Final Comprehensive Report

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EXECUTIVE SUMMARY

Ecosystem-based management of coastal marine resources requires an understanding of spatial and temporal relationships among apex predators (including marine mammals), their prey, and habitat. Although many species of marine mammals co-occur and may occupy similar roles as apex predators, little is known about their partitioning of prey resources or the degree of competitive interactions among sympatric species. Because ecosystems are complex, it is difficult to study these relationships over large geographic areas and long periods of time. Therefore we undertook a three-part study to address predator-prey interactions and foraging overlap on a geographically-restricted scale in Kodiak Island's near-coastal waters. In this study we examined prey use and foraging patterns of Kodiak's gray, fin, and humpback whales, harbor seals, and Steller sea lions. We employed a combination of techniques to concurrently assess prey availability and monitor the distribution and foraging behavior of resident and transitory pinnipeds and cetaceans sharing common prey resources.

The highly productive nearshore waters of the Kodiak Archipelago support significant seasonal aggregations of zooplankton (euphausiids, copepods) and shrimp which in turn support spawning and nursery aggregations of salmon, herring, pollock, and capelin (Loewen 2007). These resources also support a highly mobile, opportunistic, and ecologically diverse group of marine mammals. Among Kodiak's baleen whales, gray (*Eschrichtius robustus*), humpback *(Megaptera novaeangliae)* and (assumedly) fin whales *(Balaenoptera physalus)* are seasonal migrants that must store enough energy while foraging in Kodiak's productive waters to sustain them during the energetically demanding months during which they migrate, fast, and mate in warmer and less productive low latitude waters (Aidley 1981, Webster *et al.* 2002, Witteveen *et al*. 2008). Kodiak's pinnipeds (harbor seals (*Phoca vitulina*) and Steller

sea lions (*Eumetopias jubatus*)) are mobile but non-migratory piscivores whose diets and distribution patterns reflect their opportunistic exploitation of seasonally and regionally abundant prey sources (Pitcher 1980, Tollit *et al.* 1997, Womble *et al.* 2005, Womble and Sigler 2006, Mckenzie and Wynne 2008). This diversity of sympatric marine mammals in Kodiak waters allows assessment of potential dietary overlap for subsequent exploration of niche separation and prey partitioning in a region of high prey abundance. Long-term monitoring of marine mammal diets, distribution, and foraging patterns in this area allows examination of tropho-dynamic interactions and species-specific effects of changes in those patterns.

PURPOSE

In this project we continued GAP's multi-year examination of the distribution, diet, and foraging patterns of marine mammals in Kodiak as a means of exploring species-specific responses to changes in prey availability. Specifically, our objectives in 2008 and 2009 were to investigate

1. Fin and humpback whale foraging overlap in Marmot Bay
2. Gray whale presence and feeding in Ugak Bay
3. Dietary overlap of sympatric harbor seals and Steller sea lions

Due to logistical issues detailed below, the original grant end date was extended to allow completion of activities, with modification, in 2010.

FIN AND HUMPBACK WHALE FORAGING OVERLAP

APPROACH

We examined the foraging patterns of fin and humpback whales and the degree to which they overlap in Kodiak waters. To do so, we used a suite of methods including a) photographically identifying whales of both species to assess abundance and residency patterns, b) tagging both species concurrently to determine synchronous dive profiles, c) assessing local prey availability in areas where the species co-occur, and d) assessing the trophic level at which each species is feeding via analysis of carbon and nitrogen stable isotope ratios in skin samples. In addition, monthly aerial surveys used to monitor gray whale presence (Objective 2) were also used to monitor the distribution of fin and humpback whales in north Kodiak waters.

Identification, residency, and distribution

Whenever encountering whales in the study area, we attempted to photograph the ventral surface of humpback flukes and dorsal fin/chevrons of fin whales to identify individuals of each species. When possible the age class, sex, and behavior of each whale were recorded at the time it was photographed. These photos were compared to previously catalogued whale photographs to document individual whale's presence and movement patterns. Within-year comparisons of foraging individuals present in each sampling area were used to assess spatial and temporal overlap of fin and humpback foraging in Kodiak waters. Confirmation of between-year matches (resights) were used to document inter-annual fidelity to feeding sites by individual whales. Close approach to photograph fin and humpback whales was authorized under provisions of NMFS Scientific Permit No.1049-1718 and IACUC # 08-25.

Distribution

We conducted systematic monthly aerial surveys along transects traversing waters from Kodiak south to Dangerous Cape on the eastside of Kodiak Island bays (Figure 1). Surveys were scheduled monthly from July 2008 through June 2009; these dates were later adjusted to September 2008 to September 2009 to match grant initiation. The exact timing of surveys was dictated by weather and sighting conditions (minimal conditions of 1500' ceiling and Beaufort ≤ 4). A team of 2-3 observers flew the survey in a Cessna 206 or Bushhawk on floats at an altitude of 1000ft and speed of 100kn. The GPS location and estimated group size of all whales spotted from transects were recorded in order to monitor the distribution and relative density of fin (FW) and humpback (HB) whales in Kodiak's nearshore waters. The plane broke effort and circled groups to confirm species identification when time allowed, otherwise unconfirmed species were recorded as Unidentified Whales (UW).

Whale foraging, prey use and trophic level determination

One method of determining the degree of foraging overlap between fin and humpback whales found feeding together in nearshore Kodiak waters involved tagging free-swimming whales with acoustic time depth transmitters (ATDTs). To measure the degree of foraging overlap between fin and humpback whales, we planned to tag individuals of both species where found in close proximity and document their dive patterns and the prey fields each was targeting.

Potential foraging overlap was assessed by examining the depth, location, and characterization of species-specific foraging dives. Tags used to collect real-time data consisted of a PVC or syntactic foam housing containing both an ATDT (V22P continuous transmitter, VEMCO, Nova Scotia, Canada) and VHF transmitter (MOD125, Telonics, Mesa, Arizona USA). ATDT tags weighed ca. 360g, had a depth range of 0 to 204 m, resolution of 1.2 m, and a frequency range of 34.0 to 48.0 kHz. Each was affixed to a whale via an 8 cm diameter suction cup and deployed remotely using a pneumatic launcher. Whales were closely followed for 2-4 hours or for the duration of tag attachment to allow data to be collected from these tags in real-time. Acoustic signals from ATDTs were received at distances up to 1 km by a vessel-mounted directional hydrophone (VEMCO VR-60) and recorded into a text file. In instances when this distance was exceeded or the acoustic signal was lost, tagged whales were re-located by listening for the VHF signal upon surfacing. All dive data received from ATDTs were time-linked to the position (latitude and longitude) of the whale tracking vessel which, due to its constant close proximity to the whale, represented the track of the tagged individual. Tagging of fin and humpback whales was authorized under provisions of NMFS Scientific Permit No.1049-1718 and IACUC # 08-25.

Recorded raw dive data were subsequently filtered for erroneous data (i.e. negative depths) and then charted for visual assessment. Individual dives were categorized as either foraging or non-foraging based on shape, as reflected by changes in depth over time, and the presence of lunges at depth (Croll *et al.* 2001, Witteveen *et al.* 2008). Previous analysis showed that characteristics of foraging dives were significantly different than non-foraging dives (Witteveen *et al.* 2008). Therefore, we were able to focus our analysis on foraging dives to address questions relating to whale feeding ecology, such as mean depth of foraging dives.

Whale dive profiles were then combined with results from hydroacoustic prey sampling to describe the prey fields near foraging whales. The location and range of dive depths made by tagged whales were reported in real-time to the accompanying prey survey vessel to coordinate concurrent prey assessment in the vicinity of tagged whales. The prey survey vessel towed a Simrad EK-60 dual frequency (38 kHz and 120 kHz) split beam transducer through the area to measure pelagic volume backscatter, reported as the Nautical Area Scattering Coefficient (NASC; m^2/nmi^2).

Differences in acoustic target strength can often be detected during visual comparison of dual frequency backscatter outputs. Zooplankton species are weak acoustic scatterers when compared to fish, and therefore have low backscattering characteristics at 38 kHz compared to 120 kHz (Axenrot *et al.* 2009). Therefore, we first visually compared dual frequency backscatter outputs to detect differences in relative acoustic target strength and differentiated prey into two broad prey categories (zooplankton *vs* schooling fish) (Madureira *et al.* 1993, Axenrot *et al.* 2009). Next, a subtraction algorithm applied to the two frequencies (38 and 120 kHz) allowed for quantitative proportional assignment of recorded prey fields as either zooplankton or fish without physically sampling the biomass present (De Robertis *et al.* 2010).

Finally, we used stable isotope analyses as a less direct means of assessing the trophic level, or potential consumptive role, of fin and humpback whales in nearshore Kodiak waters. We quantified the ratio of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios present in whale skin samples to determine the relative trophic level at which these whales are foraging. Samples were collected by biopsying whales remotely using a hollow-tipped dart fired from a modified .22-caliber rifle. When possible these were collected from photographically identified whales. The relative ratios were used to assess the trophic level at which each whale species was foraging. Biopsy sampling of fin and humpback whales was authorized under provisions of NMFS Scientific Permit No.1049-1718 and IACUC # 08-25.

RESULTS

Identification, residency, and distribution

GAP08 supported vessel surveys in summers 2008 and 2009, during which 277 individual humpback and 76 individual fin whales were photo-identified (Table 1). Adding GAP08 data to the humpback whale catalog initiated in 1999, we were able to examine humpback whale residency over the period 1999-2009, during which UAF/GAP has monitored whale presence in Kodiak and Shumagin Island areas. During this 10-year period 1472 individual humpback whales were photo-identified and catalogued; annual effort and results from 1999 to 2009 in both Kodiak and the Shumagin Island waters are summarized in Table 1. Humpback whale photo- identification effort was fairly consistent over this period, so sighting data collected may be used to examine annual variations in the distribution and relative abundance of the Kodiak humpback whale feeding aggregation. A discovery curve shows that the rate at which new animals were being photographed was increasing and not yet reached a plateau (Figure 2). The lack of a plateau, or leveling off of the curve, suggests either the entire population has yet to be documented, is experiencing population growth, or is part of an open population. The latter is not a likely explanation. Previous studies suggest that Kodiak Island humpback whales belong to a distinct feeding aggregation (Waite *et al.* 1999, Witteveen *et al.* 2007, Calambokidis *et al.* 2008) and new immigrants are not likely to any significant extent. Population growth, however, has been estimated at between 4.9 and 6.8% for North Pacific humpback whales (Calambokidis *et al.* 2008). Despite the fact that the Kodiak humpback whale aggregation seems to be growing, the number of humpback whales sighted in Marmot Bay has decreased since 2006, with the exception of 2007 which was a year marked by extremely high number of both humpback and fin whales in the bay (Table 2, Figure 3).

Eleven monthly aerial surveys were completed between September 2008 and September 2009. Incessant inclement weather precluded survey attempts in November 2008 and February 2009. In addition, an unscheduled extended offshore survey was conducted in August 2009 in an effort to locate large aggregations of humpback whales (Figure 4).

To maximize their value, GAP08 sighting data were added to the multi-year record of fin and humpback whales sightings made during aerial surveys conducted throughout the Kodiak archipelago since the late 1990's (Figure 5). Prior to 2007, the focus of the aerial surveys was to document pinniped abundance on haul outs and cetacean sightings were recorded opportunistically. Surveys directed at documenting cetacean distribution were initiated as a part of GAP goals in 2007. More than twice as many humpback whales as fin whales have been documented during aerial surveys (Table 3). Both species are seen in every month, though fin whales sightings show a more even distribution throughout the year and humpback whales are clearly most likely to be seen in August (Figure 6).

Overall, the horizontal distribution of whales seen in aerial surveys suggests some degree of habitat separation of fin and humpback whales throughout the Kodiak archipelago. This pattern shows little variation across seasons (Figure 7). In general, more humpback whales were seen in the east and north portions of the archipelago, while fin whale aggregations were seen primarily on the west side of Kodiak Island. However, spatial overlap is evident from Uganik Bay through Kupreanof Strait, and in particular Marmot Bay (Figures 5 & 7). A pattern similar to that observed in aerial sightings is seen in the distribution of sightings made during vessel sightings, with the greatest level of species overlap occurring in Marmot

Bay (Figures 8 & 9). It should be noted that aerial and vessel survey effort did not include waters of the southwestern portion of the Kodiak Archipelago where both species are known to occur.

Whale foraging

We were unable to accomplish our goal of simultaneously tagging fin and humpback whales to assess the degree of their foraging overlap. In 2008 and 2009, humpback whales were found to be relatively scarce in areas typically used by dense nearshore feeding aggregations within the Kodiak study area (Figure 3) and the small numbers that were sighted were difficult to approach for tagging (see details below in Modifications Section). Therefore, as an alternative means of addressing this objective, we combined information gathered on species-specific dive patterns (from tagging efforts), horizontal distribution (from aerial surveys), and biochemistry (from stable isotope ratios) from GAP08 and previous GAP studies to summarize the potential for foraging overlap between fin and humpback whales.

Although we were unable to tag humpbacks in 2008 or 2009, three different fin whales were successfully tagged in summer 2009, allowing the documentation of 11, 21 and 9 dives for each whale respectively (Table 4). Real-time dive depth data received from ATDTs were visually analyzed and categorized as foraging or non-foraging based on the presence of lunges at depth. Results showed that tagged fin whales were diving to an average depth of 127.9 m (± 41.22 S.D.) when foraging (Table 4). Between 2004 and 2009, all GAP efforts have resulted in the successful tagging of three fin and seven humpback whales in Marmot Bay, resulting in the documentation of nearly 240 dives (Table 5). Dive parameters were calculated for each foraging dive and then averaged for each of the 10 whales. A total of 10 parameters for each dive, including maximum dive depth, dive duration and rates of ascent and descent, were calculated (Table 6). Again, we were able to strengthen our analyses by supplementing GAP08 data with those collected during previous GAP whale tagging efforts.

When all years of tagging data were combined, fin whale dives, on average, were deeper (Depth; 126.5 m ± 17.33 SD) than humpback whales (119.9 m ± 26.45), covered more vertical distance (BottVertDist; 143.8 m ± 75.13 vs. 115.4 m ± 60.08) and spent more time during the bottom phase of the dive (Botttime; 4.3 min ± 1.64 vs. 3.6 min ± 2.09). Humpback whale foraging dives, however were slightly longer in duration (6.0 min ± 1.92 vs. 5.9 min ± 1.78) with shorter surface intervals (2.4 min ± 1.00 vs. 3.1 min ± 1.83). Using these values to calculate Efficiency (see Table 6), fin whales were found to have more efficient dives (0.5 ± 0.21) than humpback whales (0.4 ± 0.13). T-tests showed that Surface (t_{162} = -2.7, p =0.024), BottVertDist (t_{171} = -2.3, p = 0.024) and Efficiency (t_{166} = -2.7, p = 0.007) were all significantly different between the two species.

Prey assessment

Acoustic surveys were conducted concurrent to whale tagging efforts to assess potential prey availability broadly through Marmot Bay and in the vicinity of foraging whales. Acoustic backscatter was recorded both during active tracking of tagged whales and while searching for tagging candidates. Analysis of approximately 3 GB collected in 2009 of acoustic data showed that available prey layers descended approximately 20 to 30 meters deeper in the water column between the first tag attachment on August 15 and the last on August 30 (Figure 10). This change in prey depth corresponded to a change in whale diving depth from average maximum depths of 123.7 and 110.1 for the first two tagged whales (August 15 and 16) to 150.0 for the final tagged whale (August 30), respectively (Table 4).

As with dive data, hydroacoustic data collected concurrent to GAP whale tagging studies were also examined in aggregated. There were clear differences in prey composition in years when prey fields were dominated by schooling fish (2004), mostly schooling fish with a deep, weak zooplankton layer (2005), few schooling fish with a deep, strong zooplankton layer (2007), and one with virtually no fish schools but a deep, moderate zooplankton layer (2009) (Figure 11). Thus, visual interpretation of prey categories from acoustic backscatter provided a qualitative means of assessing prey-type availability, relative densities across years, and presence at tagged-whale dive depths (Figure 11). Additionally, in years (all but 2004) of dual frequency data collection, acoustic backscatter records of pelagic prey fields were determined to represent either zooplankton or fish based on differences in relative acoustic target strength through a signal differencing algorithm (De Robertis, *et al.* 2010). This method allowed for quantitative proportional assignment of NASC near tagged whales to one of the two broad prey categories without direct sampling. This quantitative analysis confirmed our initial visual assessments, such as very high zooplankton backscatter in 2007 and the lowest backscatter in 2009 (Figure 12).

For each year, the depth distribution of whale foraging dives was compared to the depth distribution of NASC attributed to either zooplankton or fish. Results showed that depth of foraging dives was significantly correlated to fish backscatter in 2005 (Spearman's rho = 0.46, p = 0.04) and to zooplankton in 2007 (Spearman's rho = 0.44, p = 0.03) (Table 7). Previous analysis of tagging and prey data collected in 2004 determined that humpback whales were foraging on schooling capelin (Witteveen *et al.* 2008). Depth of dive was not significantly correlated to either prey category in 2009. We attribute this to the 2009 acoustic data being particularly noisy and, therefore difficult to accurately analyze in this manner.

Using the multiple methodologies described above, prey being targeted by each tagged whale could be inferred by comparing backscatter strength, qualitatively and quantitatively, and prey collected in net tows (when available) to the corresponding depth of a whale's foraging dives. We inferred that humpback whales were foraging on fish in 2004 and 2005 and on zooplankton in 2007, while fin whales tagged in 2009 were foraging on zooplankton (Table 5).

Trophic level

Stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope ratios in skin samples collected from free-ranging fin and humpback whales were used to examine trophic-level differences in their foraging behavior. To date, 134 humpback and 3 fin whale skin samples have been analyzed for δ^{13}C and δ^{15}N. The mean values for fin whales were -18.4 (±0.41 SE) for δ^{13}C and 12.3 (±0.24) for δ^{15}N (Figure 13). The mean values for humpback whales were -17.8 (±0.05) for δ^{13}C and 13.5 (±0.08) for δ^{15}N (Figure 13). Analysis of variance (ANOVA) showed that δ^{13}C means were not significant different between species ($F_{1,135}$,= 3.0, p = 0.08), but that the δ^{15}N means were ($F_{1,135}$,= 4.6, p = 0.03). Because δ^{15}N is an indicator of relative trophic level, the significantly more enriched values observed for humpback whales compared to fin whales suggests they are foraging on a diet comprised of a higher proportion of fish than zooplankton. These findings suggest humpback whales are feeding at a higher trophic level and are more reliant on fish as prey than are the fin whales.

Potential for foraging overlap

Combined results of GAP studies suggest that within the Kodiak archipelago there are regions of distinct fin whale habitat and distinct humpback whale habitat but that regions of overlap are also present. Within these regions of overlap, particularly Marmot Bay, the potential for foraging overlap may exist under certain conditions. Within Marmot Bay, our findings suggest that humpback whale distribution and abundance is dependent on schooling fish (most likely capelin) or high densities of euphausiids. It also appears fin whales may require a lower density threshold of a wider variety of zooplankton to forage. Evidence to support this can be seen when comparing dive behavior of each species with prey composition across years. In 2004 and 2005, when dense capelin schools dominated the water column, humpback whales were shown to be targeting these schools (Witteveen *et al.* 2008) and were present in Marmot Bay in relatively high numbers (Figures 3 & 9). In 2009, when virtually no humpback whales were sighted in Marmot Bay, the prey field showed no schooling fish and a relatively low density of zooplankton. In each of these years, however, fin whales remained present in similar densities. Both fin and humpback whales were present in extremely high numbers in 2007, a year marked by a very dense layer of euphausiids in Marmot Bay (Table 2, Figure 11). Dive data from tagged humpbacks showed they were targeting this layer and not fish. Assignment of acoustic backscatter showed that zooplankton was much more abundant than fish in that year. Thus, it appears that humpback whales may require either the presence of schooling fish or high densities of euphausiids to warrant foraging in Marmot Bay. Because fin whales were present in years of relatively low prey density (i.e. 2009), their threshold foraging requirements appear to be lower than humpback whales.

Stable isotope data further supports the idea that humpback whales are more reliant on fish than fin whales. Since δ^{15}N is an indicator of relative trophic level, the significantly more enriched values observed for humpback whales compared to fin whales suggests they are foraging on a diet comprised of a higher proportion of fish. As previously modeled using stable isotope ratios and potential prey, the diet of humpback whales was dominated by capelin, juvenile walleye pollock, Pacific sand lance and euphausiids (Witteveen et al. *in press*). Currently the number of fin whale skin samples analyzed is inadequate to explore a similar diet model for fin whales.

Reasons for the potential differences in distribution and foraging behavior between fin and humpback whales are unclear. Results from tagging suggest fin whales may be more efficient in their dive behavior and, therefore, may be able to exploit smaller or less dense prey fields. Humpback whales have been called "fast maneuverers" as a result of their preference for fast-moving, schooling fish species (Woodward *et al.* 2006), a preference that may reduce their diving and foraging efficiency. It does appear that when euphausiids are present within Marmot Bay at a high level, the potential for fin and humpback whales to overlap in their foraging behavior is at its greatest. The ability to qualitatively assess differences in backscatter between fish and zooplankton will be critical to exploring this concept in other years.

When combined, our distribution, foraging, and stable isotope data suggest the greatest degree of foraging overlap between fin and humpback whales in Kodiak waters likely occurs in areas of high-density zooplankton availability.

MODIFICATION OF GOALS AND METHODS

We encountered two major hurdles while attempting to describe foraging overlap between fin and humpback whales that required us to adapt our sampling and analytical approaches, as described in our Interim Progress Reports and summarized below. We feel we were ultimately able to successfully address this objective with these modifications and by integrating GAP08 data into the long time series of similar data collected in previous GAP field seasons.

Modification #1.

We could not locate a vessel to charter in 2008 for the prey assessment component of this task, as proposed. There is a paucity of USCG-licensed captains to operate the few Kodiak vessels that are rigged to tow trawl gear. Without a commercial-size trawl vessel we were not able to tow our small-mesh fish net or Tucker Trawl in 2008 to identify the prey species present within the backscatter recorded near tagged whales.

Solution: We received a No-Cost Extension to the grant to provide time to develop an alternative sampling plan. As an alternative, we chartered a smaller vessel in 2009 that could tow our mobile acoustic transducer so we could collect hydroacoustic data. This vessel, however, was not able to tow a trawl and physically sample the prey fields identified acoustically. This limited our ability to directly determine the prey species composition in the layers targeted by tagged whales. Although this reduced the detail of prey information gathered, we were still able to measure total acoustic backscatter (NASC) and assess its association to dive profiles of tagged fin and humpback whales in the area. Using a method for assigning pelagic acoustic backscatter to prey categories (i.e. fish vs. zooplankton) developed my Alex De Robertis at the Alaska Fisheries Science Center, we were able to correlate whale foraging dives with zooplankton-dominated or fish-dominated prey fields.

Impact of modification: The removal of the trawl component of our study limited our ability to collect and identify the prey species being targeted by foraging whales. It did not, however, preclude us from determining whether tagged whales were foraging in areas dominated by zooplankton *vs* fish prey resources. Both fin and humpback whales are known to utilize both of these prey categories to varying degrees- prey switching is common. However, it is not likely that either species would or could selectively prey on individual species found in a mixed prey field. Therefore discerning prey available to these whales at this gross level (fish *vs* zooplankton) is adequate for us to address our questions related to dietary overlap between these whales.

When possible, future GAP efforts will employ non-trawl methods such as videography and surrogate diets (fish stomachs) to identify the species present in prey fields targeted by tagged whales. However, we plan to continue collecting acoustic backscatter data near tagged whales in order to make inferences about the relative availability and use of zooplankton *vs* fish prey resources by each species across years. These results, combined with whale distribution, abundance, and residency data will allow us to further assess the potential for interspecific foraging overlap and assess the role of these whales as major consumers in Kodiak waters.

Modification #2. We were unable to conduct direct comparisons of foraging by sympatric tagged fin and humpback whales due to the absence of dense feeding aggregations of humpback whales in the Marmot Bay area (Table 2, Figure 3). Attempts to tag humpbacks there were made but unsuccessful because humpbacks were only found in small unapproachable groups. In our experience, tagging is most successful when there are at least 15-20 whales in close proximity. Only fin whales were found in such 'taggable' aggregations in the study area in 2009.

Solution: We attempted, unsuccessfully, to locate denser feeding aggregations of humpbacks in/near the Kodiak study area by contacting other Gulf of Alaska whale researchers and conducting an aerial survey of offshore Kodiak waters. As an alternative means of addressing this objective, we combined information gathered on pelagic backscatter (from hydroacoustics) during species-specific dives (from tagging), horizontal distribution (from aerial surveys), and biochemistry (from stable isotopes) from this and previous GAP studies to summarize the potential for foraging overlap (see description above).

Impact: With this suite of tagging, stable isotope, and prey data (collected since 2004), we were able to address this research objective, but in a less direct and timely manner than concurrent tagging of sympatric of humpback and fin whales would have allowed.

When possible, areas with dense feeding aggregations of whales (estimated at >20/km^2) will be targeted for future tagging efforts. This may involve waters outside Marmot Bay, as determined during aerial surveys.

GRAY WHALE FEEDING IN UGAK BAY

APPROACH

Eastern North Pacific (ENP) gray whales migrate past Kodiak Island as they transit through the western Gulf of Alaska to and from arctic and subarctic feeding areas. Since 1999, gray whales have also been seen throughout the year feeding in waters in and near Ugak Bay, off Kodiak's east coast (Wynne 2005). Newly recognized feeding grounds such as this may reflect diminished productivity and prey availability in the Bering and Chukchi seas (Moore *et al.* 2007) or existence of separate feeding populations (Calambokidis *et al*. 2010). Interest in their increased year-round feeding in this area prompted a preliminary photographic survey of gray whales in summer 2002 and assessment of the benthic prey available to them in Ugak Bay (Moore *et al.* 2007). Continued year-round monitoring of gray whale presence and feeding in Kodiak waters is one means of determining the persistence and significance of this habitat and prey to Eastern North Pacific gray whales. In GAP08, we assessed the seasonal importance of the Ugak Bay region to gray whales by documenting a) their monthly presence, distribution, and relative abundance and b) the timing, duration, and intensity of their feeding activity.

Activities involved in the aerial survey, photo-identification, and biopsy sampling of gray whales were authorized under provisions of NMFS Scientific Permit No.1049-1718 and IACUC # 08-25.

Seasonal presence and distribution

We conducted systematic aerial surveys along transects traversing waters between Cape Chiniak and Dangerous Cape and approximately 10nm offshore (Figure 1). Surveys were originally scheduled monthly from July 2008 through June 2009; these dates were later adjusted to match grant initiation. The exact timing of surveys was dictated by weather and sighting conditions (minimal conditions of 1500' ceiling and Beaufort ≤ 4). A team of 2-3 observers flew the surveys in a Cessna 206 or DeHavilland Beaver or Bushhawk on floats at an altitude of 1000ft and speed of 100kn. We marked the GPS location and estimated group size of whales spotted from transects in order to estimate relative abundance and density of gray whales in the area We circled groups to ascribe an activity code to the whales based on evidence of plumes/fecal trails (feeding), steady and directed travel (migration), and other behaviors. A feeding index was later calculated as the proportion of observed whales associated with plumes/poops.

Identity

We conducted a 7-day vessel-based survey in July 2008 to approach, identify, and collect samples from individual gray whales in Ugak Bay (Figure 1). Specific survey objectives were to a) photo-identify individual gray whales foraging in the study area, b) photo-document body condition, c) sample encountered mud plumes and fecal clouds and d) identify prey available to gray whales through benthic sampling. Survey effort was concentrated at the mouth of Ugak Bay where previous gray whale photo-identification had occurred (P. Gearin, S. Moore) and gray whales had been sited during aerial surveys in June 2008.

Individuals were photographed to establish their identity and, when possible, to document visual evidence of body condition. Dorsal region photographs were a) compiled to establish a Kodiak gray whale catalog and b) compared to archived photos taken previously in Ugak Bay (P. Gearin) and elsewhere along the coast (J. Clambokidis, D. Rugh) to determine identity of previously 'tagged' whales and establish links to other feeding areas. Additionally, we attempted to take a series of photographs of the nape and dorsum to contribute to NMFS researchers attempting assess the relative body condition of individual whales. After photographing individuals, we attempted to biopsy a subsample of photographed whales to collect skin and blubber samples for DNA and stable isotope analyses.

Prey availability and use

We identified benthic prey available to gray whales in Ugak Bay through a combination of fixed-random sampling and focal sampling in areas where whales were feeding. We used a 0.1-m^2 van Veen grab weighing 88.7 kg (including a 32-kg lead weight) to collect benthic/epibenthic invertebrates and a CTD to record temperature and salinity profiles at eight sites that had previously been sampled in 2002 (Moore *et al.* 2007) (Figure 14). Organisms recovered from grabs were rinsed thru a sieve and preserved in 10% seawater-buffered formalin for later analysis. To allow comparison with previous studies, the number of organisms in each taxa recovered per 0.1-m^2 grab was multiplied by 10 to estimate density as number of individuals per m^2.

Whenever encountered, we sampled the mud plumes and fecal clouds associated with feeding whales to determine what prey the whales were feeding on. Mud plumes may contain whole prey items that are expelled by whales as they surface following benthic foraging. Fecal clouds contain digested prey remains that have passed through the whales' gut. It was not always possible to determine the origin of a cloud (mud plume vs. fecal), however most were assumed to be fecal clouds due to their location relative to the whale's body. We towed or dipped a small-mesh plankton net through mud plumes and fecal clouds samples. Visible prey items collected in the cod-end were rinsed through a fine mesh sieve and remains were preserved in 10% seawater buffered formalin for subsequent identification. Contents were categorized by taxa and reported as # of individuals recovered per sample.

RESULTS

Seasonal presence, distribution, and feeding

Aerial surveys were initiated after project funding was secured in fall 2008 and continued into fall 2009. A total of 11 aerial surveys were conducted between 11 September 2008 and 21 September 2009. Incessant weather delays precluded aerial surveys in November 2008 and February 2009. No gray whales were observed during an offshore aerial survey conducted 6 August 2009 to locate humpback whale feeding aggregations (Figure 4).

Gray whales were present in Ugak Bay in all seasons (Figure 15) and during each surveyed month (Figure 16). They were observed further offshore in January than in any other survey; no whales were seen north of Cape Chiniak (Figure 15). On average, approximately 45 whales were counted during these surveys (range 1-114, Figure 16) with a peak count in September 2009 (Figure 16). Deteriorating survey conditions during the survey likely contributed to the minimal count in March 2009.

Evidence of feeding (fecal clouds or mud plumes) was observed throughout the area (Figure 15). The water depth where whales were foraging varied: some were seen in <10m waters near beaches in June while most were found in waters 50-100m deep in the mouth of Ugak Bay and up to 45 km offshore. The proportion of gray whales observed feeding generally was lowest in winter and increased through spring; approximately 75% of whales seen in the March survey were determined to be feeding (Figure 16).

Identity

A field camp was established at the head of Ugak Bay to serve as the base for vessel-based surveys of gray whales using the bay. Vessel-based surveys took place for a total of 19 hours over five days from 10 - 17 June 2008. Photographic surveys and prey sampling were conducted during day-trips made from the base camp.

A complete series of identifying photographs was attempted for each gray whale encountered, including photographs of the flukes and left and right dorsal flanks. However, this combination of photographs was difficult to obtain. At least one photograph was collected from 46 gray whales (Table 8). Of these, 11 had two identifying photographs while a complete collection of photographs was possible for only five individuals. Whales proved difficult to approach; we were unable to collect the series of photos needed to assess body condition of individual whales and could not approach within biopsy range. Consequently, no skin or blubber samples were collected for DNA and stable isotope analyses.

Of the 46 individual gray whales photographed in 2008, good quality ID photos of 24 individuals were submitted for comparison to photos in the catalog of Eastern North Pacific gray whales maintained by Cascadia Research Collective. From this sample of 24 whales, four matches were made to catalogued gray whales: one previously photographed once in Ugak Bay (2002), one previously photographed once in Vancouver, BC (2004), one photographed five times in northern BC between 1998 and 2007, and one photographed four times in northern California/Oregon between 2000 and 2006.

These matches confirm that some gray whales in Ugak Bay are members of the Pacific Coastal Feeding Group (PCFG), a group of gray whales found feeding spring through fall in subarctic waters from Kodiak to southern California (Calambokidis *et al.* 2002, Calambokidis *et al.* 2010). Further efforts to photo- identify gray whales will be needed to determine inter- and intra-annual residency patterns and feeding site fidelity of individual gray whales present in Ugak Bay.

Prey availability and use

A total of 14 benthic samples were collected from eight predetermined (previously sampled in 2002) sites in Ugak Bay (Table 9, Figure 14). Efforts were made to sample each site on both an incoming and outgoing tide but two sites were not found to be suitable bottom type (i.e. rock instead of mud) and were not resampled. A 15th (Site “A”) benthic sample was collected in the vicinity of a large number of foraging whales (Table 9). In nine of the 15 benthic samples, the dominant species present was a diastylid crustacean, the cumacean *Diastylopsis dawsoni.* All cumaceans were adult and uniform in weight and size (7 -10 mm from the carapace front tip to the telson end tip). Other taxa, including amphipods [*Ampelisca spp.* and Lysianassidae (family)], polycheate worms [*Glycera mama, Pseudochitinopoma occidentalis,* and others], and assorted bivalves [*Axinopsida serricata*, *Tellina nuculoides*, *Siliqua alta* and *S. patula*] were present in densities one to two orders of magnitude lower than cumaceans when present (Table 9).

The Ugak Bay sampling sites in which we recorded the highest densities of cumaceans (sites #2, 4, and 8, Figure 14) were also among those reported by Moore *et al.* (2007) as having the highest cumacean densities in 2002. However, the highest density of cumaceans we recorded in 2008 (42,240/ m^2) was approximately 54% lower than the highest density (91,995/ m^2) recorded among these sites in 2002 (Moore *et al.* 2007). Site #5 which had the highest cumacean density in 2002 was dominated by polychaete tubes in our sampling and had no cumaceans. Because polychaetes are known to grow in dense patchy aggregations, this disparity could either be a result of an imprecise duplication of sampling location or a habitat change that favored polychaetes.

Four mud plumes and five fecal clouds associated with feeding whales were sampled to determine the prey being fed upon by Ugak Bay gray whales (Table 10). The prey remains, identified to the lowest possible taxa, were dominated by the cumacean, *Diastylopsis dawsoni.* As in the benthic samples, the cumaceans consumed by whales were adults and of uniform in size and weight. Although cumaceans dominated the plume/fecal samples, hydromedusae and larval fish were found in 3 and 2 of the samples, respectively (Table 10). Although the presence of their remains in plumes and scats could be a result of pelagic foraging by gray whales in deep waters (50-100m), larval fish and hydromedusae recovered were likely caught incidentally during the net sampling of plumes.

Summary of gray whale presence and feeding in Ugak Bay

GAP08 gray whale sighting data and biopsy samples contributed to a broad-based effort to monitor the dynamic nature of gray whale foraging in the eastern North Pacific. Our repetitive monthly aerial surveys documented continued year-round feeding by gray whales in Ugak Bay in 2008 and 2009. Matching of identification photos taken during summer 2008 were used to document the presence of several individual gray whales of the Pacific Coastal Feeding Group that were previously seen feeding from Kodiak to California.

GAP08 data also contributed to the long-term monitoring of this species’ use of ‘peripheral’ feeding areas. By comparing data to those from 2002 (Moore *et al.* 2007), we documented that gray whales in Ugak Bay continue to feed predominantly on cumaceans. With duplicating benthic sampling sites in Ugak Bay (Moore *et al.* 2007), we found cumacean densities at the mouth of Ugak Bay remained high in 2008 but were reduced significantly from 2002 densities.

Gray whales were first documented feeding in Ugak Bay in 1999 during early GAP aerial surveys (Moore et al 2007). Through continued aerial monitoring and photo- identification, GAP08 added data to a long time-series of data on individual gray whales in Ugak Bay. Such long-term monitoring of gray whales in Ugak Bay is needed to document and measure a population-level response to changes in ocean conditions and productivity (Moore *et al.* 2007) and further understand the population structure of gray whales the Pacific Coastal Feeding Group. Future efforts should focus on determining inter- and intra-annual residency patterns and feeding site fidelity of the gray whales present in Ugak Bay.

MODIFICATION OF GOALS AND METHODS

No modifications were needed to meet our objective of describing gray whale presence and foraging in Ugak Bay.

DIETARY OVERLAP OF KODIAK'S SYMPATRIC PINNIPEDS

APPROACH

Harbor seals (P*hoca vitulina richardsi*) are pinnipeds whose diets are diverse, often reflect regional and seasonal availability of prey, and closely overlap that of Steller sea lions (Jemison 2001). Although their numbers declined more than 80% in western Alaska in the 1970's and 1980's coinciding with noted declines in Steller sea lion numbers (Pitcher 1990), they increased 5.6% annually from 1993 - 2001 (Small *et al.* 2003). This steady increase is in marked contrast to the slow recovery of Steller sea lions (Sease and Gudmundson 2002, Fritz *et al.* 2008) in the Kodiak area. The overlapping diets but disparate rates of recovery from severe decline exhibited by these two sympatric pinniped populations raise questions regarding the current degree of their dietary overlap.

In the Kodiak Archipelago there are several areas where harbor seal and Steller sea lion haulouts are in relatively close proximity. Comparing samples from these neighboring sites may illuminate the relative overlap in diets of seals and sea lions assumedly foraging in relative proximity. Fecal samples (scats) have been collected from many of these sites (Figure 17) by UAF and Alaska Department of Fish and Game (ADFG) researchers since 1999 and frozen for eventual processing and analysis. Previous GAP studies focused on monitoring Steller sea lion diets and prioritized the analysis of those samples. Consequently, there was a stockpile of frozen harbor seal scats awaiting analysis.

In GAP08 we used NOAA funds to process this multi-year sample of approximately 600 harbor seal scats. Each sample was thawed and rinsed through a series of graduated sieves to recover all possible prey remains. Hard parts were dried and sent to Pacific Identifications, Inc (Victoria, BC) to identify the species and size of vertebrate prey present.

We used frequency of occurrence of prey items in fecal samples to measure and compare the relative importance of prey items to these pinnipeds. Such indices have been shown to provide useful dietary information, given adequate sample sizes (Olesiuk *et al*.1990, Sinclair and Zeppelin 2002, Tollit *et al.* 2007). We tabulated and compared the frequency of occurrence of each prey item recovered from harbor seal scats to those recovered from Steller sea lion scats collected on sites throughout the Kodiak Archipelago (Figure 17). We used analyses of similarities (ANOSIM) to test for differences between ranked prey in the diets of harbor seals and Steller sea lions by Season and Region in which they were collected. ANOSIM R values can range from -1.0 to 1.0; higher R values indicate greater differences between the two species' diets. R values > 0.5 indicate separate diets with some overlap, while R values < 0.25 indicate almost no separation between seal and sea lion diets sampled. The significance of the ANOSIM was computed with permutation tests.

RESULTS

A total of 629 harbor seal scats collected in the Kodiak area by GAP or ADFG personnel from April 2001- March 2008 were processed and their dried remains identified to the lowest possible taxa. To allow multi-year and intraspecific comparisons, we compiled data from complementary GAP and ADFG harbor seal and sea lion diet studies in the Kodiak area. Including only the scats that contained identifiable remains, the combined dataset included 1565 harbor seal scats and 3369 Steller sea lion scats collected 2000- 2009 on haulout sites of the Kodiak Archipelago (Figure 17).

Harbor seals using haulouts in the Kodiak area were found to have a diverse diet. Combined across the region and seasons, a total of 36 different prey species/items were present in at least 1% of seal scats examined (Table 11). Seventeen prey items were found to be significant prey items, as defined by their occurrence in at least 5% of scats with identifiable remains (Trites *et al.* 2006). Six of these prey species were found in >10% of scats containing identifiable prey. In order of their frequency of occurrence, these included Irish lords, rock sole, greenlings, Pacific cod, Pacific sandlance, and arrowtooth flounder (Table 11).

Steller sea lion using haulouts within the Kodiak were also found to have a diverse diet with 29 prey species/items occurring in at least 1% of all scats containing identifiable remains (Table 12). Fourteen prey items were found to be significant prey items, as defined by their occurrence in at least 5% of scats with identifiable remains (Trites *et al.* 2006). The sea lions' diet was clearly dominated by six prey items that each occurred in >23% of the scats with identifiable remains (Table 12).

There was a high degree of overlap in the species consumed by these two species of pinnipeds in Kodiak waters - many of the same prey were present in both seal and sea lion diets (Tables 11, 12). Because the number of seal and sea lion scats were not deposited or collected evenly throughout the region, we were unable to make robust comparisons of spatio-temporal diet differences (Table 13). However, in the East region, where sample sizes were most comparable, low R values suggest there was significant overlap or similarity in seal and sea lion diets in all seasons sampled (Table 13).

The relative importance of each prey item to the seals and sea lions sampled differed however. When the "top 10" most frequently appearing prey items in seal diets (Figure 18) are compared to the Steller sea lion top 10 (Figure 19), clear differences in how these pinnipeds utilized the prey base were apparent. Harbor seals consumed a variety of benthic and demersal prey species while Steller sea lions fed heavily on more pelagic species (Figures 18, 19). Fish in the families Cottidae (sculpins) and Hexagrammidae (greenlings) were far more important as prey to Kodiak harbor seals while arrowtooth flounder, gadids (pollock and cod), salmon, and forage fish (sand lance, herring, and capelin) were more prevalent in the diet of Steller sea lions.

Potential dietary overlap of Kodiak harbor seals and Steller sea lions

We found that harbor seals and Steller sea lions the Kodiak area have diverse diets that include dozens of prey species, many of them in common. For both species, Pacific sand lance, Pacific cod, and arrowtooth flounder were found to be important and present in > 10% of the scats examined. Although consuming many of the same prey items, seals and sea lions appear to forage predominantly in different habitats (pelagic vs demersal) where different prey dominate. As a result, the broad diet of the harbor seals we sampled was dominated by benthic, demersal, non-schooling species including Irish lords and greenlings. The Steller sea lion scats sampled, however, demonstrated a greater use of pelagic, schooling species including, pollock, cod, and salmon, and a variety of forage fish including sand lance, herring, and capelin. Future efforts should focus on collecting larger seasonal scat samples from neighboring harbor seals and sea lion haulouts to increase the potential for inter-specific and spatial-temporal comparisons. Samples collected from 2010 onward are needed to compare to the existing GAP scat diet database (2000-2008) to monitor long-term shifts in prey use resulting from environmental variability.

PROJECT SUMMARY AND CONCLUSIONS

Synoptic studies that simultaneously assess foraging by multiple sympatric predators on a communal prey resource will help define interactions among diverse marine predators and their prey in a changing environment (Guinet 1996, Shurin *et al*. 2002, Ives *et al*. 2002, Hughes and Grabowski 2006). In GAP08 we investigated trophic interactions among five marine mammal species on small spatial and temporal scales that will provide a basis for interpreting broader ecological relationships and the processes that drive them. Our preliminary findings suggest the diets of sympatric Kodiak marine mammals often do overlap under conditions of resource abundance. But the diets we have examined appear diverse and flexible enough that exclusive exploitation of a communal resource is avoided. Fin and humpback whales are mobile enough to exploit shifting prey fields and are known to readily shift from feeding on dense aggregations of zooplankton to forage fish. Our comparison of pinniped diets suggests sympatric seals and sea lions may exploit the same prey resources but avoid direct competition (if prey is limited) by foraging more heavily on either pelagic or demersal species.

Ultimately this study has contributed data needed for species-specific, spatial, and temporal quantification of apex predator trophic relationships for ecosystem-based energetic and fisheries management models. Such understanding is also key to assessing and forecasting species-specific responses to natural and anthropogenic changes in marine prey resources.

PRODUCTS

Data and/or samples gathered with GAP08 funding will be combined with data collected in past and future GAP (GAP09 and GAP10) studies to allow multi-year analyses and long-term monitoring of the distribution and dietary overlap of Kodiak's marine mammals. To date, data and/or samples gathered in GAP08 were used either alone or in conjunction with associated findings in the following publications and presentations:

Publications

- Witteveen, B.H. and K.M. Wynne. Initial investigations into potential differences in dive behaviors of fin (*Balaenoptera physalus*) and humpback (*Megaptera novaeangliae*) whales. Submitted for publication as a note to Aquatic Mammals
- Calambokidis, J, J. L. Laake, and A. Klimek. 2010. "Abundance and population structure of seasonal gray whales in the Pacific Northwest, 1998-2008". IWC Working Paper SC/62/BRG32, 50pp

Presentations

- Witteveen, B.H. and K.M. Wynne. 2008. "Gray whale feeding off Kodiak, Alaska". Oral presentation at the Gray Whales and Climate Change Symposium, Monterey, CA, November 2008.
- Witteveen, B.H. and K.M. Wynne. 2008. "Consumption and prey removals by humpback whales (*Megaptera novaeangliae*) near Kodiak Island, Alaska: A revision of previous estimates". Poster presentation at "The Role of Marine Mammals in the Ecosystem in the 21st Century Symposium", Dartmouth, Nova Scotia, Canada October 2008.
- Witteveen, B. and K.Wynne. 2011. "Kodiak Whales: A synthesis of 10 years of GAP Research". Kodiak Area Marine Science Symposium, Kodiak, Alaska April 2011

REFERENCES

Aidley, D. J. 1981. Animal migration. Cambridge University Press, Cambridge, New York.

Axenrot, T., M. Ogonowski, A. Sandstrom and T. Didrikas. 2009. Multifrequency discrimination of fish and mysids. ICES Journal of Marine Science 66: 1106-1110.

Calambokidis, J., Darling, J. D., Deecke, V., Gearin, P., Gosho, M., Megill, W., Tombach, C.M., Goley, D., Toropova, C., and Gisborne, B. (2002a). Abundance, range, and movements of a feeding aggregation of gray whales (*Eschrichtius robustus*) from California to southeastern Alaska in 1998. Journal of Cetacean Research and Management, 4(3):267-276.

Calambokidis, J., E. A. Falcone, T. J. Quinn II. 2008. SPLASH: Structure of Populations, Levels of Abundance and Status of Humpback whales in the North Pacific. Pages 57. Final report for contract AB133F-03-RP-00078 for U.S. Dept of Commerce Western Administrative Center, Seattle, WA.

Calambokidis, J, J. L. Laake, and A. Klimek. 2010. Abundance and population structure of seasonal gray whales in the Pacific Northwest, 1998-2008. IWC Working Paper SC/62/BRG32, 50pp

Croll, D. A., A. Acevedo-Gutierrez, B. R. Tershy and J. Urbán R. 2001. The diving behavior of blue and fin whales: is dive duration shorter than expected based on oxygen stores? Comparative Biochemistry and Physiology, A. 129: 797-809.

De Robertis, A., D. R. Mckelvey and P. H. Ressler. 2010. Development and application of an emperical multifrequency method for backscatter classification. Canadian Journal of Fisheries and Aquatic Sciences 67: 1459-1474.

Fritz, L., M. Lynn, E. Kunisch, and K. Sweeney. 2008a. Aerial, ship, and land-based surveys of Steller sea lions (*Eumetopias jubatus*) in the western stock in Alaska, June and July 2005-2007. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-183, 70 p.

Guinet, C., Cherel, Y., Ridoux, V., and Jouventin, P. 1996. Consumption of marine resources by seabirds and seals in Crozet and Kerguelen waters: changes in relation to consumer biomass 1962-85. *Antarctic Science*, 8, 23-30.

Hughes, A.R. and J.H. Grabowski. 2006. Habitat context influences predator interference interactions and the strength of resource partitioning. Oecologia 149: 256-264.

Ives A.R., B.J. Cardinale, and W.E. Snyder. 2005. A synthesis of subdisciplines: predator–prey interactions, and biodiversity and ecosystem functioning. Ecol Lett 8:102–116

Jemison, L.A. 2001. Summary of harbor seal diet data collected in Alaska from 1990–1999. *In* Harbor seal investigation in Alaska. Annual Report for NOAA Award NA87FX0300.Alaska Department of Fish and Game, Division of Wildlife Conservation, Anchorage Alaska.

Loewen, M. B. 2007. Seasonal oceangraphic influences on Pacific herring and Walleye pollock distribution and abundance in nearshore embayments of Kodiak Island, Alaska. University of Alaska Fairbanks, Fairbanks, Alaska.

Madureira, L. S. P., I. Everson and E. J. Murphy. 1993. Interpretation of acoustic data at 2 frequencies to discriminate between antarctic krill (Euphasia-superba dana) and other scatterers. Journal of Plankton Research 15: 787-802.

Mckenzie, J. and K. Wynne. 2008. Spatial and temporal variation in the diet of Steller sea lions in the Kodiak Archipelago, 1999-2005. Marine Ecology Progress Series 360: 265-283.

Moore, SE, K.M. Wynne, J.C. Kinney, and J.M. Grebmeier. 2007. Gray whale occurrence and forage southeast of Kodiak Island, Alaska. Mar. Mammal Sci. 23(2): 419-428.

Olesiuk, P.F., M.A. Bigg, G.M. Ellis, S.J. Crockford, and R.J. Wigen. 1990. An assessment of the feeding habits of harbour seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia, based on scat analysis. Can. Tech. Rep. Fish. Aquat. Sci. No. 1730.

Pitcher, K. W. 1980. Food of the harbor seal, *Phoca vitulina richardsi*, in the Gulf of Alaska. Fishery Bulletin 78: 544-549.

Sease J.L. and C.J. Gudmundson 2002 Aerial and land-based surveys of Steller sea Lions (*Eumetopias jubatus*) from the western stock in Alaska, June and July 2001 and 2002. NOAA Technical Memorandum NMFS-AFSC-131.

Shurin J.B., E.T. Borer, E.W. Seabloom, K. Anderson, C.A. Blanchette, B. Broitman, S.D. Cooper, and B.S. Halpern. 2002. A cross-ecosystem comparison of the strength of trophic cascades. Ecol Lett 7:153–163

Sinclair, E.H. and T.K.Zeppelin (2002). Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). J. Mammal. 83:973-990.

Small, R.J., G.W. Pendelton, K.W. Pitcher. 2003. Trends in the abundance of Alaska harbor seals, 1983-2001. Mar. Mammal Sci. 19(2): 344-362

Tollit, D. J., S. P. R. Greenstreet and P. M. Thompson. 1997. Prey selection by harbour seals, *Phoca vitulina*, in relation to variations in prey abundance. Canadian Journal of Zoology 75: 1058-1518.

Trites, A.W., D.G. Calkins, A.J. Winship. 2007. Diets of Steller sea lions (*Eumetopias jubatus*) in Southeast Alaska, 1993−1999. Fish. Bull. 105:234–248

Waite, J. M., M. E. Dahlheim, R. C. Hobbs, S. A. Mizroch, O. Von Ziegesar-Matkin, J. M. Straley, L. M. Herman and J. Jacobsen. 1999. Evidence of a feeding aggregation of humpback whales (Megaptera novaeangliae) around Kodiak Island, Alaska. Marine Mammal Science 15: 210-220.

Webster, M. S., P. P. Marra, S. M. Haig, S. Bensch and R. T. Holmes. 2002. Links between worlds: unraveling migratory connectivity. Trends in Ecology & Evolution 17: 76-83.

Witteveen, B. H., R. J. Foy, K. M. Wynne and Y. Tremblay. 2008. Investigation of foraging habits and prey preference of humpback whales (*Megapatera novaeangliae*) near Kodiak Island, Alaska using acoustic tags. Marine Mammal Science 24: 516.

Witteveen, B. H., G. A. J. Worthy, K. Wynne and R. J. Foy. In press. Modeling the diet of humpback whales: an approach using stable carbon and nitrogen isotope tations in a Bayesian mixing model. Marine Mammal Science.

Witteveen, B. H., K. M. Wynne and T. J. Quinn II. 2007. A feeding aggregation of humpback whales near Kodiak Island, Alaska: current and historic abundance estimation. Alaska Fisheries Research Bulletin 12: 187-196.

Womble, J. N., M. F. Wilson, M. F. Sigler, B. P. Kelly and G. R. Vanblaricom. 2005. Distribution of Steller sea lions *Eumetopias jubatus* in relation to spring-spawning fish in SE Alaska. Marine Ecology - Progress Series 294: 271-282.

Womble, J. N. and M. F. Sigler. 2006. Seasonal availability of abundant, energy-rich prey influences the abundance and diet of a marine predator, the Steller sea lion *Eumetopias jubatus*. Marine Ecology - Progress Series 325: 281-293.

Woodward, B. L., J. P. Winn and F. E. Fish. 2006. Morphological specializations of baleen whales associated with hydrodynamic performance and ecological niche. Journal of Morphology 267: 1284-1294.

Table 1. Summary of seasonal field effort, sightings, resights, and biopsies collected in GAP's Kodiak and Shumagin Island study areas, 1999-2009.

		Humpback Whales					Fin Whales				
Year	Effort Days	Sightings	Individuals	New	Resights	Biopsies	Sightings	Individuals	New	Resights	Biopsies
1999	13	26	22	22	0	-	-	-	-	-	-
2000	26	178	75	67	6	-	-	-	-	-	-
2001	25	236	127	103	31	14	-	-	-	-	-
2002	48	273	179	152	29	8	80	67	67	0	-
2003	30	84	76	65	11	1	34	32	31	1	-
2004	24	512	378	317	55	71	-	-	-	-	-
2005	22	523	284	197	87	121	-	-	-	-	-
2006	15	174	115	84	31	28	-	-	-	-	1
2007	51	712	449	308	140	37	22	12	12	-	4
2008	39	278	167	103	63	19	82	57	57	-	2
2009	20	135	110	49	61	11	42	19	17	2	0

Table 2. Total number of sightings of humpback and fin whales in Kodiak and the Shumagin Islands during vessel surveys, 1999 - 2009.

Year	Humpback Whales				Fin Whales			
	All Kodiak	Marmot Bay	All But Marmot	Shumagin Is.	All Kodiak	Marmot Bay	All But Marmot	Shumagin Is.
1999	5		5	21				
2000	20		20	158				
2001	78	2	76	158				
2002	217	57	160	56	80	71	9	
2003	84	31	53		34	34	0	
2004	384	71	313	128				
2005	323	101	222	200				
2006	174	2	172					
2007	543	359	184	169	222	203	19	3
2008	98		98	180	36	4	32	46
2009	50	18	32	85	17	17	0	3

Table 3. Summary of sightings of fin and humpback whales during both opportunistic and directed aerial surveys, 1999-2009.

Effort	Year	Fin Whales	Humpback Whales
Opportunistic	1997	0	2
	1998	0	1
	1999	8	3
	2000	16	79
	2001	120	110
	2002	101	120
	2003	83	103
	2004	124	227
	2005	8	165
	2006	3	22
Directed	2007	26	38
	2008	109	64
	2009	5	502
Grand Total		603	1436

Table 4. Averages of dive parameters calculated for foraging dives of fin whales. Duration is defined as the total length of a dive, which begins at the terminal dive or when no blows were observed for more than 30 seconds. Surface is defined as the total length of the surface interval between dives.

				Foraging Dives			
Tag Number	Date	Tracking Time	Total No. of Dives	No. of Dives	Average maximum dive depth (m)	Average dive duration (min)	Average surface interval (min)
1	8/15	1:25:37	11	11	123.7	5.6	2.4
2	8/16	2:12:28	21	11	110.1	6.2	3.9
3	8/30	1:13:03	9	9	150.0	5.9	2.8
Group Total or Average		4:51:08	41	31	127.9	5.9	3.0

Table 5: Details including date, tracking time and number of recorded dives, of 10 successful fin and humpback whale tagging events between 2004 and 2009 in Marmot Bay. Inferred prey is based on acoustic and/or net sampling of pelagic backscatter. All prey sampling was concurrent to tagging efforts.

Date	Species	Tag_ID	Track Time	Number of Dives	Inferred Prey
3-Aug-04	HB	HB04-01	6.22	42	Fish
7-Aug-04	HB	HB04-02	5.78	29	Fish
8-Aug-04	HB	HB04-03	1.91	11	Fish
8-Aug-04	HB	HB04-04	2.82	22	Fish
5-Aug-05	HB	HB05-01	3.39	12	Fish
15-Aug-07	HB	HB07-01	3.57	25	Zooplankton
16-Aug-07	HB	HB07-02	8.12	52	Zooplankton
15-Aug-09	FW	FW09-01	1.43	11	Zooplankton
16-Aug-09	FW	FW09-02	2.21	21	Zooplankton
30-Aug-09	FW	FW09-03	1.22	9	Zooplankton
Total	10		36.67	234	

Table 6. Descriptions and units of dive parameters calculated for each dive and then averaged across individual whales.

Parameter	Unit	Description
No. of dives		Total number of dives used for analysis
MaxDepth	m	Mean maximum depth reached
Duration	min	Total duration of the dive. Defined as the interval of time between initiation of descent to time of resurface
Bottime	min	Duration in the bottom phase of the dive
DescRate	ms^{-1}	Rate of descent
AscRate	ms^{-1}	Rate of ascent
Surface	min	Time spent between successive dives
BottVertDist	m	Sum of the total vertical distance traveled during the bottom phase of the dive
BottRange	m	Range of depth transited during the bottom phase
Efficiency		Relative efficiency of the dive. Determined by Bottime/(Duration+Surface)
Lunges		Number of vertical deviations greater than 8m recorded during the bottom phase. Indication of foraging.

Table 7. Results of non-parametric correlation (Spearman's rho) between depth of whale foraging dives and NASC in 2005, 2007 and 2009. Bold values indicate significant results.

	Fish		Zooplankton	
Year	Rho	*p*	Rho	*p*
2005	**0.456**	**0.038**	-0.178	0.439
2007	**-0.405**	**0.05**	**0.435**	**0.034**
2009	0.355	0.125	0.326	0.161

Table 8: Summary of the number of van Veen grabs completed, plumes or fecal samples collected, and gray whales photographed in Ugak Bay, July 2008.

Date	No. of vanVeen Grabs	No. of Plumes/Fecals	No. of Whales Photographed
10-Jul-08	0	1	5
11-Jul-08	5	0	5
12-Jul-08	3	1	18
14-Jul-08	5	3	16
17-Jul-08	2	3	2
Total	15	8	46

Table 9. Density (number individuals per /m^2) of organisms collected during benthic sampling by van Veen grab on incoming (IN) and outgoing (OUT) tides at sites in Ugak Bay, July 2008. Locations of sampling stations are presented in Figure 14.

			DENSITY *(# individuals /* m^2)									
Station #	Date	Tide Direction	*Diastylopsis dawsoni* (cumacean)	polychaete	amphipod	nematode	megalopa/ glaucothoe	bivalve	brittle stars	sea cucmbr	hermit crabs	barnacle
1	07/12/08	OUT	1,420	10	20	10						
1	07/17/08	IN	1,840	40	30			50				
2	07/11/08	OUT	2,380		70		50	70				
2	07/17/08	IN		50	50			60				
3	07/11/08	OUT		200				3,200				
4	07/11/08	OUT	42,240	20	100			640				
4	07/14/08	IN	20,640	70	60	20		120	40	20		
5	07/11/08	OUT						100	20		20	
5	07/14/08	IN		20				490	10			
6	07/12/08	OUT	2,040	50				50	10			
6	07/14/08	IN						30	20	30		
7	07/11/08	OUT		10							10	10
8	07/12/08	OUT	7,680	10	110			120	20			
8	07/14/08	IN	10,720	20	90			100	10			
Extra Site "A"	07/14/08	OUT	1,820	20	90							

Table 10. Contents (# of individuals) recovered from mud plumes and fecal clouds sampled in immediate vicinity of feeding gray whales in Ugak Bay, July 2008.

Sample #	Collection date	Sample Type	*Diastylopsis dawsoni* (cumacean)	polychaetes	amphipods	nematode	hydromedusae	larval fish
LG01	7/11/2008	Plume	7					
LG02	7/13/2008	Fecal	121	1	1			
LG03	7/14/2008	Plume	56					
LG04	7/14/2008	Plume	9					
LG05	7/14/2008	Plume	16				7	
LG06	7/14/2008	Plume	172			1	5	2
LG07	7/17/2008	Fecal	42					1
LG08	7/17/2008	Fecal	65				2	
LG09	7/17/2008	Fecal	170					

Table 11. Rank order and % frequency of occurrence (FO %) of prey remains found in 1565 harbor seal scats containing identifiable remains, collected in the Kodiak area 2001-2009.

PREY	FO %	RANK
IRISH LORD SP	28.05	1
ROCK SOLE	18.59	2
UNIDENTIFIED FISH	18.21	3
GREENLING SP	18.21	3
PACIFIC COD	13.04	5
SAND LANCE	11.82	6
ARROWTOOTH FL	10.42	7
SALMON OR TROUT	9.90	8
POLLOCK	8.95	9
HERRING	7.92	10
UNIDENTIFIED SCULPIN	7.35	11
HALIBUT	6.90	12
CEPHALOPOD	6.65	13
TRIGLOPS SP	6.26	14
SEARCHER	5.94	15
OCTOPUS	5.50	16
GYMNOCANTHUS SP	5.37	17
UNIDENTIFIED FLAT FISH	4.86	18
UNIDENTIFIED GADID	4.54	19
POLYCAETE UNID	4.35	20
ROCKFISH SP	3.71	21
DOVER SOLE	3.07	22
SAND FISH	2.88	23
SNAILFISH SP	2.75	24
CAPELIN	2.68	25
GUNNEL	2.30	26
FLATHEAD SOLE	2.17	27
RONQUIL SP	1.85	28
REX SOLE	1.66	29
BUTTER SOLE	1.53	30
SLENDER SOLE	1.28	31
BUFFALO-TYPE SP	1.21	32
SQUID UNIDENT	1.21	33
HIGH COCKSCOMB	1.15	34
POACHER SP	1.15	35
EULACHON	1.09	36

Table 12. Rank order and % frequency of occurrence (FO %) of prey remains found in 3369 Steller sea lion scats containing identifiable remains, collected in the Kodiak area 2000-2008.

PREY	FO %	RANK
POLLOCK	39.92	1
ARROWTOOTH FL	38.05	2
SAND LANCE	36.87	3
PACIFIC COD	33.99	4
HERRING	26.65	5
SALMON OR TROUT	23.60	6
CAPELIN	14.57	7
UNIDENTIFIED FISH	14.01	8
SAND FISH	11.16	9
ROCK SOLE	9.82	10
IRISH LORD SP	9.29	11
POLYCAETE UNID	7.90	12
SNAILFISH SP	5.94	13
SKATE	5.02	14
ROCKFISH SP	4.36	15
UNIDENTIFIED GADID	3.62	16
HALIBUT	3.38	17
GREENLING SP	3.21	18
OCTOPUS	2.52	19
EULACHON	2.26	20
CEPHALOPOD	2.23	21
SM_ LUMPSUCKER	1.96	22
UNIDENTIFIED SCULPIN	1.69	23
ATKA MACKEREL	1.57	24
DOGFISH	1.54	25
STARRY FLOUND_	1.54	26
GUNNEL	1.48	27
UNIDENTIFIED FLAT FISH	1.42	28
HIGH COCKSCOMB	1.34	29

Table 13. Number (#) of scat samples collected and analyzed from Kodiak area harbor seals (HS) and Steller sea lion (SSL) haulouts by Region and Season, 2001-2008. R values = analysis of similarity (ANOSIM) with p-value significance determined by permutation. Regional assignment of sampled haulouts is demonstrated in Figure 17.

REGION	SEASON	# HS scats	#SSL scats	R	p-value
EAST	FALL	212	181	0.234	0.001
EAST	SPRING	25	81	0.339	0.001
EAST	SUMMER	16	15	0.285	0.001
EAST	WINTER	112	515	0.124	0.001
NORTH	FALL	24	691	0.196	0.001
NORTH	SPRING	5	159	0.450	0.001
NORTH	SUMMER	24	246	0.140	0.002
NORTH	WINTER	89	421	0.214	0.001
SOUTH	FALL	255	43	0.161	0.001
SOUTH	SUMMER	621	75	0.151	0.001
WEST	FALL	43	220	0.152	0.002
WEST	SPRING	9	96	-0.03	0.562
WEST	SUMMER	30	116	0.137	0.004
WEST	WINTER	62	510	0.046	0.090

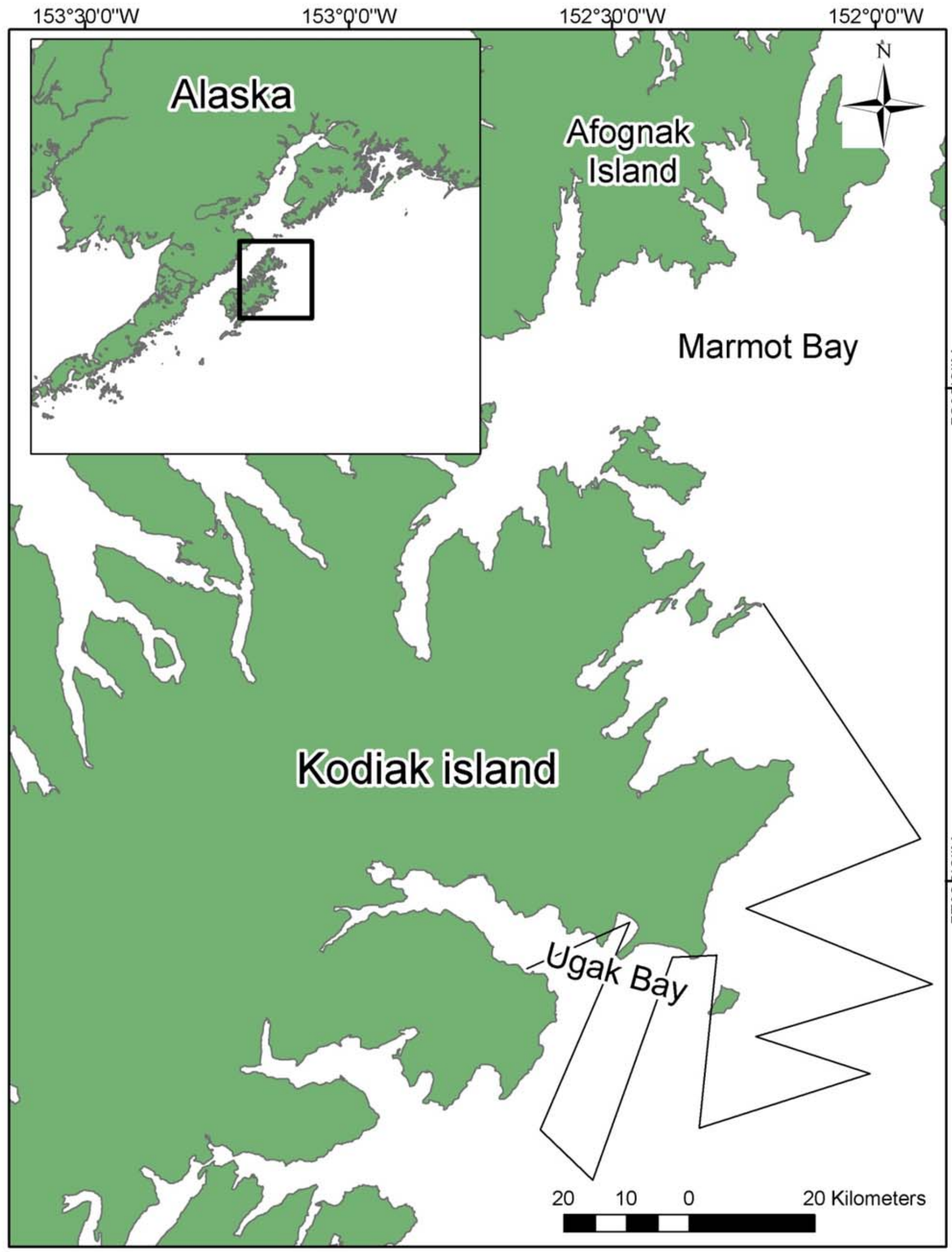

Figure 1. Map of Kodiak waters and trackline surveyed during 11 monthly GAP08 aerial surveys, September 2008 to September 2009 .

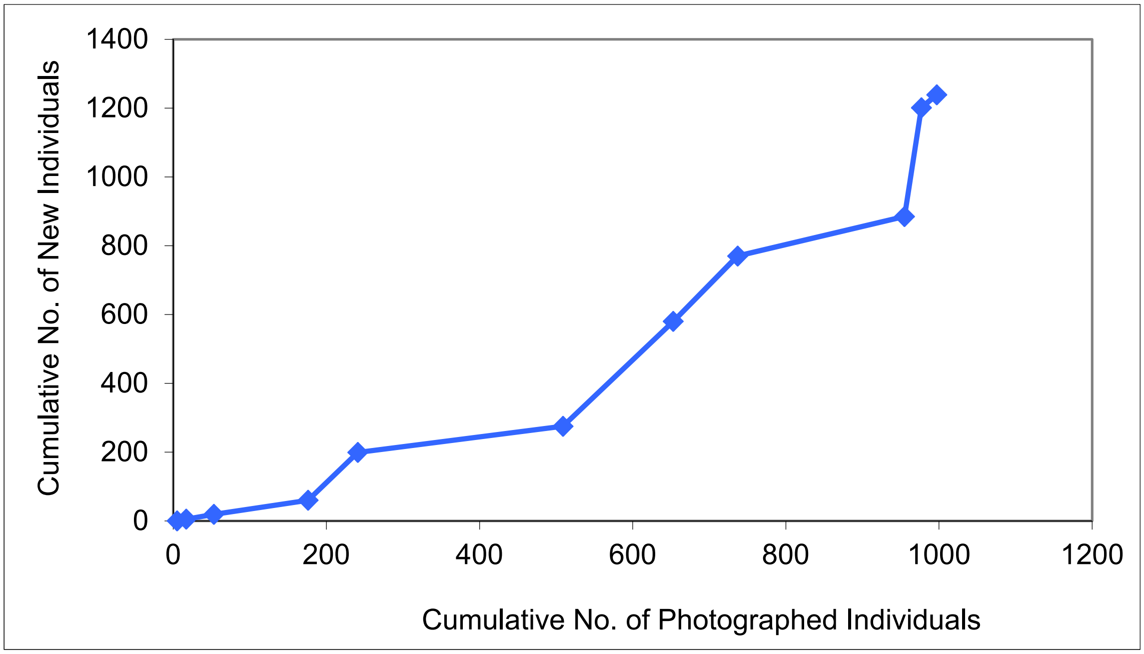

Figure 2. Discovery curve for humpback whales belonging to the Kodiak Island feeding aggregation between 1999 and 2009. The discovery curve represents the number of newly photographed (not previously encountered) individual whales as a proportion of the total number of whales in the photographic catalog.

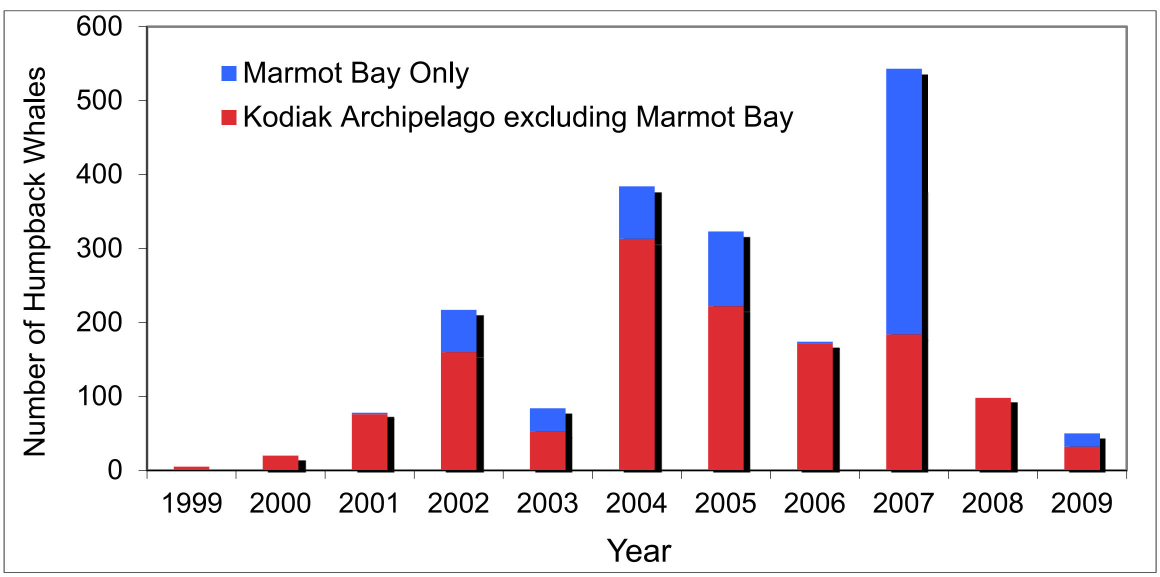

Figure 3. The number of individual humpback whales photo-identified in Marmot Bay and the remainder of the Kodiak archipelago, 1999- 2009.

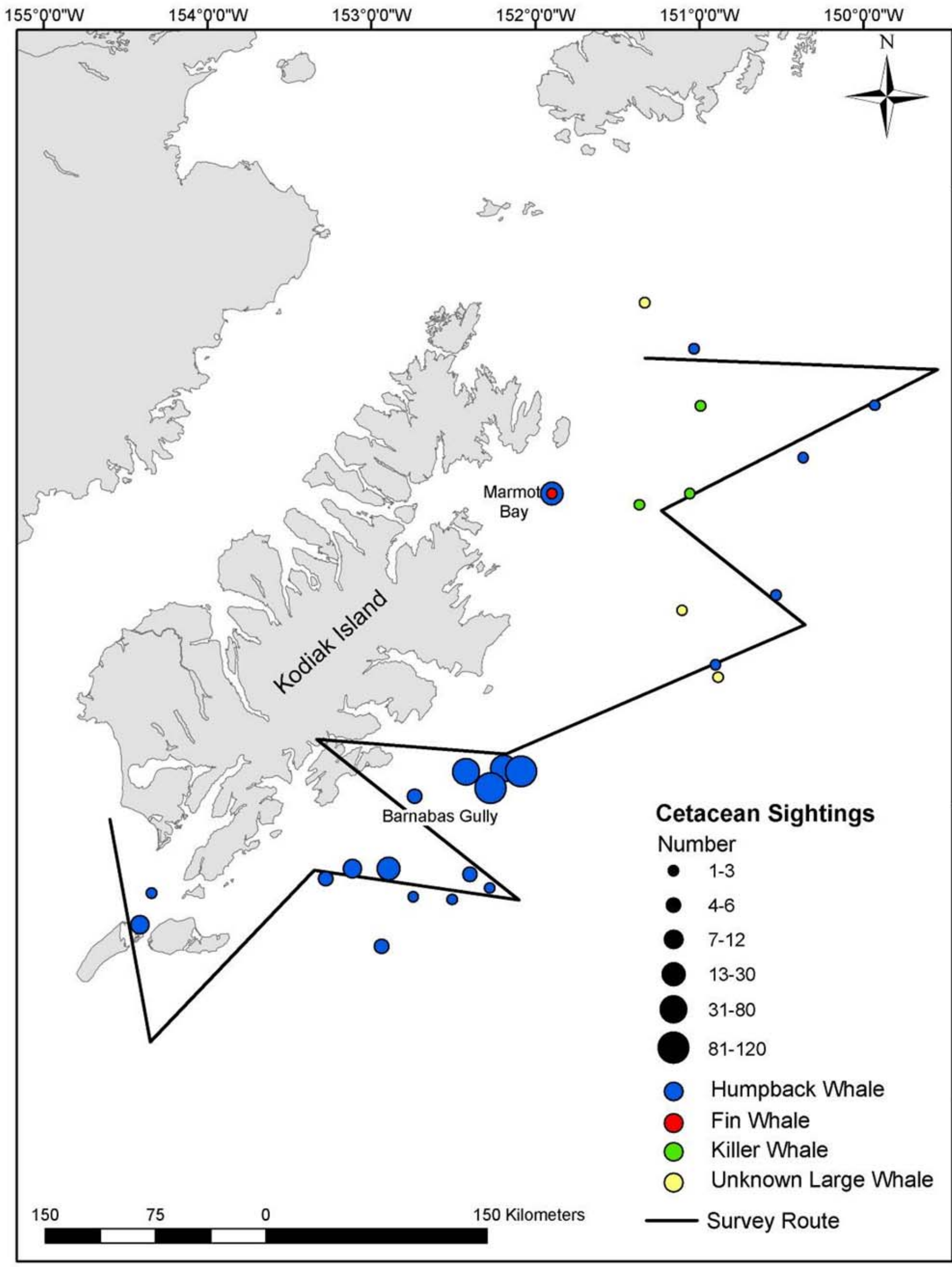

Figure 4. Locations and number of cetaceans seen during an offshore aerial survey conducted on August 6, 2009

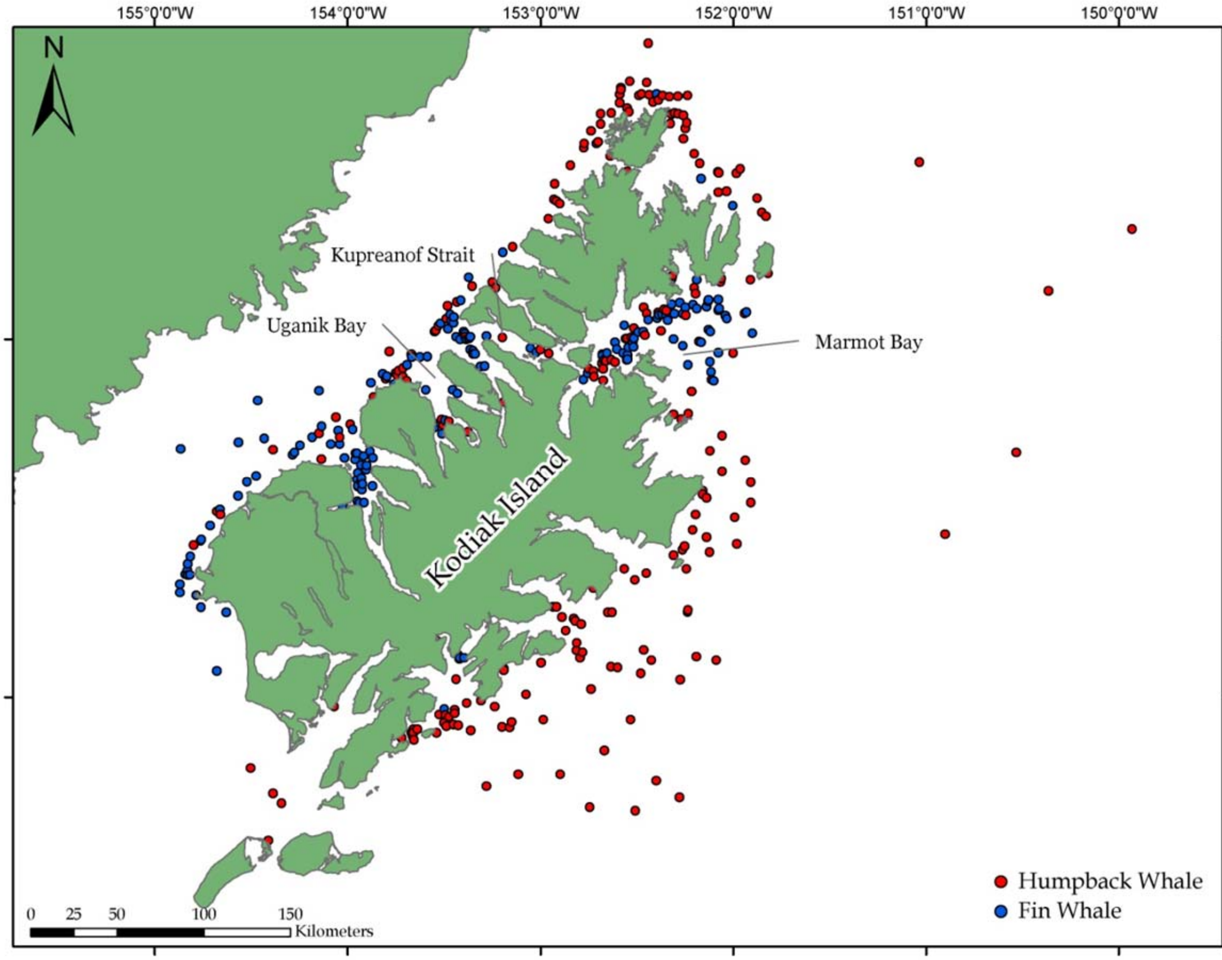

Figure 5. Cumulative sightings of fin and humpback whales recorded during aerial surveys conducted, 1999-2009.

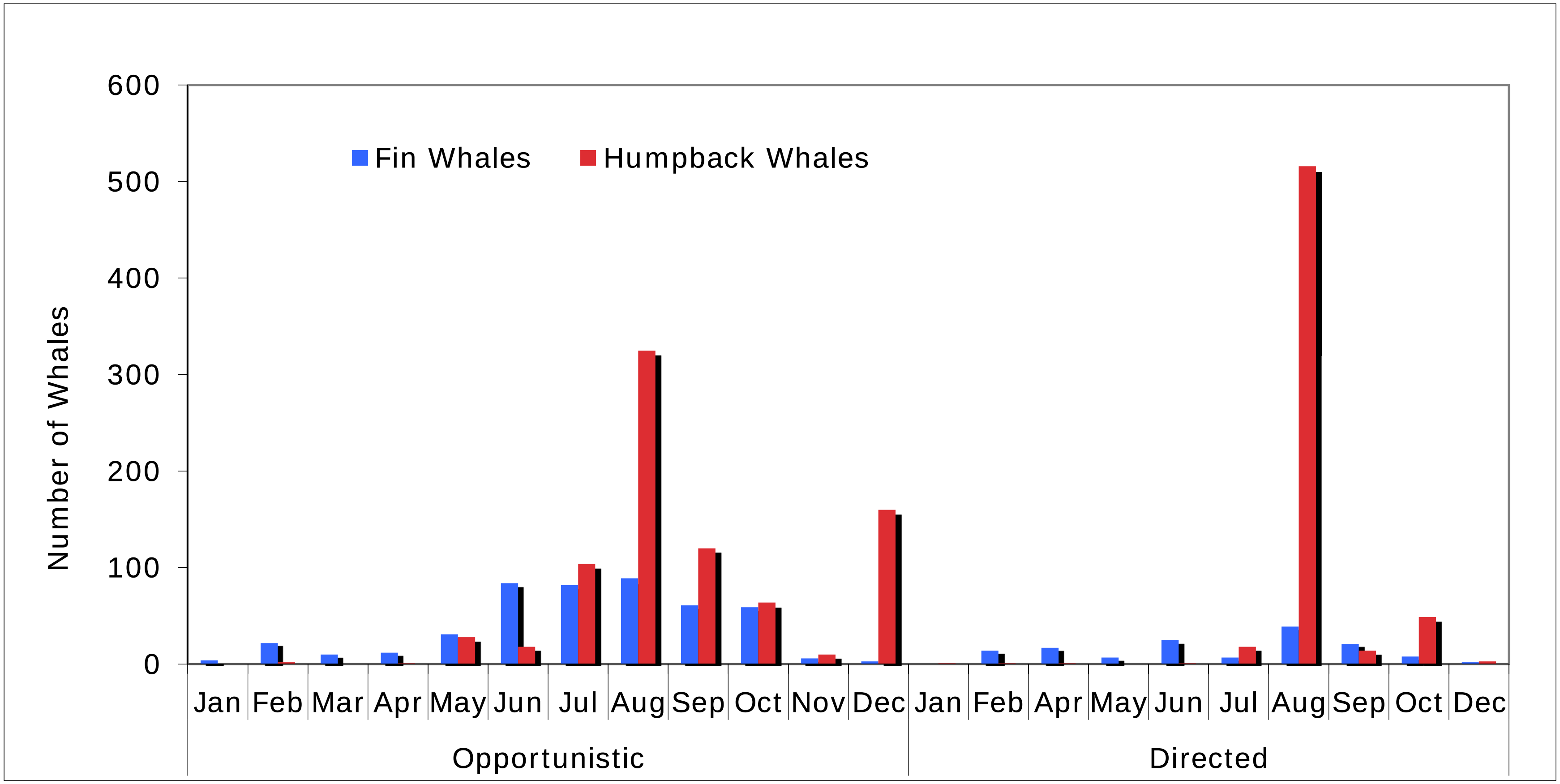

Figure 6. Cumulative monthly distribution of fin and humpback whale sightings made during opportunistic and directed aerial surveys in the Kodiak area, September 1999 to September 2009.

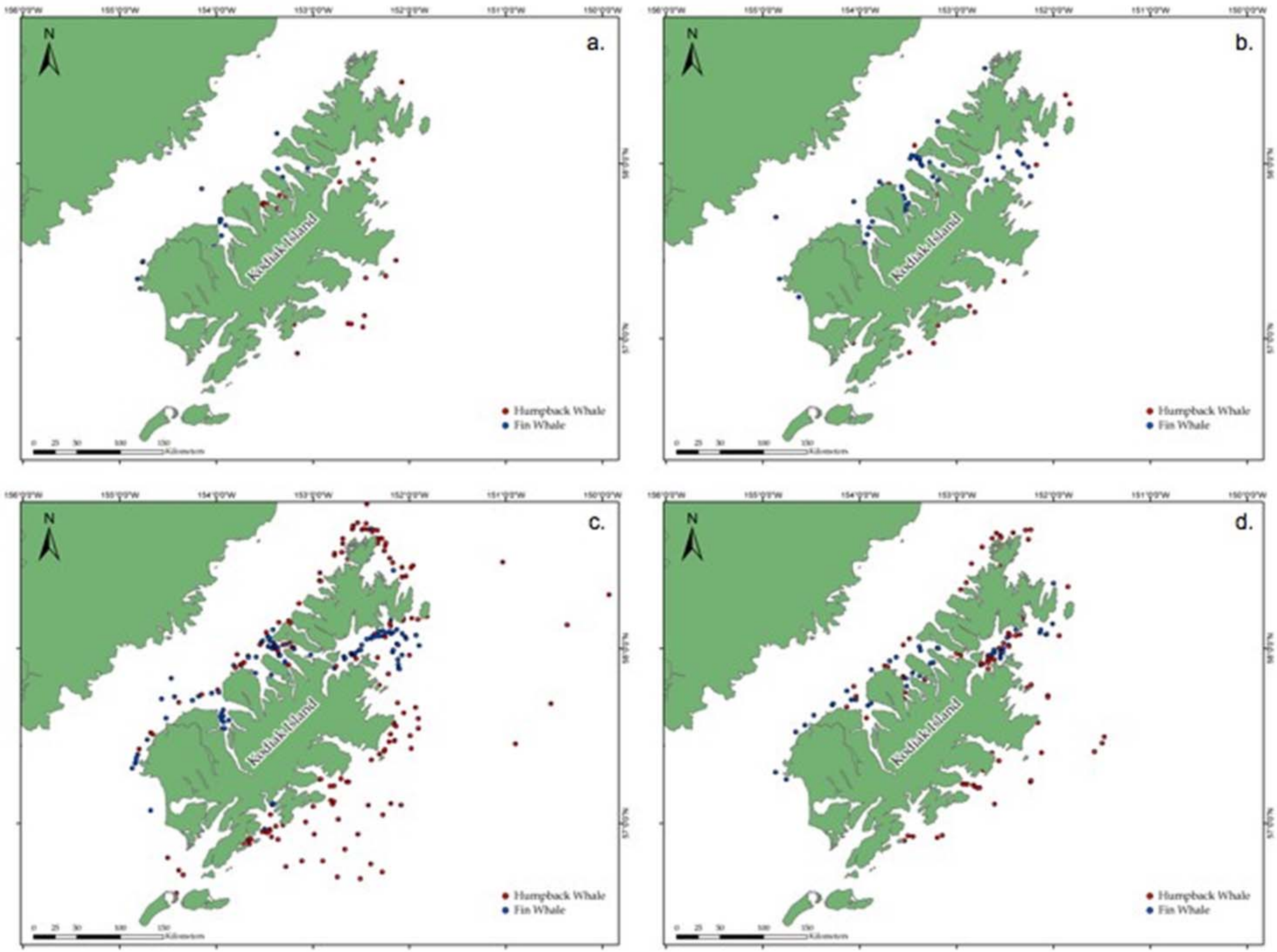

Figure 7. Cumulative aerial sightings of fin and humpback whales in (a) winter (Dec – Feb), (b) spring (March – May), (c) summer (June – Aug) and (d) fall (Sept – Nov). Aerial surveys were conducted between September 1999 and September 2009.

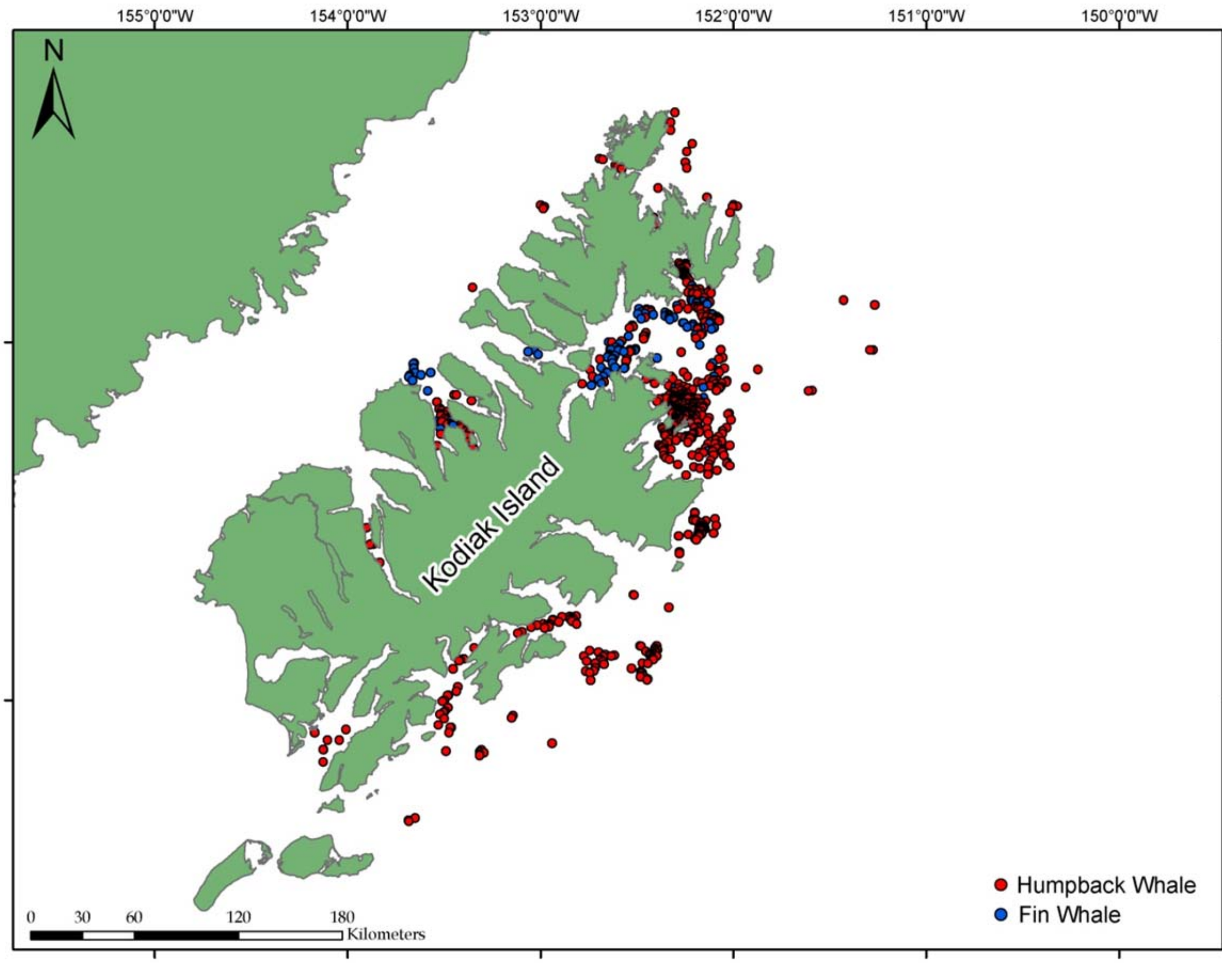

Figure 8. Vessel sightings of fin and humpback whales collected between August 1999 and August 2009.

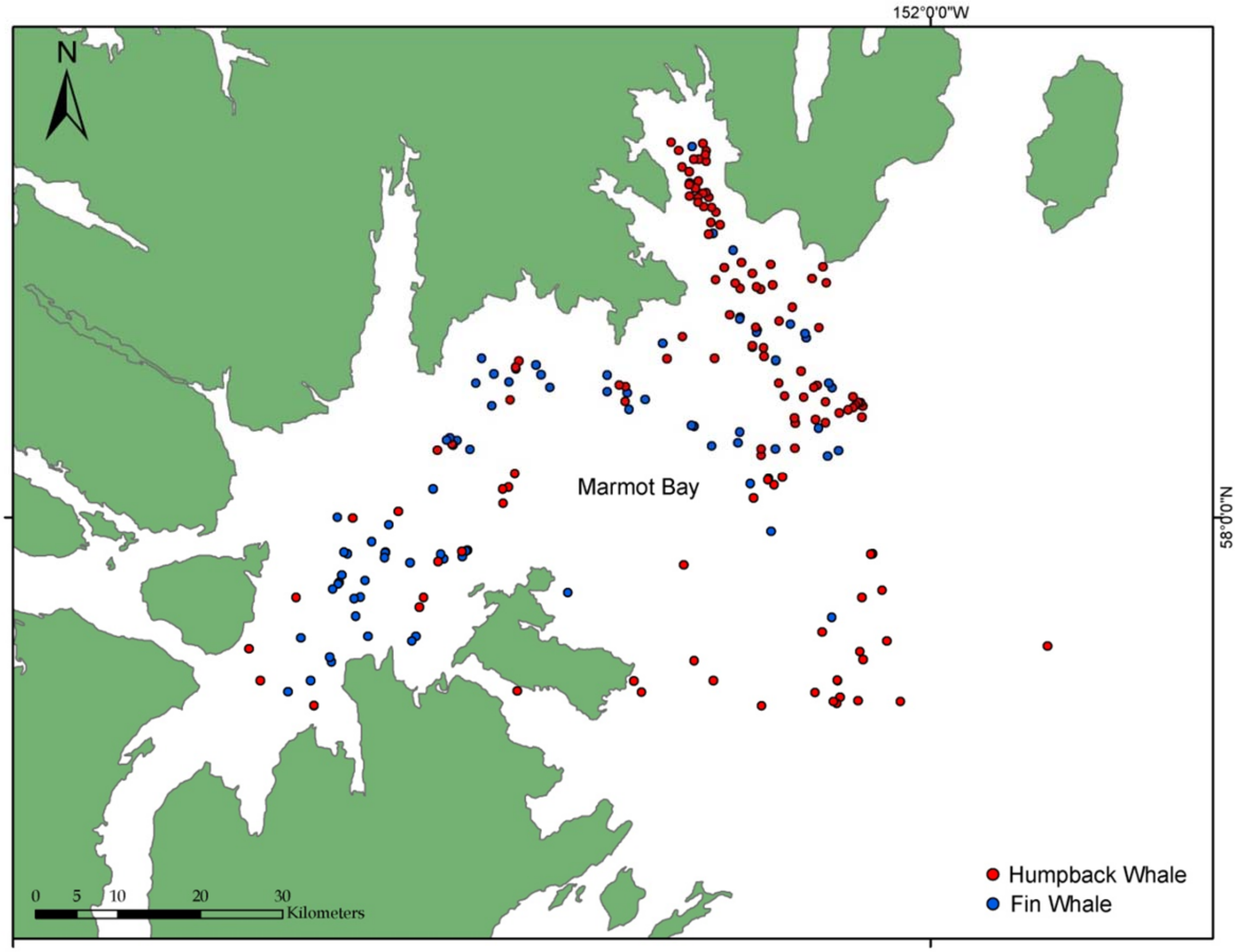

Figure 9. Sightings of fin and humpback whales recorded during vessel surveys in Marmot Bay between the months of June and August for the years 2001 to 2009.

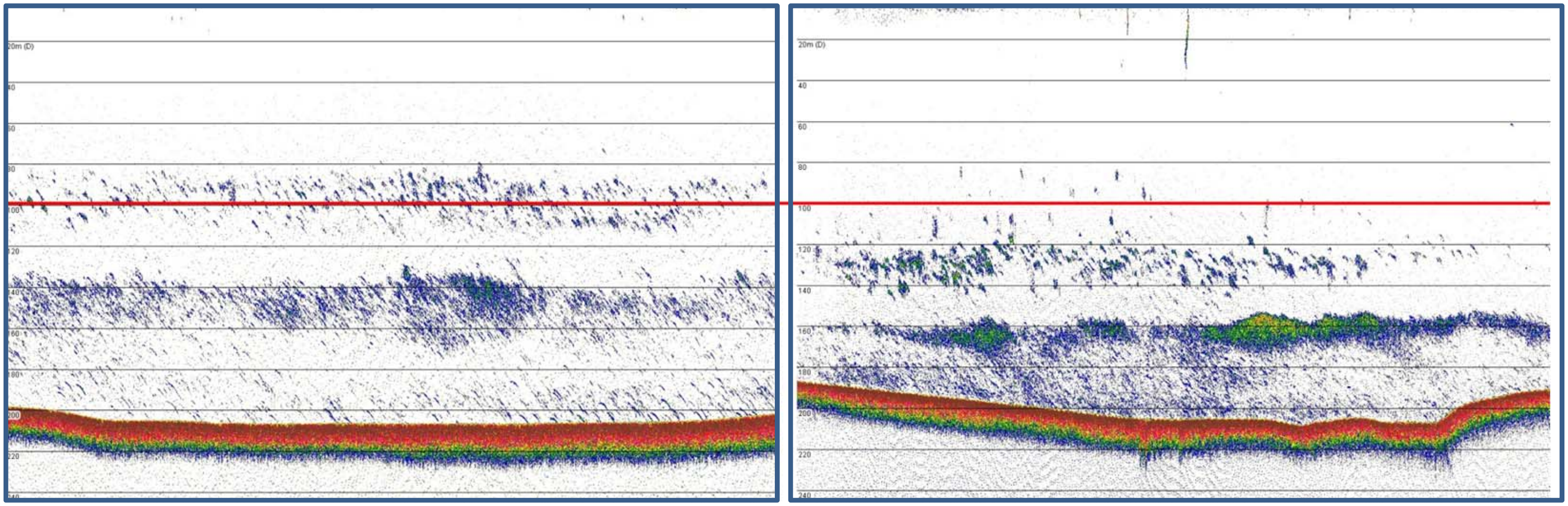

Figure 10: Screen shots of acoustic backscatter from the Simrad 38 kHz transducer showing the downward movement of bands of prey between August 15th, 2009 (left) and August 30, 2009 (right). Thin black lines indicate 10 m depth increments, while the thicker red line highlights the 100 m depth line for reference.

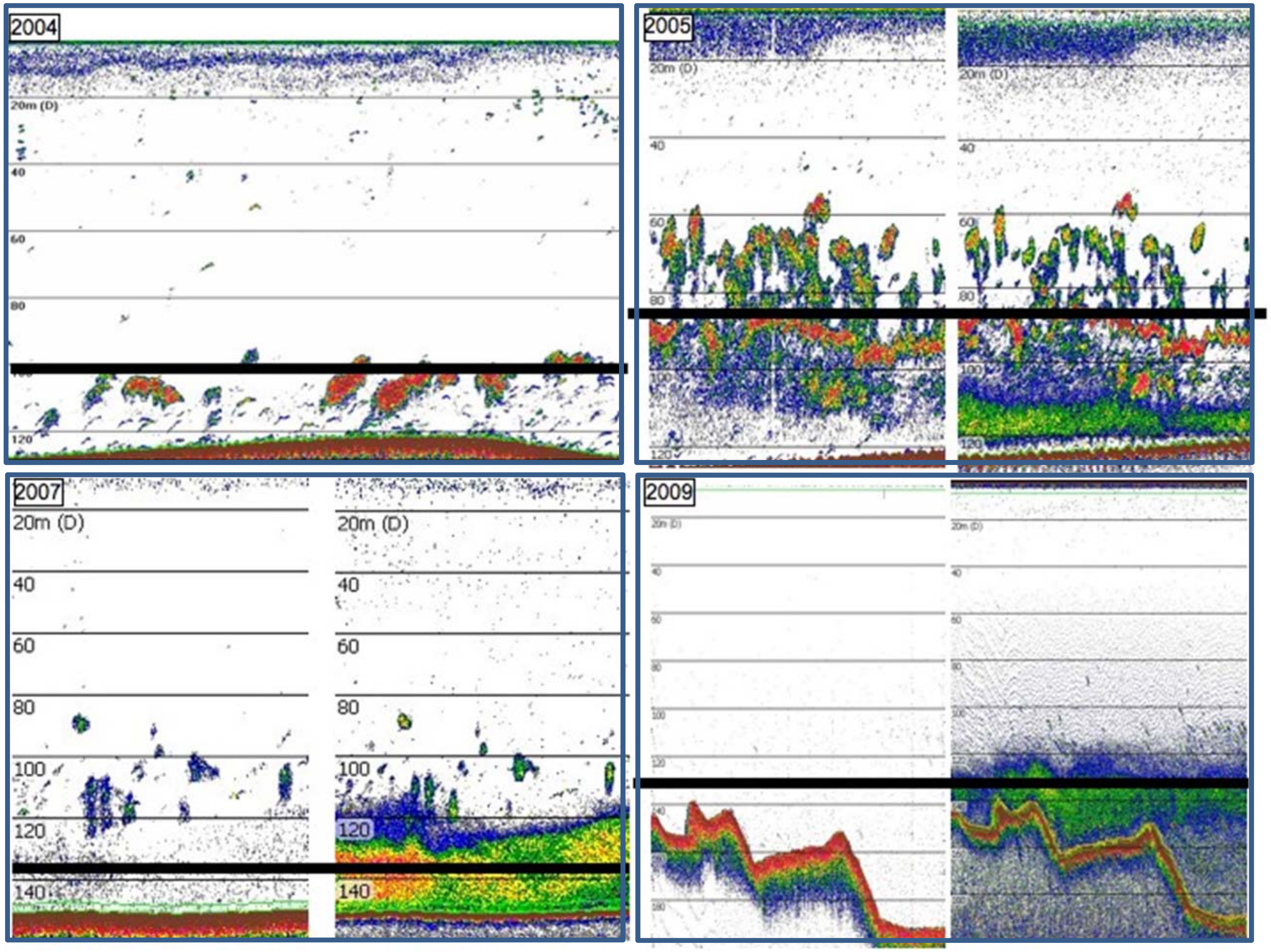

Figure 11. Screenshots of acoustic backscatter collected concurrent to tagging efforts in August of (clockwise from upper left) 2004, 2005, 2007 and 2009. In each year, left panels are from the 38 kHz transducer and the right panels are from the 120kHz transducer. No 120 kHz data was collected in 2004. The thick black line in each year represents the average dive depth of tagged whales.

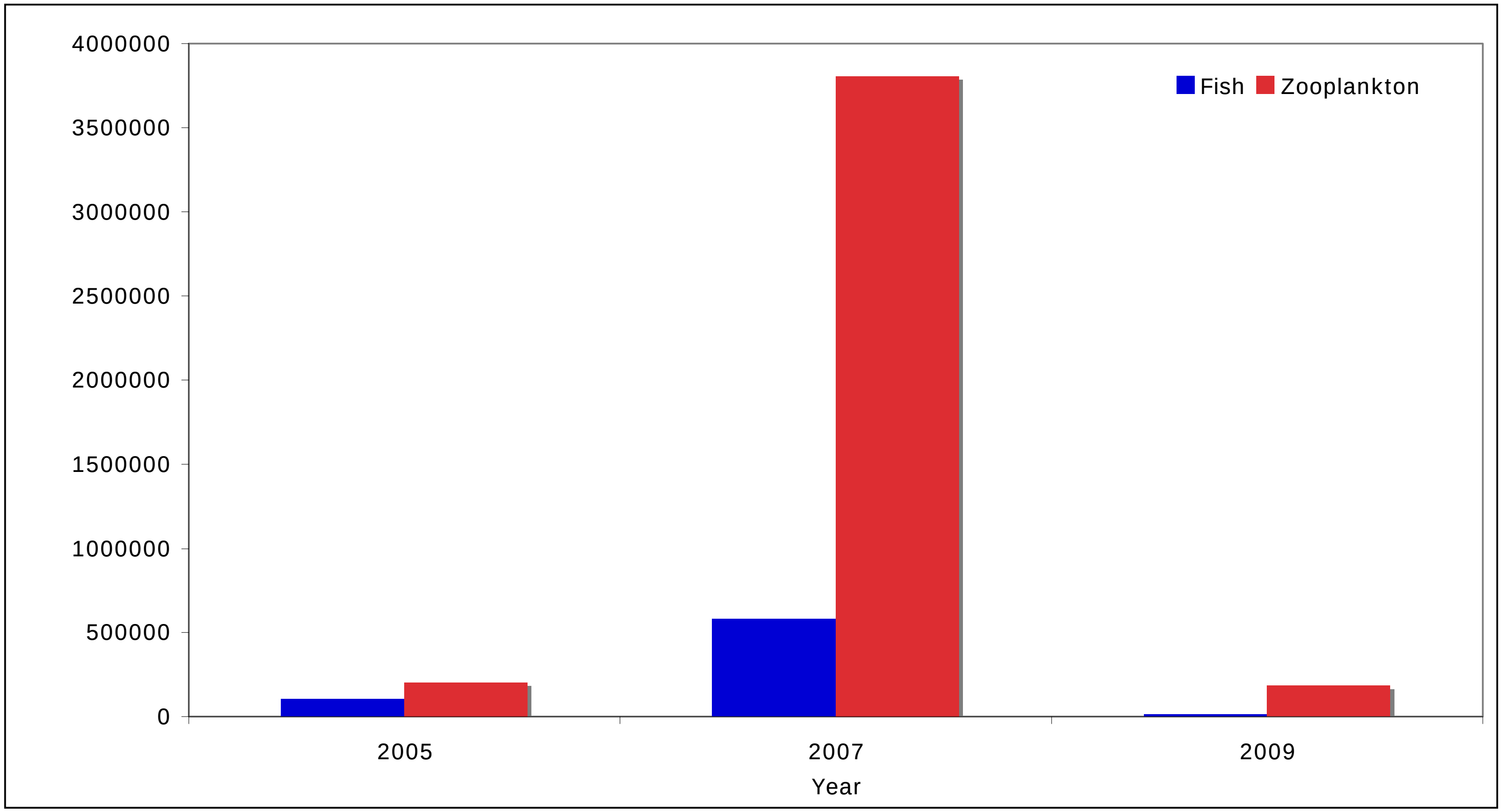

Figure 12. Sum of NASC (m^2/nmi^2) attributed to either fish or zooplankton collected concurrent to whale tagging efforts in Marmot Bay in 2005, 2007, and 2009.

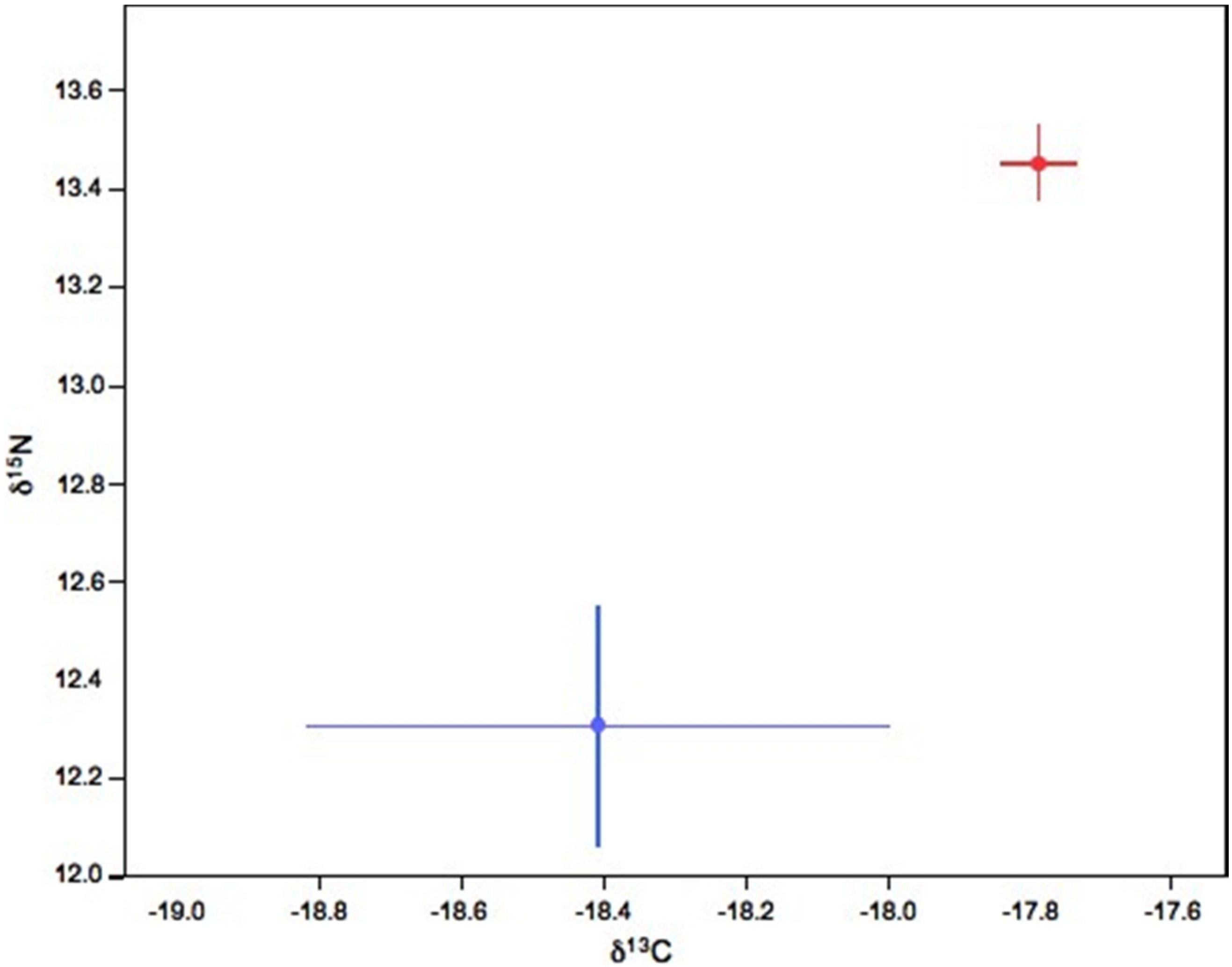

Figure 13. Mean stable carbon (d^{13}C) and nitrogen (d^{15}N isotope ratios for fin whales (blue) and humpback whales (red) from skin samples collected in the Kodiak area.

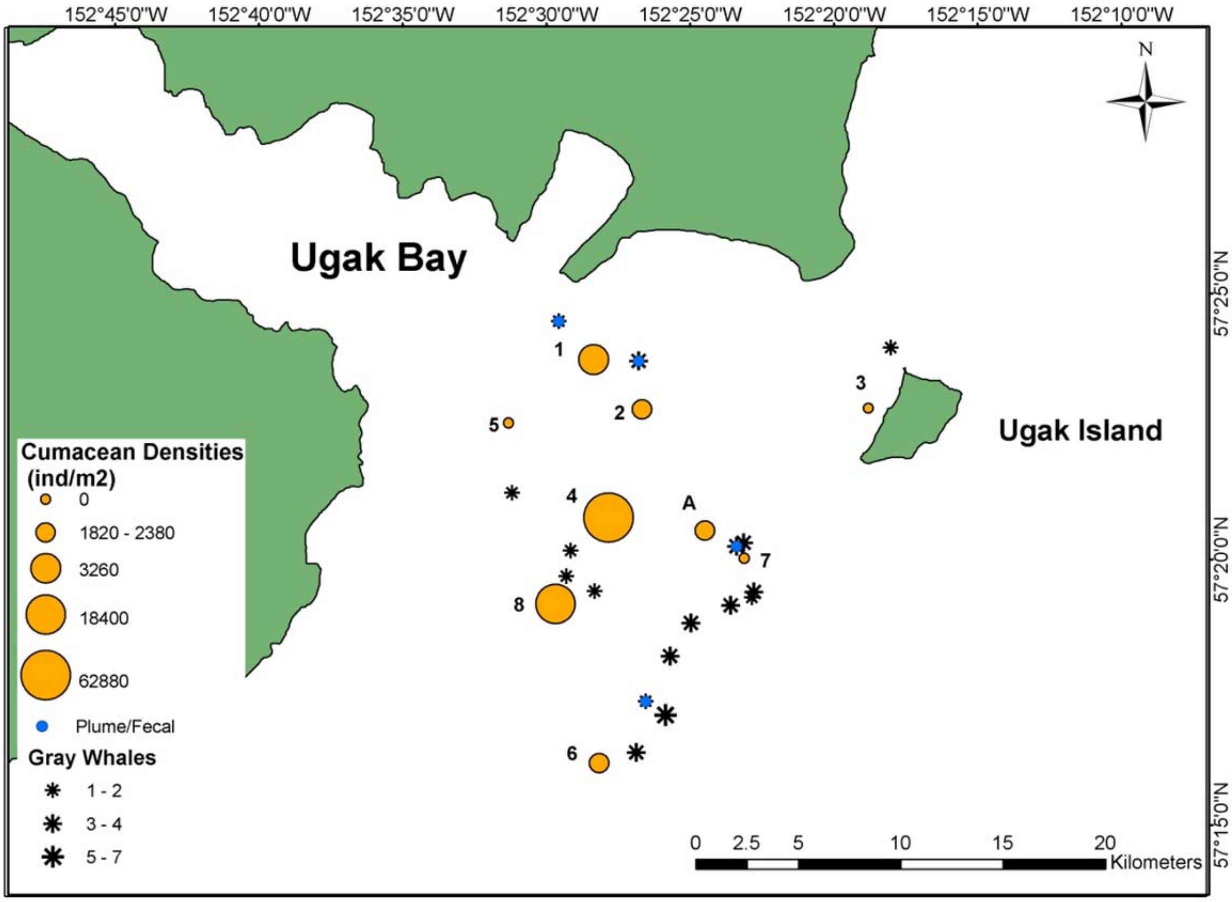

Figure 14. Area of Ugak Bay used by gray whales and surveyed in 2008. Shown are locations of gray whale sightings (stars), benthic sampling stations (numbered orange circles), and sampled mud or fecal plumes (blue circles).

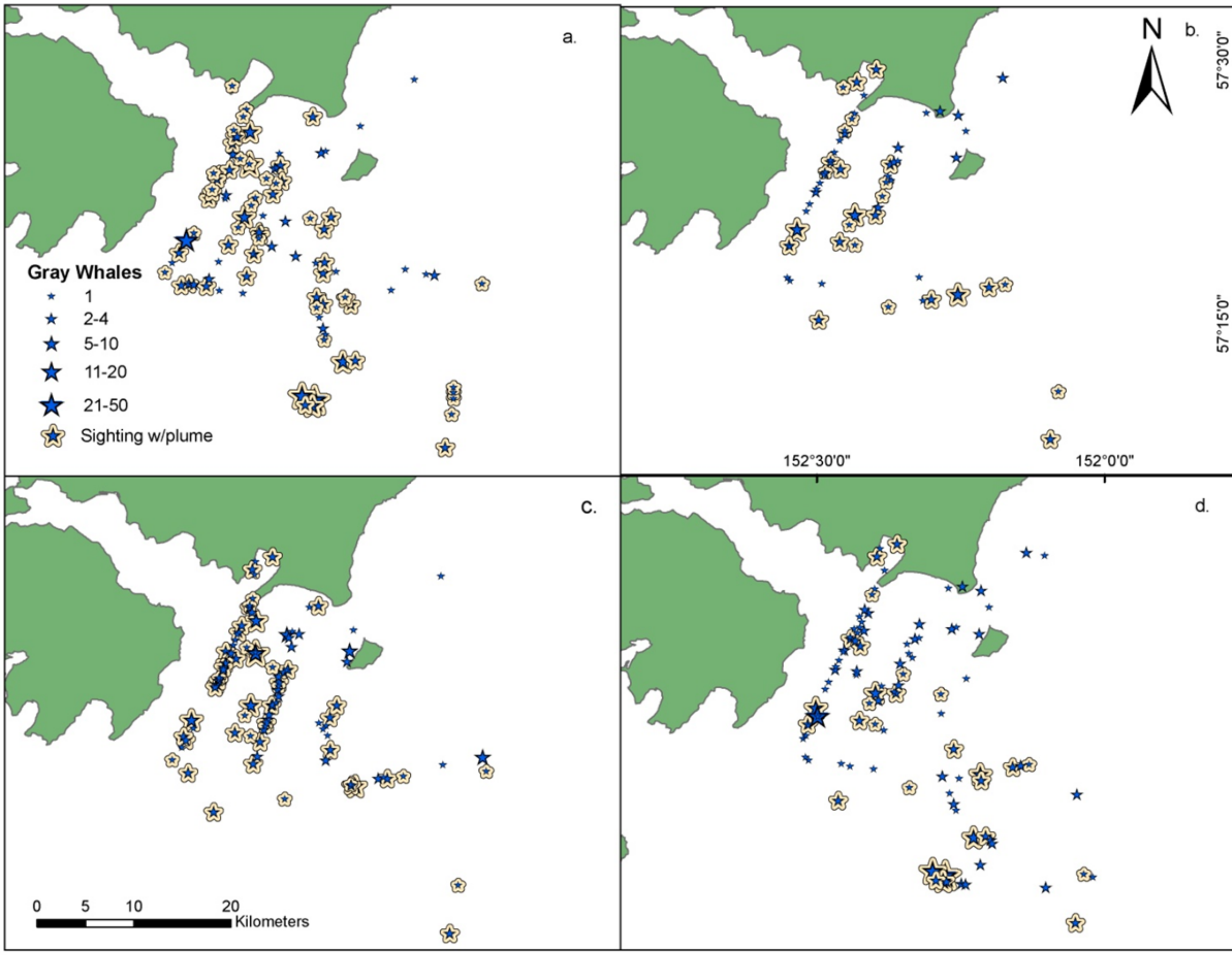

Figure 15. Map showing relative abundance of gray whales sighted during aerial surveys, grouped by season (a)winter (Dec – Feb), (b) spring (March – May), (c) summer (June – Aug) and (d) fall (Sept – Nov). Gray whales seen with mud plumes are indicated as evidence of feeding activity

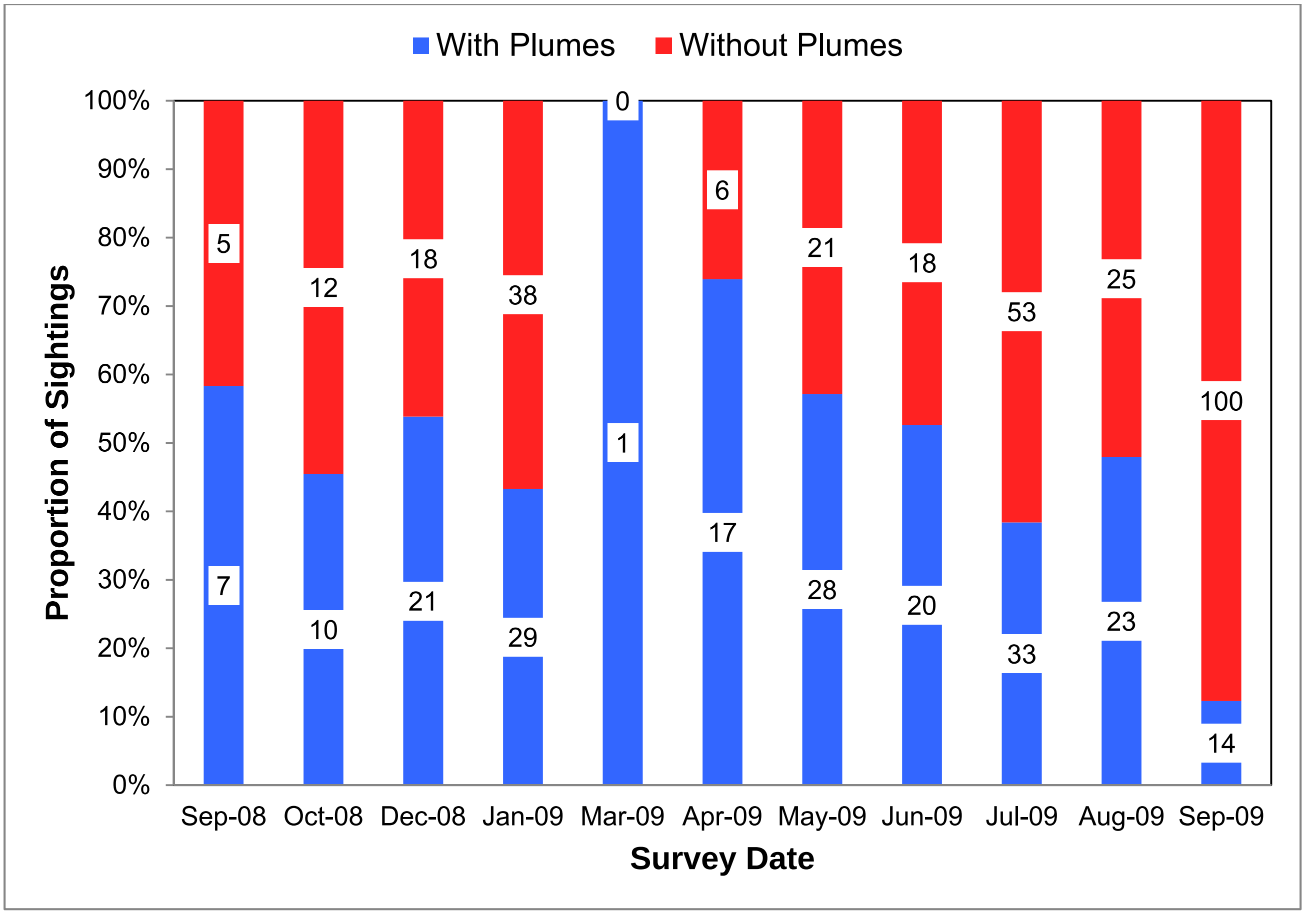

Figure 16. Percent of gray whales observed either with (blue) or without (red) mud plumes by aerial survey date, Sept 2008 – Sept 2009. Whales associated with plumes were categorized as feeding. Values shown represent the total number of individual gray whales sighted in each category. No survey was conducted in November 2008 or February 2009 due to adverse weather conditions.

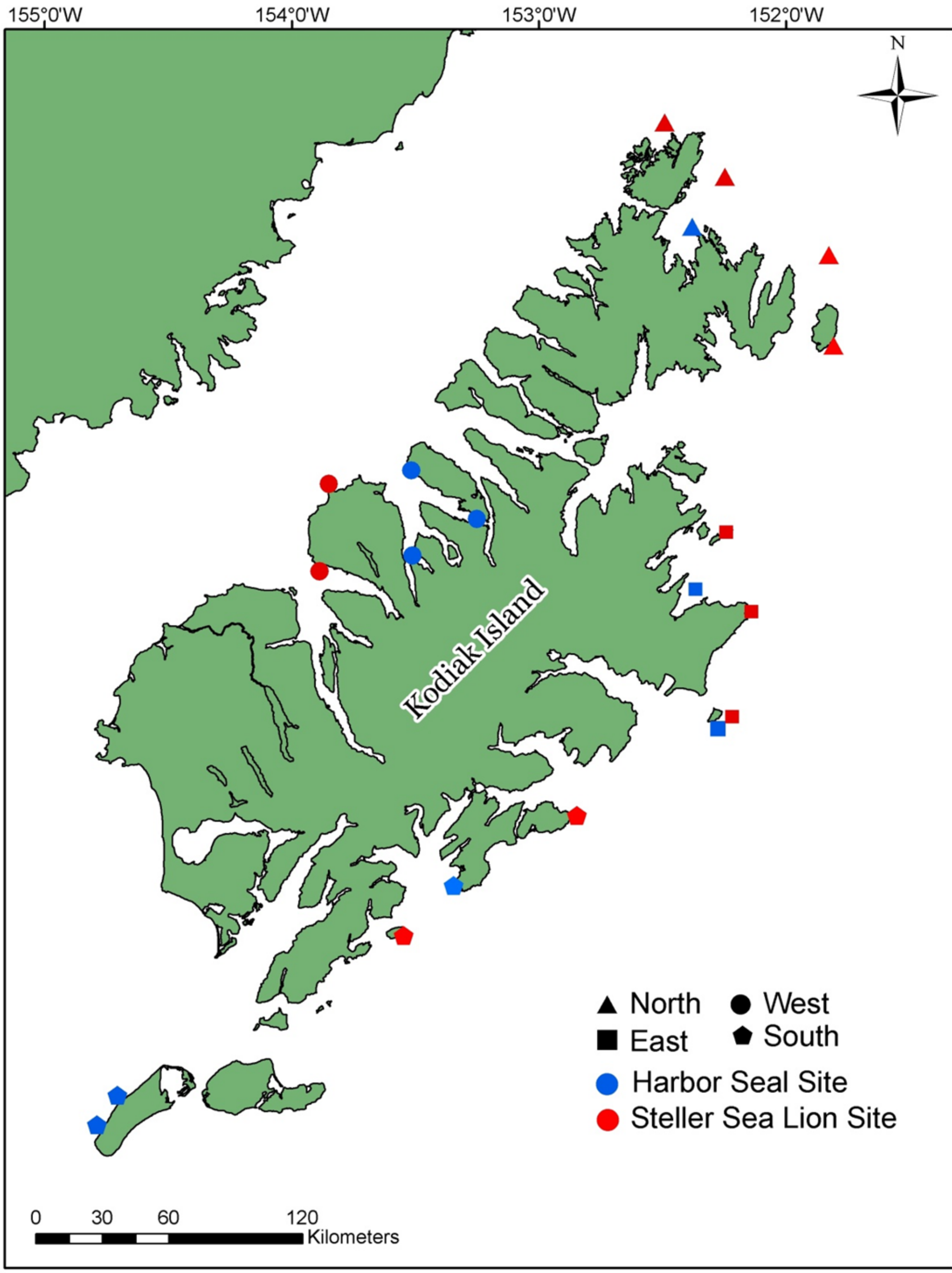

Figure 17. Location of harbor seal (blue) and Steller sea lion (red) haulouts from which scats were sampled in the Kodiak area, 2000-2009. Samples from multiple sites were grouped into Regions as indicated to exam spatial differences in the diets of these pinnipeds.

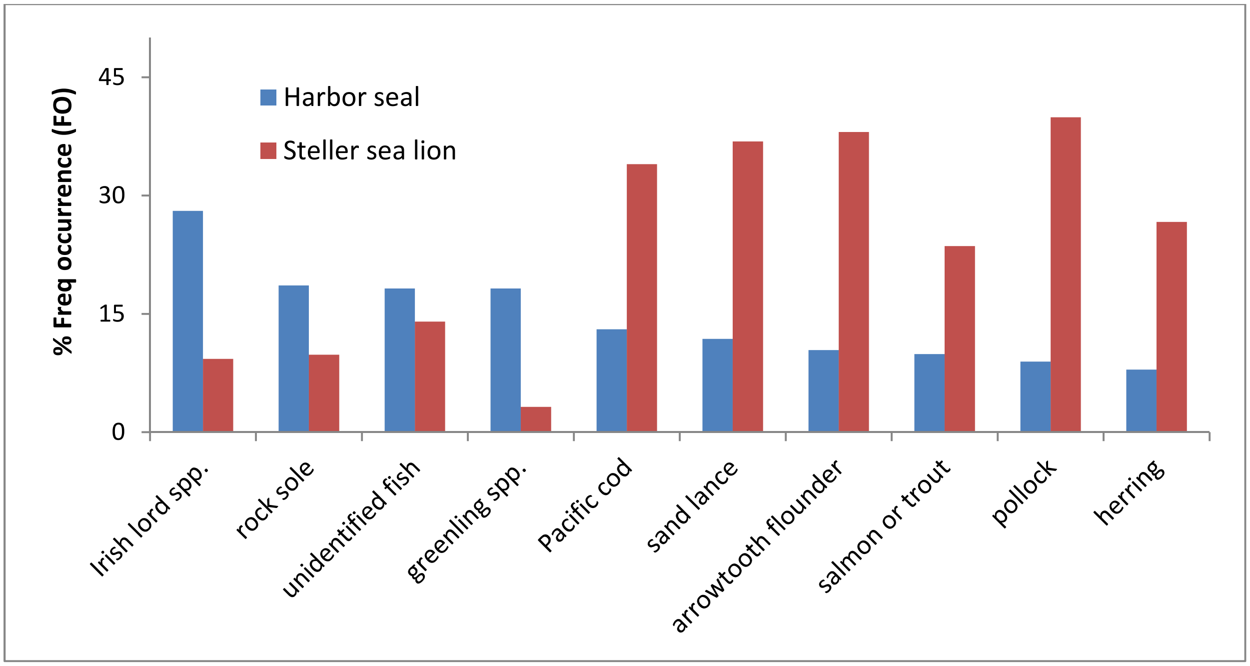

Figure 18. Frequency of occurrence (FO) of the top 10 ranked prey items found in 1565 Kodiak area harbor seal scats compared to their FO in 3369 Kodiak area Steller sea lion scats collected 2000-2009.

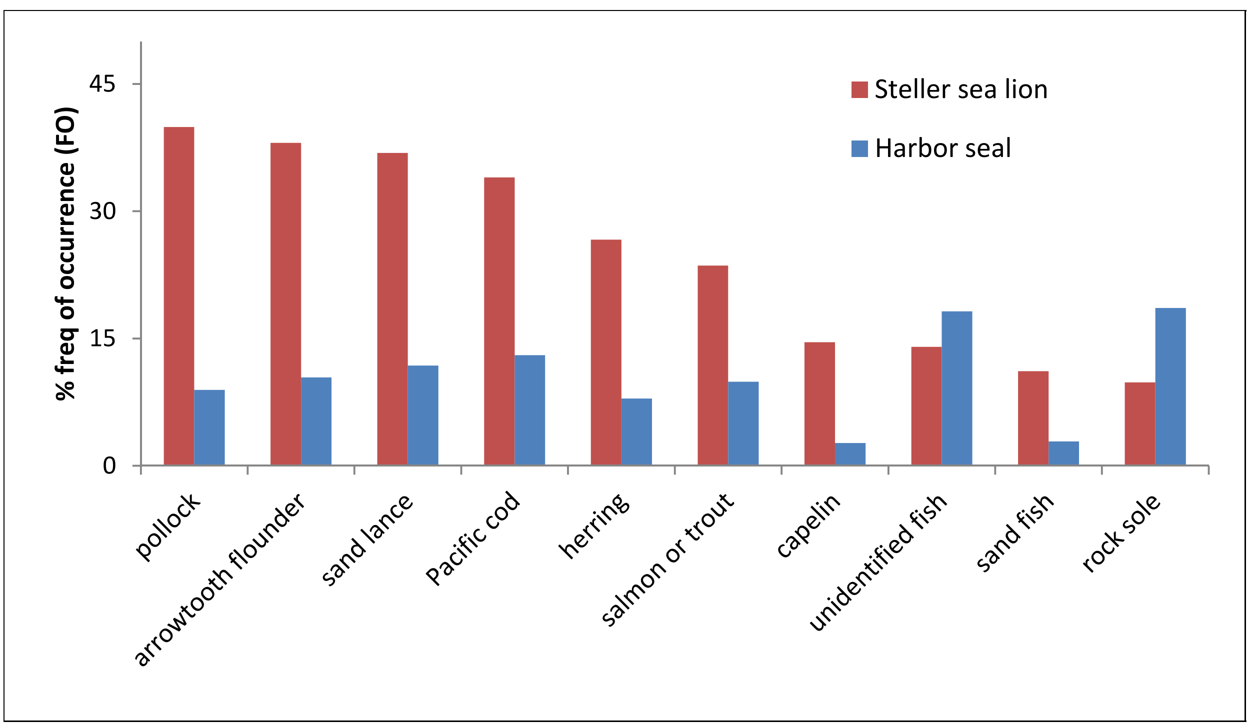

Figure 19. Frequency of occurrence (FO) of the top 10 ranked prey items found in 3369 Kodiak area Steller sea lion scats compared to their FO in 1565 Kodiak area harbor seal scats collected 2000-2009.