians was another location with multiple sightings. Resident killer whales were particularly abundant near Dutch Harbor on Unalaska Island; it is suspected that this high density of resident type whales is at least partially due to the high density of fishing boats, as residents are well known for depredating fish from longline gear and consuming discards from groundfish trawlers. There is a large gap in the distribution of residents stretching from just west of Kodiak Island to the Unimak Pass area. It is interesting that this approximately 800-km gap has been consistent in July and August over 3 years of surveys.

Offshore type killer whales were seen twice on CAEP's dedicated killer whale surveys, once south of Kodiak Island in 2001 and once just outside of Dutch Harbor in the Aleutian Islands in 2003 (Fig. 2). Offshore type killer whales were seen a third time just west of Dutch Harbor by NOAA researchers on an oceanography cruise conducted in 2002 (see below). These encounters in the eastern Aleutians represent the farthest west that offshore type killer whales have been found. Offshore type killer whales were not previously recognized as a regular component of the ecosystem in the western Gulf of Alaska and Aleutian Islands. However, their consistent, if infrequent, detection across multiple years suggests they are regularly found in this region. Though few groups were seen, the group sizes were large (13, 40, and 60). The 100 offshore killer whales seen during the CAEP surveys were more than the total number of transient type killer whales seen during the same surveys.

Photographs of uniquely identifiable killer whales collected during the 3-year dedicated study will be compared to existing photographic catalogs and to photographs collected by other research efforts. For example, previous CAEP surveys in 1992 and 1993 led to a catalogue of 289 individual killer whales from the central Gulf of Alaska to the southeastern Bering Sea (see Dahlheim 1997, NOAA Technical Report NMFS 131). Photographic comparisons will allow characterization of both local and long-range movements of killer whales. A complete analysis of matches and movements at this date has only been completed through the 2001 NMML survey data. Matches within and between the 2001 dedi-

Resident-type (fish-eating). The dorsal fin is often more falcate and there is greater saddle patch variation. In particular, a black cup, finger, swirl or open area may intrude into the top of the white saddle patch. Photo by Nancy Black.

Transient-type (mammal-eating). The dorsal fin is often more triangular with a broad base and the saddle patch is large and uniform (without black intrusions, although sometimes with a "feathering" pattern along the front edge of the saddle). Photo by Janice Waite.

Offshore-type. The dorsal fin is often rounded at the tip with multiple nicks in the fin. The saddle patch can also have black intrusions like resident-type whales. Photo by John Durban.

Photographs illustrating how the three recognized NE Pacific killer whale ecotypes can be distinguished based on examination of morphological differences in the dorsal fin and adjacent saddle patch region.

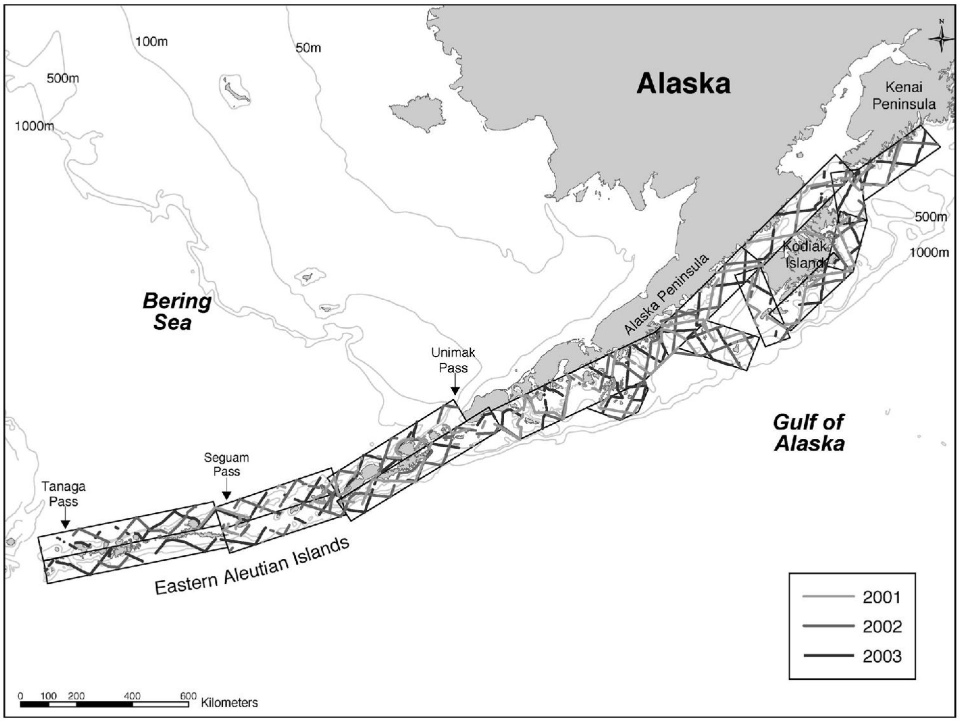

Figure 1. Study area (rectangles) and on-effort tracklines accomplished during the 2001-03 dedicated killer whale surveys.

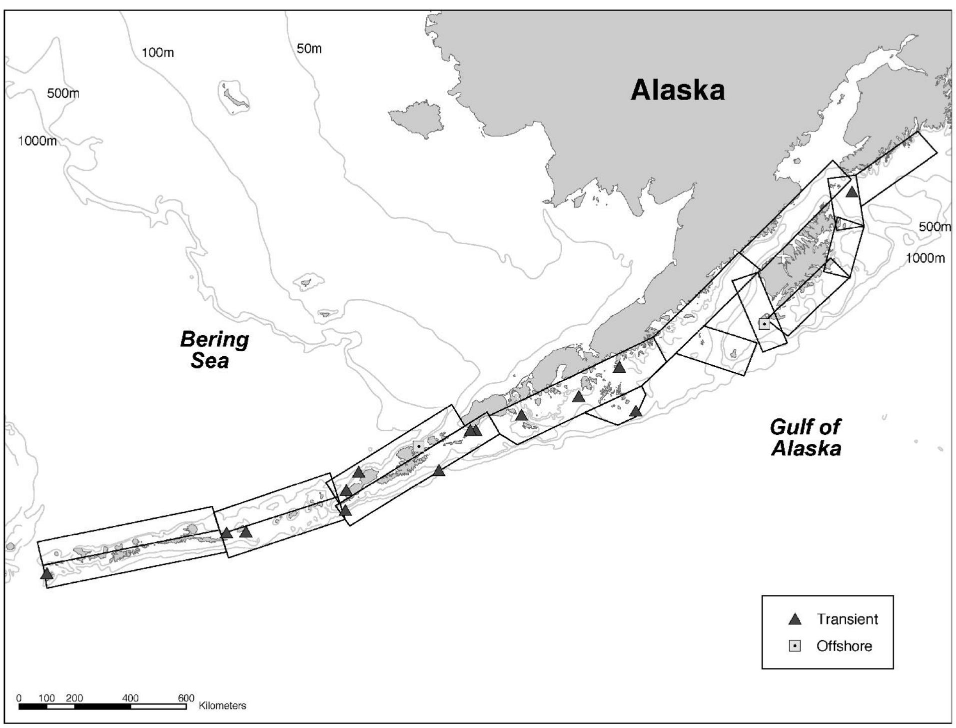

Figure 2. Location of encounters with groups of transient-type (triangles) and offshore-type (box) killer whales during the 2001-03 dedicated killer whale surveys.

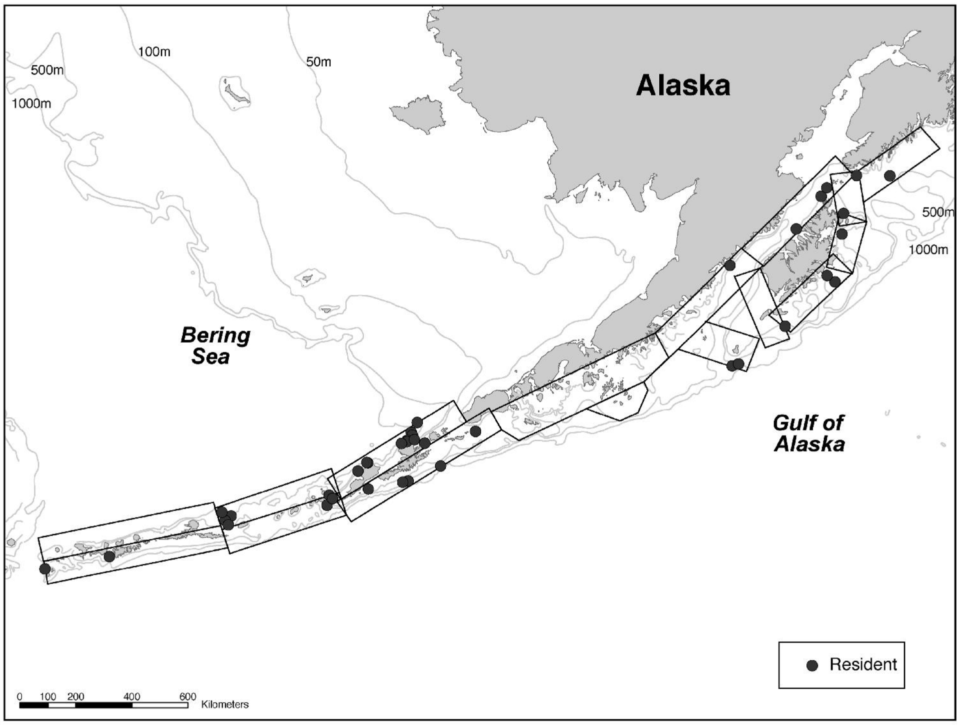

Figure 3. Location of encounters with groups of resident-type killer whales during the 2001-03 dedicated killer whale surveys.

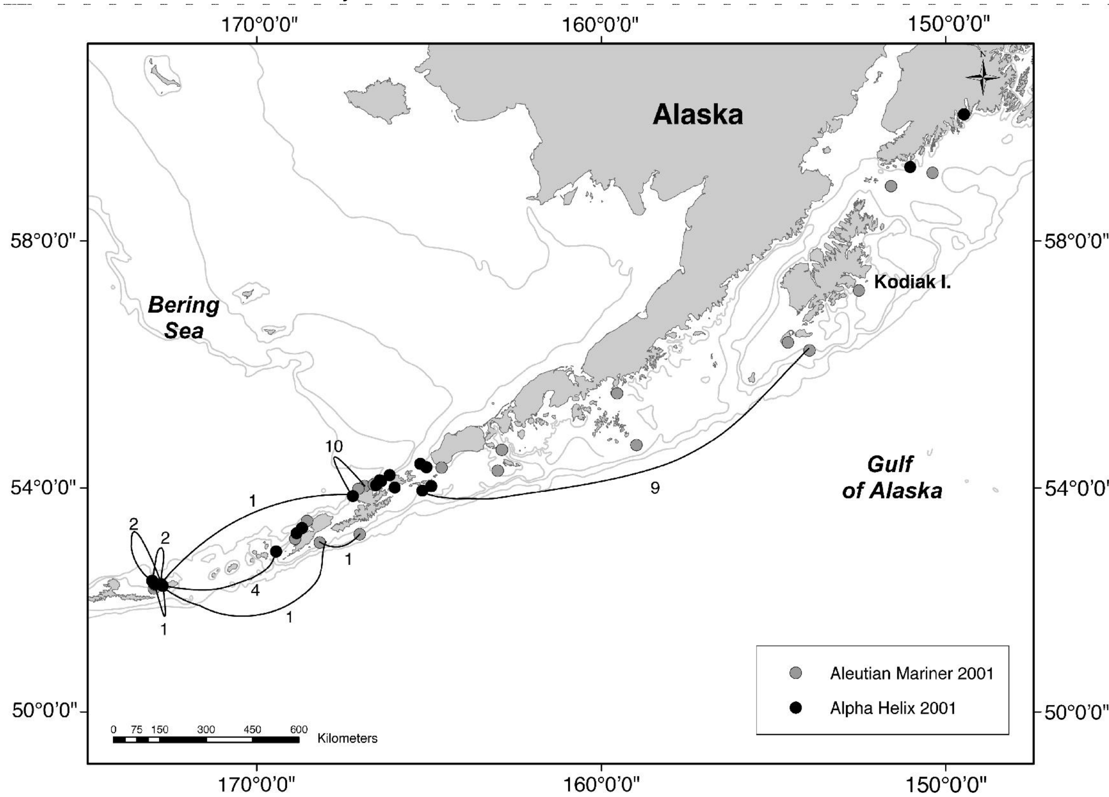

Figure 4. Location of all killer whale encounters in 2001 from both the dedicated killer whale survey on the *Aleutian Mariner* in July/August and from the killer whale survey conducted during the Aleutian Passes oceanography study on the *Alpha Helix* in May/June. Lines drawn between encounters indicate that at least one individual whale was seen in both encounters. The number next to each line indicates the numbers of individual whales that were seen in both encounters.

Table 2. Killer whale encounters during the 2001-2003 dedicated killer whale surveys. Visual ecotypes were determined in the field based on morphology and behavior of the whales. These were “unknown” if they could not be approached close enough for a visual assessment. Photo ecotype was determined from examination of photographs, based on morphology of the dorsal fin and saddle patch pigmentation. Genetic analyses of biopsy samples were provided by the Southwest Fisheries Science Center, La Jolla, California; mitochondrial DNA haplotypes are not shared between the three killer whale ecotypes in the North Pacific and can therefore be used to unambiguously identify ecotypes.

YEAR	DATE	ENCOUNTER	GROUP SIZE	LOCATION	LAT.	LONG.	PHOTOS	BIOPSIES	VISUAL ECOTYPE	PHOTO ECOTYPE	MOLECULAR ECOTYPE
2001	20-Jul-01	1	25	NE Kodiak Island	59:02	150:23	Yes	0	Resident	Resident	No Data
	21-Jul-01	2	4	NE Kodiak Island	59:03	151:35	Yes	1	Transient	Transient	Transient
	24-Jul-01	3	25	S Kodiak Island	59:04	152:31	Yes	0	Resident	Resident	No Data
	25-Jul-01	4	90	Trinity Islands	59:05	153:57	Yes	4	Resident	Resident	Resident
	26-Jul-01	5	40	Trinity Islands	59:06	154:35	Yes	2	Offshore	Offshore	Offshore
	31-Jul-01	6	7	Shumagin Islands	59:07	159:33	Yes	0	Transient	Transient	No Data
	1-Aug-01	7	3	Shumagin Islands	59:08	158:59	Yes	1	Transient	Transient	Transient
	3-Aug-01	8	3	Unimak Pass	59:09	164:38	Yes	1	Transient	Transient	Transient
	4-Aug-01	9	17	N Unalaska Island	59:10	166:53	Yes	0	Resident	Resident	No Data
	5-Aug-01	10	10	N Unalaska Island	59:11	167:03	Yes	0	Resident	Resident	No Data
	5-Aug-01	11	10	N Unalaska Island	59:12	166:36	Yes	1	Resident	Resident	Resident
	11-Aug-01	12	3	SE Unimak Island	59:13	162:53	Yes	0	Transient	Transient	No Data
	11-Aug-01	13	4	Sanak Island (E Alaska Peninsula)	59:14	163:00	No	0	Unknown	No Data	No Data
	14-Aug-01	14	10	NW Umnak Island	59:15	168:34	Yes	1	Resident	Resident	Resident
	14-Aug-01	15	2	SW Umnak Island	59:16	168:55	Yes	0	Transient	Transient	No Data
	17-Aug-01	16	3	Seguam Pass	59:17	172:59	Yes	1	Transient	Transient	Transient
	17-Aug-01	17	50	Seguam Pass	59:18	172:57	Yes	2	Resident	Resident	Resident
	24-Aug-01	18	38	S Umnak Pass	59:19	168:10	Yes	1	Resident	Resident	Resident
	25-Aug-01	19	15	SW Unalaska Island	59:20	167:00	Yes	2	Resident	Resident	Resident

Table 2. Continued

YEAR	DATE	ENCOUNTER	GROUP SIZE	LOCATION	LAT.	LONG.	PHOTOS	BIOPSIES	VISUAL ECOTYPE	PHOTO ECOTYPE	MOLECULAR ECOTYPE
2002	12-Jul-02	20	3	Unalaska Bay	59:21	166:50	No	0	Unknown	No Data	No Data
	12-Jul-02	21	12	Unalaska Bay	59:22	166:52	Yes	0	Resident	Resident	No Data
	13-Jul-02	22	14	E Unalaska Island	59:23	166:15	Yes	1	Resident	Resident	Resident
	17-Jul-02	23	46	Samalga Pass	59:24	169:35	Yes	2	Resident	Resident	Resident
	18-Jul-02	24	8	S Sequam Pass	59:25	172:26	Yes	1	Resident	Resident	Resident
	25-Jul-02	25	13	Amukta Pass	59:26	172:19	Yes	0	Transient	Transient	No Data
	27-Jul-02	26	5	Samalga Pass	59:27	169:24	Yes	0	Resident	Resident	No Data
	28-Jul-02	27	5	S Umnak Island	59:28	168:55	Yes	2	Transient	Transient	Transient
	29-Jul-02	28	22	East Unalaska Island	59:29	165:43	Yes	0	Resident	Resident	No Data
	29-Jul-02	29	5	East Unalaska Island	59:30	165:43	Yes	0	Transient	Transient	No Data
	1-Aug-02	30	39	S Unimak Pass	59:31	164:31	Yes	1	Resident	Resident	Resident
	13-Aug-02	31	24	S Shelikof Strait	59:32	155:50	Yes	0	Resident	Resident	No Data
	15-Aug-02	32	9	S Kodiak Island	59:33	152:15	Yes	0	Resident	Resident	No Data
	16-Aug-02	33	62	Marmot Bay, Kodiak Island	59:34	152:01	Yes	2	Resident	Resident	Resident
	19-Aug-02	34	8	West Barren Island	59:35	152:32	Yes	0	Resident	Resident	No Data
	20-Aug-02	35	22	Shelikof Strait	59:36	153:34	Yes	2	Resident	Resident	Resident
2003	3-Jul-03	36	60	Unalaska Bay	59:37	166:24	Yes	1	Offshore	Offshore	Offshore
	3-Jul-03	37	15	NW Akutan Island	59:38	166:15	No	0	Unknown	No Data	No Data
	5-Jul-03	38	3	S Unimak Island	59:39	164:28	Yes	0	Transient	Transient	No Data
	6-Jul-03	39	18	SW Unalaska Island	59:40	166:52	Yes	1	Resident	Resident	Resident
	7-Jul-03	40	3	N Umnak Island	59:41	167:33	No	0	Unknown	No Data	No Data

Table 2. Continued

YEAR	DATE	ENCOUNTER	GROUP SIZE	LOCATION	LAT.	LONG.	PHOTOS	BIOPSIES	VISUAL ECOTYPE	PHOTO ECOTYPE	MOLECULAR ECOTYPE
2003	7-Jul-03	41	6	NW Umnak Island	59:42	168:22	Yes	5	Transient	Transient	Transient
	7Jul-03	42	5	NW Umnak Island	59:43	168:11	Yes	1	Resident	Resident	Resident
	7-Jul-03	43	12	N Umnak Island	59:44	168:16	Yes	0	Resident	Resident	No Data
	10-Jul-03	44	6	NW Seguam Island	59:45	172:52	Yes	4	Resident	Resident	Resident
	10-Jul-03	45	20	NW Seguam Island	59:46	173:07	Yes	3	Resident	Resident	Resident
	11-Jul-03	46	8	NW Seguam Island	59:47	173:12	Yes	1	Resident	Resident	Resident
	14-Jul-03	47	15	Amchitka Pass	59:48	179:10	Yes	0	Resident	Resident	No Data
	14-Jul-03	48	5	Amchitka Pass	59:49	179:08	Yes	1	Transient	Transient	Transient
	15-Jul-03	49	21	SW Adak Island	59:50	177:01	Yes	1	Resident	Resident	Resident
	19-Jul-03	50	22	Samalga Pass	59:51	169:29	Yes	1	Resident	Resident	Resident
	21-Jul-03	51	18	N Unalaska Island	59:52	166:43	Yes	2	Resident	Resident	Resident
	21-Jul-03	52	50	N Unalaska Island	59:53	166:41	Yes	4	Resident	Resident	Resident
	23-Jul-03	53	14	N Unalaska Island	59:54	166:29	Yes	1	Resident	Resident	Resident
	28-Jul-03	54	2	Shumagin Islands	59:55	160:56	Yes	0	Transient	Transient	No Data
	1-Aug-03	55	6	Chirikof Island	59:56	155:44	Yes	0	Resident	Resident	No Data
	1-Aug-03	56	4	Chirikof Island	59:57	155:53	Yes	0	Resident	Resident	No Data
	6-Aug-03	57	24	East Afognak Island	59:58	151:58	Yes	5	Resident	Resident	Resident
	7-Aug-03	58	22	SE Kenai Peninsula	59:59	151:30	Yes	2	Resident	Resident	Resident
	10-Aug-03	59	22	North Kodiak Island	59:60	152:42	Yes	0	Resident	Resident	No Data

Table 3. Summary of sightings over 3 years (2001-03) on the dedicated killer whale surveys.

Species	Sightings	Mean Group Size	Individuals	Biopsy Samples
Killer whale	59	17.6	1,038	61
Pacific white-sided dolphin	1	8	8	
Dall's porpoise	592	3.5	2,072	
Harbor porpoise	19	1.8	34	
Unidentified porpoise	12	1.8	22	
Sperm whale	37	1.2	44	8
Baird's beaked whale	8	10.8	86	9
Unidentified ziphiid whale	1	2	2	
Gray whale	22	5.6	123	3
Minke whale	96	1	96	
Fin whale	276	2.1	580	14
Humpback whale	407	1.9	773	31
Unidentified rorqual	8	1.4	11	
Unidentified small whale	2	1.5	3	
Unidentified large whale	174	1.5	261	
Unidentified whale	12	1	12	
Unidentified cetacean	12	1	12	
Total	1,738	3.0	5,178	126

cated survey and the 2001 *Alpha Helix* survey show movements of resident killer whales between several sighting locations (Fig. 4). Most matches were made throughout the eastern Aleutian Islands (Unalaska Island to Seguam Pass), with three within Seguam Pass itself. One long-range movement was found from near Unimak Pass to Kodiak Island. Movements from the following 2 years of surveys will be examined to look at within- and between-year movements, as well as differences by ecotype.

Predation

Killer whale predation on marine mammals in Western Alaska has rarely been observed. Despite the fact that 14 encounters with transient whales were observed between 2001 and 2003, only one predation event was witnessed. This event took place near the Shumagin Islands (54°43.4'N; 158°58.5'W) on 1 August 2001 in close proximity to a Steller sea lion rookery. High-quality, identification photographs and digital video of the three killer whales involved in this event were collected. The killer whale group included an adult male, an adult female, and a smaller whale of undetermined sex. Analysis of a biopsy sample collected from the smaller (young) whale genetically identified it as a transient whale. As the *Aleutian Mariner* approached the killer whales, the observers could see that the killer whales were surrounding a small minke whale. The minke whale was alive when first seen but apparently died a few minutes later. The adult male killer whale was observed dragging the dead minke whale around for at least an hour after the kill, and the young whale was also seen with food in its mouth. Birds were also observed dipping down to pick up small bits of flesh or oil droplets from the water.

A possible incidence of killer whales harassing humpback whales was observed on 28 July 2003, just east of the Shumagin Islands. This event involved two killer whales (an adult male and female) and a humpback mother and calf within a widely dispersed aggregation of 10-15 humpback whales. Despite the rough seas, digital photographs of the two killer whales were successfully collected, and evaluation of the photographs suggested that these were transient whales. During this encounter, the humpback mother and calf were observed to be in very close

Two whales from a group of about 60 offshore-type killer whales surface just outside the breakwater at Dutch Harbor, Alaska. Photo by Paul Wade.

proximity to each other, which may have been an attempt by the mother to protect the calf. The two killer whales were observed rapidly "surfing" down a swell in the direction of the mother/calf pair. During this pass, the humpbacks came within meters of the survey vessel, the *Coastal Pilot*, which was stationary at the time, and the calf slightly grazed the starboard side of the bow. The killer whales approached the humpbacks on one other occasion before leaving the area. The humpback mother and calf were not observed to be injured during this encounter.

Abundance Estimates From Line-Transect Methods

Total abundance of killer whales within the survey area will be estimated using line-transect methods, which is a form of distance sampling. This method will use the perpendicular distance data from the sightings to the trackline to estimate the probability of detecting a group of killer whales within a strip on each side of the observation platform. Preliminary analyses of the data investigated different factors that might be important covariates of the detection process, such as observation height, Beaufort sea state, and group size. For killer whales, group size proved to be the most important factor, where the detection of small groups (2-5 individuals) falls off rapidly more than 1 km from the trackline. In contrast, the detection of large groups (>20 individuals) remains high as far as 5 km from the trackline. This is a particularly important factor to account for, as transients tend to be found in much smaller groups than resident-type killer whales. Abundance is estimated by multiplying the total number of sightings recorded on effort, the average group size, and the average detection probability, which will be different for transients and residents. If the influence on detection of group size was not accounted for, the abundance of transients would be underestimated and the abundance of residents would be overestimated. A manuscript summarizing line-transect abundance estimates is in preparation.

Abundance Estimates from Photographic Mark-Recapture

Mark-recapture methods are widely used to assess the abundance of wildlife populations. Conventionally, marking or tagging is used to uniquely identify individuals in successive capture samples, and mark-recapture models use information on the recapture rate to estimate abundance and related parameters. The conventional approach of physical capture

A pair of resident adult males. Photo by Robert Pitman.

and marking has also been generalized to other types of individual detection, greatly increasing the range of species that are amenable to mark-recapture analysis. For cetaceans, photo-identification methods have developed as a more practical alternative for studying these large and mobile marine mammals. In this technique, photographic documentation of natural markings allows photographic "captures" and "recaptures" to be used as samples of the population to which analytical techniques can be employed. This photographic mark-recapture approach is being used to estimate the number of killer whales of each ecotype that are using the study area.

A group of four transient-type killer whales. Photo by Carolyn Jenkins.

There is a wide array of mark-recapture models, and the choice of which to use depends on matching characteristics of the sample data to the inherent assumptions made by the chosen model. This is particularly important for populations that are sampled using nonconventional mark-recapture approaches. There are three main assumptions that are required for nonbiased parameter estimates using most mark-recapture models: 1) all marks are recorded correctly, 2) individuals do not lose their marks, 3) individuals have equal probabilities of capture.

The aim when analyzing killer whale photo-identification data is to ensure that the included data conform to the assumptions of the statistical models as closely as possible, in order to minimize bias in estimates of abundance and survival. An additional aim is to not only estimate the most likely value for these parameters but also to fully communicate the associated uncertainty. To address assumptions 1 and 2, identification photographs are graded based on photographic quality and individual distinctiveness, to minimize errors due to incorrect mark recognition and mark loss. In parallel with the data processing, novel mark-recapture models are being developed to address assumption 3. A prominent feature of killer whale populations is that individuals travel within stable groupings, leading to both individual differences in catchability and to dependencies in capture probabilities of associating individuals (i.e., the probability one individual is captured is not independent of the probability another individual is captured, if the two individuals are typically found in the same group). Traditional mark-recapture models ignore these sources of heterogeneity in capture probabilities, which can lead to biased estimates and overestimation of precision. Work is under way to develop an approach that models the distribution of capture probabilities as a mixture of latent variables and uses Bayesian model selection approaches to simultaneously estimate the number of mixtures, assign observed individuals into component clusters with similar capture probabilities, and predict the number of unobserved individuals. The Bayesian methods for model fitting employ Markov chain Monte Carlo computational methods to estimate a full probability distribution for killer whale abundance.

Photo-identification Data From Other Sources

One of the benefits of mark-recapture methods is that identification photographs from other researchers taken during the same time period can be included in the analysis. Several other NOAA surveys collected killer whale photographs and biopsy samples during the same study period as our dedicated surveys. These photographs will be used in the mark-recapture analysis by matching to the photographs from the dedicated surveys, and ecotype will also be confirmed with genetic samples, where available. These include 1) killer whale surveys conducted by CAEP aboard the *Alpha Helix* as part of an oceanographic survey of the Aleutian passes in June 2001 and again in May - June 2002 (33 killer whale encounters photographed and 27 biopsy samples collected); 2) a CAEP cetacean survey conducted aboard the NOAA ship *Miller Freeman* during the AFSC's Resource Assessment and Conservation En-

Three of six transient killer whales seen near Umnak Island in the Aleutian Islands chain. Photo by Robert Pitman.

gineering Division's acoustic pollock survey in June - July 2002 (central and southeastern Bering Sea) and June 2003 (Gulf of Alaska) (photographs from 11 killer whale encounters were collected with no biopsy samples); and 3) the Southwest Fisheries Science Center's (SWFSC) right whale survey on the NOAA ship *McArthur* in the southeastern Bering Sea in July - August 2002 (10 killer whale encounters photographed, and 13 biopsy samples collected). In addition, occasional photographs are submitted by NMFS fisheries observers from the Bering Sea and the Gulf of Alaska.

Additionally, killer whale studies have been conducted in the Gulf of Alaska and in the Aleutians by the North Gulf Oceanic Society (NGOS website: http://www.whalesalaska.org/). Those studies have been directed by Craig Matkin (NGOS) and Lance Barrett-Lennard (Vancouver Aquarium), who are collaborating in the mark-recapture transient abundance study; the addition of their photographs will substantially increase the sample size for the analysis, while the CAEP dedicated survey data provides a geographically widespread sample that was collected in a randomized systematic way. The combination of the two data sets should provide a more accurate and precise estimate than would be possible from each data set alone.

Analysis of Biopsy Samples

Tissue from the biopsy samples collected during the CAEP surveys is being used for several ongoing studies. Genetic analyses of the CAEP samples have been conducted by the SWFSC, and these samples will be utilized in a North Pacific-wide study of killer whale genetics. These confirmations of ecotype from genetics were all consistent with the designation of ecotype from visual observations and from evaluation of photographs (Table 2).

CAEP has initiated a collaborative study of fatty acids with the chemistry lab at the Northwest Fisheries Science Center (NWFSC). Preliminary results indicated there were strong differences in fatty acids between resident, transient, and offshore ecotypes of killer whales. Analyses are ongoing to determine if coarse information about dietary preferences can be determined from fatty acids, such as distinguishing between a diet of baleen whales, pinnipeds, or fish. If successful, it is hoped that this information will be useful in determining if any transient killer whales sampled during CAEP surveys have a diet that is primarily pinnipeds.

The NWFSC chemistry lab has also undertaken stable isotope analysis of CAEP's killer whale samples, which can provide information about the trophic level that the sampled whales are feeding at. Preliminary results are encouraging that stable isotope analysis will provide some coarse-level indications of dietary preference in killer whales. As an example, it appears that some resident-type whales in western Alaska have substantially different isotopic values from resident whales in Washington, British Columbia, and Southeast Alaska that are known to prey on salmon during summer months. This suggests the hypothesis that some resident whales in western Alaska have a primarily non-salmon diet.

The NWFSC chemistry lab is also using the CAEP samples as part of an on-going study of contaminants in killer whales from California to Russia, including Alaska.

Future Research

Once the photographic data are fully analyzed through 2003, additional studies of movements and distribution will be undertaken by CAEP personnel. In particular, an analysis will be undertaken comparing transient killer whale distribution relative to the location of Steller sea lion rookeries and haulouts. An additional survey is planned for July and August in 2004, at a reduced level (25 days). This survey will focus on the region from the Shumagin Islands to Umnak Island that appears to have a greater density of transient killer whales. Biopsy samples of transients will be a priority for the survey, to contribute in particular to the fatty acid study, which has shown promise that it could provide information about what the primary diet of transient killer whales is in this region. This information will be directly relevant in evaluating the hypothesized role that killer whales may have in limiting pinniped and sea otter populations in this area.