PROJECT SUMMARY

The Gulf Apex Predator-prey research program (GAP) was initiated in 1999 by University of Alaska Fairbanks faculty in Kodiak to address trophic-level questions of immediate biological and economic concern in the western Gulf of Alaska. From 2001-2006, GAP received annual Congressional appropriations through a NOAA grant to address Steller sea lion-driven questions and hypotheses regarding the interactive effects of environment, prey, competitors, and predators in the Kodiak region. Results from research conducted with NOAA funds appropriated in FY2004-06 (hereafter "GAP04-06") are summarized in this Comprehensive Report.

GAP04-06 consisted of numerous independent but integrated studies focused in the coastal waters northeast of Kodiak Island. This small geographic scale enhanced the logistic feasibility of seasonal surveying but provided insights into complex process issues of broader ecological and managerial concern. The Kodiak area was chosen for study because it has historically supported the North Pacific's largest Steller sea lion and harbor seal rookeries, numerous and productive seabird colonies, a commercial whaling station, long-term marine resource monitoring, communities dependent on commercial and subsistence fishing, and a port which has ranked among the nation's leaders in commercial fish landings for decades.

GAP04-06 data support the long-term monitoring of spatial and temporal changes in biotic and abiotic components of Kodiak’s nearshore environment. Spanning three years and augmenting prior (GAP01-03) datasets, GAP04-06 studies were able to document a high degree of inter- and intra-annual variability in prey resource availability and how this variability was manifested in the diet, habitat use, and/or productivity of Kodiak’s pinniped, baleen whale, and sea bird populations. While monitoring the structure and variability of Kodiak’s nearshore environment, GAP04-06 studies gathered data needed to examine the physical processes, energetic pathways, and physiological mechanisms that link its biotic and abiotic components. These data are key to understanding the variability and tropho-dynamic processes that influence Kodiak’s marine prey and their apex predators. Ultimately, taxa-specific information gathered in GAP04-06 will become input for multi-species modeling and ecosystem-level syntheses.
PURPOSE

The productive waters around Kodiak Island support diverse and abundant populations of marine fishes, birds, and mammals that in turn have supported coastal communities for centuries. GAP’s primary goal was to document trophic relationships among these apex predators, their prey and potential competitors in waters near Kodiak Island. Our primary objectives were to a) monitor the abundance, distribution, and quality of available prey resources, b) determine diets and monitor populations of sympatric consumers of these prey species, and c) monitor environmental conditions that affect these prey and their consumers.

Although originally addressing questions regarding Steller sea lion (SSL; *Eumetopias jubatus*) declines, GAP questions have broader managerial relevance as well. Ecosystem-based marine resource management relies on understanding both the structural components of the system and the functional mechanisms of their interactions. By monitoring the seasonal distribution and abundance of marine consumers and prey, GAP helped define their ‘habitats of particular concern’. By tracking oceanographic variability in relationship to zooplankton and fish populations, GAP explored effects of environmental change on primary and secondary production. As a multi-year study, GAP helped develop the time-series needed to forecast and predict effect of potential natural and anthropogenic perturbations. Ultimately, by considering predators and prey in terms of energetic content and their interactions as energetic exchange, data collected by GAP related research can be used to develop a holistic model of the Kodiak marine ecosystem.

OVERALL APPROACH

A fundamental feature of the GAP program is the integration of distinct but related hypothesis-driven research projects that explored processes that drive populations and their prey within a dynamic marine environment. Although focused on SSL concerns, GAP’s interrelated studies also broadly assessed the degree of temporal variability and dietary overlap among Kodiak’s sympatric apex predators. These studies overlapped spatially and temporally, allowing synchronous collection of environmental, predator, and prey data and synoptic assessment of their seasonal interactions.

Such an ambitious approach required a team of PIs to focus on specific program components. Kate Wynne was responsible for integrating marine mammal research objectives into GAP’s overall goals and coordinating integration with marine mammal-associated collaborators. She and Jane McKenzie, PhD were responsible for collecting and analyzing GAP’s pinniped data while Briana Witteveen, PhD coordinated and analyzed GAP’s cetacean research.

Robert Foy, PhD was responsible for coordinating the collection and analysis of GAP’s prey and oceanographic data. He also led GAP-related laboratory analyses of prey quality that was conducted with separate funding. Lei Guo, PhD and Andreas Winter, PhD assisted with the analysis of prey survey data and comparison to pinniped diets.

Loren Buck, PhD was responsible for coordinating and integrating seabird studies into GAP’s predator-prey studies and overall objectives. Dean Kildaw PhD and Andre Breton, PhD played key roles in the collection, analysis, synthesis, and publication of GAP’s seabird data.

The Approach, Methods, and Results for each specific objective identified within the ‘Mammal’, ‘Bird’, ‘Fish’ and ‘Human’ components of GAP04-06 are summarized and presented separately in the text below.
I) MAMMALS
   A) Steller Sea Lions
      i) OBJECTIVES
         (a) Terrestrial habitat use
             (1) Estimate seasonal abundance and distribution of SSLs on 14 terrestrial sites in the Kodiak Archipelago.
             (2) Document sea lion movements among haulouts by recording presence of branded animals.
         (b) Diet
             (1) Assess the relative size, diversity, and frequency of occurrence of prey in the diets of Kodiak SSLs.
             (2) Compare relative regional and seasonal importance of prey species in the Kodiak Archipelago.
             (3) Compare seasonal prey use to prey availability determined in GAP prey surveys.
             (4) Compare seasonal diets of Kodiak SSLs to those diets of sympatric piscivores and SSLs found southeast Alaska and elsewhere.
             (5) Monitor long-term trends in sea lion diets.
         (c) Protracted Weaning
             (1) Document the number of known-aged SSLs seen on Long Island and other Kodiak area haulouts.
             (2) Document the number of suckling animals and their approximate age and photograph all branded animals.
      ii) APPROACH
         (a) Terrestrial habitat use

SSLs are known to make regular and traditional use of certain terrestrial sites, or haulouts, throughout their range for resting. Traditional haulout sites – whether used seasonally or year-round- are identified as terrestrial components of Critical Habitat for SSLs (50 CFR 226.202). Use of these sites by sea lions varies seasonally throughout Alaska. Some studies have found that age and sex-specific use patterns and seasonal movements are associated with the reproductive status of animals (Call and Loughlin 2005, Ban and Trites 2007). Other studies have found strong links between haulout use patterns and the seasonal availability of ephemeral but abundant or energy dense prey species (Womble and Sigler 2006, Sigler et al. 2009, Winter et al. 2009, Womble et al. 2009). Therefore, assessing seasonal and regional patterns of haulout use may reflect exploitation of foraging opportunities by these central-place foragers (Raum-Suryan et al. 2004) and further describe use of terrestrial components of their critical habitat. In this study we used a combination of aerial surveys and brand resights to document the relative and seasonal importance of 12 haulout sites in the Kodiak Archipelago that were listed as Critical Habitat sites for SSLs (50 CFR 226.202).

(1) Seasonal abundance and distribution of SSLs on Kodiak Area haulouts

Methods: Aerial surveys were conducted monthly or quarterly from a fixed-wing floatplane (Cessna 206 or DeHavilland beaver) flown at an altitude of approx. 600ft, following standard National Marine Mammal Laboratory (NMML) survey methodology (Loughlin et al. 1992). We photographed and visually estimated sea lions present at 12 designated critical haulouts (50 CFR 226.202), as well as add two additional sites, Dog Bay Harbor and Chief Cove (Figure M1). All animals visible were later counted from digital images and recorded for each site. Monthly comparisons were made of sea lion counts on each haulout, without attempting to correct for animals not hauled out. In addition, the location and number of SSL observed swimming or in “rafts” in Uganik, Viekoda, and Kizhuyak Bays were plotted relative to apparent fish aggregations and other marine mammal species. Overall trends in sea lion numbers and distribution within the Kodiak archipelago were assessed by comparing counts on each of 13 sites (we did

Results and Conclusions: A total of 17 aerial surveys were conducted from Jan 2004-Dec 2006 (Table M1). Two major breaks in survey effort occurred during this study due to NOAA-mandated circumstances beyond our control (see “Problems” below). This loss of survey effort makes valid statistical comparisons over the two years of this study and with previous surveys difficult. However several trends in SSL abundance and distribution within the study area are suggested by comparing maximum and multi-year mean counts on 13 haulouts surveyed 2004-2006 to those on the same sites using the same methodology from 1999-2003 (Wynne 2005) (Figure M1). Both multi-year maximum and mean counts showed stable or slight downward trends on the majority of haulouts with the exception of two eastern sites (CB, TH) that showed modest increases. Opposite trends in these indices were noted for Long Is. (LI) and Marmot Is. (MA) where the maximum number of sea lions on the sites decreased (Figure M2, A) even though the multi-year mean count increased (Figure M2B). This conflicting result may relate to bias introduced by the mandatory survey shutdowns that occurred during months when maximum counts are typically found on these sites. During aerial surveys we recorded the location and number of SSL observed swimming or in “rafts” in the vicinity of apparent fish aggregations. During the 2004-2006 surveys no such sea lion aggregations were observed in Uganik, Viekoda, or Kizhuyak Bays.

The use of traditional terrestrial habitat by sea lions was found to vary seasonally, as evident when results from haulout surveys conducted from 1999 to 2006 were combined (Figure M3). MA is the only major (recognized) rookery within the study area although newly born pups have been observed on Two-Headed Island as well. In the non-breeding season, MA is used for resting and other non-breeding activities, as are the rest of the Kodiak area haulouts. The seasonal shift in use is seen as the numbers on MA peak June–Sept during the breeding season and reach minimums in mid-winter when many mother/pup pairs leave the site (Figure 3M, A&C). Conversely, SSL numbers on LI haulout, approx. 30 nm to the south, peak in the winter and decrease drastically during the summer. The assumption that much of this shift is due to female sea lions moving to LI with their pups after the breeding season is substantiated by winter observations on LI of individual pups that were born or branded the previous summer on both MA and Sugarloaf Rookeries (see Section IAiia2.). Although individual branded sea lions have been observed using both LI and Cape Chiniak (CH) haulouts (approx. 10nm south), LI is used by more animals in winter than CH (Figure 3MA), possibly due availability of prey resources for females (Winter et al. 2009) and/or to its sheltered waters and southern-exposed rock ledges- characteristics that would benefit pup security.

To the north and west of MA, sea lions use two major haulouts at Sea Otter Island (SO) and Latax Rocks (LA). Peak numbers on LA and SO occur mid- to late summer in synchrony or just after those on MA (Figure 3MC). Immediately following the breeding season the majority of sea lions using SO are adult bulls while more females with pups use this haulout during winter. In the summer, waters surrounding SO and LA support a high biomass of capelin (*Mallotus villosus*) and scats collected on these sites (see Section IAiib3) suggest sea lions may also use these sites in summer months while exploiting this seasonally abundant and energy-rich prey resource. Seasonal use patterns on these sites appear to reflect both reproductive and foraging opportunities for SSL.

Seasonal patterns of use seen on Kodiak’s three western haulouts (Figure 3MB) may reflect physical site characteristics as well as seasonal changes in nearshore prey resources. At Cape Ikolik (IK), sea lions haulout on narrow ledges on steep rock pinnacles that are often awash in storms and strong seas. Although rarely used by large numbers of animals, its use is consistently lower in winter when the site is often awash.
Seasonal patterns of use on Cape Ugat (CU) and Chief Cove (CC) – which offer dry sheltered haulout substrate year-round – are more likely related to seasonally available prey resources. Peak use of CU occurs in late winter-early spring (Figure 3MB) when pre-spawning and spawning Pacific herring schools aggregate in western Kodiak bays. The dominance of herring in CU scats in spring (see Section IAiib) confirms they exploit this seasonally abundant and energy-dense prey resource. Sea lion counts on CU decrease through summer while counts simultaneously increase at nearby CC haulout (approx. 11 nm south). As CC is only used in summer months, it is likely sea lions shift from CU to CC while exploiting summer salmon runs and, specifically, scavenging salmon caught in commercial set gillnets in the area. It is noteworthy that, despite the substantial physical distances between Western, Northern, and Eastern haulouts, SSLs can transit between these without leaving sight of the shoreline, a benefit for young SSLs (Raum-Suryan et al. 2004).

Problems: Two NOAA-related issues arose during this project that affected our ability to conduct SSL research and, specifically, impaired our ability to complete this objective as originally proposed. In December 2004, NOAA’s VADM Lautenbacher issued an aircraft safety “stand down” during which no NOAA employee or NOAA-supported project was allowed to conduct research from non-NOAA aircraft without review and specific authorization by NOAA’s Office of Marine and Aviation Operations (NMAO). Because GAP is a NOAA-funded project, we were obligated to apply for a NMAO exemption and had to postpone our fixed-wing surveys of SSL distribution and abundance scheduled between December 2004 and June 2005 until an exemption was granted (June 2005). Then in June 2006, all SSL research activity nationwide was suspended by a federal court-ordered vacation of the Scientific Research Permit under which we conduct SSL research. Consequently, we were unable to conduct aerial surveys from June to September 2006. Although this resulted in the irreplaceable loss of survey opportunities, we attempted to compensate for the shortfall in survey effort by combining 2004-06 results with prior survey results (1999-2003) to elucidate trends individual haulouts and throughout the study area.

(2) SSL movements among haulouts by recording presence of branded animals

Between 1988 and 2004, NMFS and the Alaska Department of Fish and Game (ADFG) researchers branded over 4400 SSL pups on their Alaskan rookeries of birth, allowing the identification and tracking of known-aged individuals over time. Of these, over 1000 were pups born on the two rookeries in the Kodiak area, Marmot Is (n=671) and Sugarloaf Is (n=366). As one means of monitoring the relative importance of individual terrestrial haulouts to SSLs in the Kodiak area, we recorded the presence of individual branded animals during both dedicated and opportunistic observations on area haulouts.

Methods: Using a helicopter as transport for scat collections, we were able to approach several haulouts on land in such a way as to avoid detection by the sea lions present. This approach was possible regularly on SO, LA, and LI and occasionally on MA, CU, and TH, allowing opportunistic scanning of the herd and photographing of branded animals prior to scat collection. The LI haulout proved to be the easiest to approach undetected and also the closest and most accessible site from the city of Kodiak. Because we could reliably observe branded SSLs there without disturbing animals on the site, we made dedicated land-based brand resight trips (3-6hrs duration) to LI sporadically through 2008 and with greater regularity through May 2011. During both dedicated and opportunistic resight opportunities, digital photographs were taken of all branded animals when possible and their general behavior, parental/maternal association, and activity were recorded. During the course of this study, we also received reports and photographs of branded sea lions from charter operators and other researchers in the area. These data were included in our data set only if accompanied by photographic verification. Copies of all data and photographs were shared with NMML.
and ADFG personnel responsible for archiving brand resight data for these agencies. Because the primary value of permanently marking animals is in tracking known-aged individuals over time, results presented here include all brand resighting data collected from December 1999-May 2011.

**Results and Conclusions:** Our SSL brand resighting efforts were primarily land-based. The date, location, and number of branded SSLs observed during both dedicated and opportunistic resighting efforts from 2004 to May 2011 are summarized in Table M2. Two-thirds of the observations of branded sea lions were made by land-based observers present on LI during trips designed specifically in search of branded or radio-tagged individuals. Another 25% of branded animals were observed by land-based observers present on haulouts prior to the collection of scats. Only about 9% of brand resights in our records were made by volunteers who photographed branded animals while passing near haulouts in motor vessels.

The alphanumeric brand applied to SSL in Alaska indicates the year and rookery of the sea lion’s birth. Although the majority of branded sea lions observed in this study were born on Kodiak area rookeries (T brands from Marmot Is., X brands from Sugarloaf), resights of sea lions branded on rookeries in southeast Alaska (F, H, W brands), Russia (M, P) and Prince William Sound (E) were also observed on Kodiak haulouts (Figure M4).

The majority of branded SSLs observed in this project were young-of-the-year (YOY) and were sighted in the months following their birth and branding on Marmot and Sugarloaf Island rookeries (Figure M4). The number of Marmot-born brands decreased rapidly after the first year but increased somewhat at age 5-6, perhaps when animals were returning to or using this area as adults. During the subadult years (age 2-6 years), when SSLs often make extensive movements away from their natal area (Raum-Suryan et al. 2004), local (T and X) brands were less frequently seen but observations of SSLs born/branded on SE Alaskan rookeries were more frequent. The few (n=6) animals seen that were greater than 10 years old were branded on Marmot in the late 1980’s, which is expected since it was the only site of pup branding of SSLs prior to 2000.

To assess regional patterns of haulout use by known-aged animals, we looked at resights thru 2007 only, the years in which we were observing animals on multiple sites during scat collections. Haulouts where branded animals were seen were grouped for regional comparisons into Northern (LA, MA, SO), Eastern (DB, LI, CH) and Western (CC, CU, Uyak Bay, Uganik Bay). Marmot-born SSLs (T brand) were observed on haulouts throughout the study area, but most frequently (63%) on Eastern haulouts and exclusively on Eastern sites approximately 47% of the time. The distribution of Sugarloaf-born SSL (X brand) resights was more evenly spread among Western, Northern, and Eastern haulouts (Table M3) but only 7% were seen on haulouts in more than one region (Table M3).

**Problems:** A federal court ordered vacation of all SSL research permits (June 2006-Sept 2006) prevented NMFS/MML from branding SSLs in 2006. Because that was the year NMML planned to brand pups on Marmot and Sugarloaf rookeries, there were no “local” Kodiak area young-of-the-year (YOY) branded SSLs to observe in 2006. We requested and received a No-Cost Extension to enable us to renew our resighting effort when branding on Marmot/Sugarloaf resumed (2008, 2010). Our regional assessment of haulout use in the study area ended in 2007 when cessation of scat collection reduced subsequent opportunities to observe branded animals on most Kodiak haulouts. Residual funds were used to support helicopter transport to LI haulout periodically through May 2011 to collect land-based brand resights.

**(b) Diet**
Documenting the diet of SSLs is fundamental to testing the “prey limitation hypothesis”, assessing the potential for competition between SSLs and commercial fisheries, and determining the seasonal and regional overlap with other consumers of common prey resources. We used fecal samples (“scats”) to monitor diet diversity and the seasonal and regional importance of prey species to SSL throughout the Kodiak region. Despite acknowledged limitations and biases (Olesiuk et al. 1990a, Gales and Cheal 1992), scats represent a “reasonable index of prey field sampled by foraging sea lions” (Merrick et al. 1997). Because diet diversity has been correlated to SSL population health and trends (Merrick et al. 1997), it is critical to monitor the diversity of sea lion diets in the Kodiak area where the rate of recovery has been slow (Fritz et al. 2008).

Methods: Pinniped scats have been collected on Kodiak area haulouts since 1999 (Figure M5). From 2004-2006, we made 8 scat sampling trips to five Kodiak area SSL haulouts and collected 1040 scats. Individual scats were subsequently rinsed to recover identifiable hard parts (eye lenses, otoliths, vertebrae, cephalopod beaks, and scales) that pass through the digestive tract. Dried remains were identified by Pacific ID (Victoria, BC) to lowest possible taxon and characterization of prey size class. The species, number, and relative size of prey (when possible) contained in each scat were used to calculate a simple frequency of occurrence (FO), relative occurrence (RO), and relative abundance (RA) seasonally on regional haulouts, as detailed in McKenzie and Wynne (2008).

Results and Conclusions:

(1) Assess the relative size, diversity, and frequency of occurrence of prey in the diets of Kodiak SSLs

In McKenzie and Wynne (2008), we reported on the analysis of over 2700 scats with identifiable prey collected from haulouts surrounding Kodiak Island from 1999 to 2005. Of 76 prey types identified using hard remains, the most important species in terms of frequency of occurrence and numerical abundance were Pacific sand lance, walleye pollock (Theragra chalcogramma), arrowtooth flounder (ATF; Atheresthes stomias), Pacific cod (Gadus macrocephalus), Pacific salmon (Oncorhynchus spp.), and Pacific herring. The size range for each prey item is detailed in McKenzie and Wynne (2008). The gadids (pollock and cod), flatfish, and salmon are all pelagic and/or demersal species. The two commonly consumed forage fish species, sand lance and herring are found in locally aggregated pelagic schools.

The additional analysis of scats collected through 2006 confirmed these six prey species as dominant in the diet of Kodiak’s SSLs. However, it should be noted that 80 prey species were identified in these scats and that rock soles and sandfish were also found to be significant prey (found in >10% of scats) prey (Figure M6).

(2) Compare relative regional and seasonal importance of prey species in the Kodiak Archipelago

Spatial and temporal variation in the diet of Kodiak area SSLs were investigated using scat samples collected from haulouts in four regions in the Kodiak Archipelago (McKenzie and Wynne 2008). Significant differences in diet composition were found among regions, seasons, and years, suggesting that the diet of sea lions is strongly influenced by local and temporal distributions and abundances of prey. Herring dominated scat collections from the west coast and accounted for most (14 to 30%) of the differences in regional diet in spring and winter. Although capelin was not a dominant prey item on an annual basis, SSLs using Northern haulouts made almost exclusive use of them when available. Annual variation in diet was relatively low in winter, whereas
spring and fall diets varied from year to year, with regional-specific shifts in dominant prey (McKenzie and Wynne 2008).

(3) Compare seasonal prey use to prey availability determined in GAP prey surveys

We found that Kodiak area sea lions appear to exploit seasonally abundant prey resources when available (McKenzie and Wynne 2008). The noted seasonality of capelin and herring in Kodiak area SSL scats was found to coincide with the relative seasonal abundance of those species near regional haulouts. Capelin abundance in coastal surveys showed profound seasonality, from millions of individuals per square kilometer in August to being rarely encountered in November. The largest aggregations were encountered in the northeast side of the Archipelago, or the “North” region. Because capelin in the Gulf of Alaska spawn between mid-May and late July (Pahlke 1985, Doyle et al. 2002) and none of the examined specimens were at the stage of pre-spawning or spawning, these capelin aggregations were probably attracted by favorable oceanographic conditions and high zooplankton prey availability. During daylight hours, most of capelin aggregated at depths between 70 to 130 m. Among pelagic fishes in the region, capelin was the species of the highest abundance and of either the highest or the second highest (following walleye pollock) biomass. The largest aggregations of Pacific herring were encountered in the west side of the Archipelago in surveys conducted from November to April. These pre-spawning and spawning aggregations occupied relatively shallow waters in bays (typically less than 100-m deep) and were of higher abundance and biomass than other pelagic fish species. Furthermore, pre-spawning and spawning herring was relative rich in lipid compared to all forage fishes, which makes them better prey energetically for predators at upper trophic levels.

We assessed the relative importance of prey availability to SSL use of terrestrial habitat by comparing their seasonal occupation of a Kodiak area haulout and rookery to the availability and quality of prey near those sites, as determined by GAP prey surveys (Winter et al. 2009). Using prey surveys conducted in May and November of 2002 (just before and after the breeding season), we found significantly higher prey energy density (total fish biomass density × energy content; kJ/nmi²) around the LI haulout than around the MA rookery. A similar survey conducted in July of 2002 (during breeding season) showed prey energy densities that were not significantly different between LI and MA but that were more concentrated in a single area by MA. Major prey species groups in all surveys were ATF, walleye pollock, cod, and soles; all are known prey of SSLs in this area. SSL counts at LI during nonbreeding seasons from 2000 to 2004 correlated significantly with midwater prey energy densities. SSL counts at MA over the same period were not correlated with midwater prey energy densities in either breeding or nonbreeding seasons. The results of the study indicate that prey availability may be an important factor in the choice of haulout sites by SSLs.

(4) Compare seasonal diets of Kodiak SSLs to those diets of sympatric piscivores and SSLs found southeast Alaska and elsewhere

The diversity and composition of Kodiak SSL diets is similar in many respects to that documented for SSLs in Southeast Alaska (SEAK) (Trites et al. 2007) and previously in the Gulf of Alaska (Merrick et al. 1997, Sinclair and Zeppelin 2002). Key prey species include gadids (walleye pollock, Pacific cod), flatfish (ATF and soles), salmon, and a variety of forage fish including herring, capelin, and sand lance (Figure 5A). As reported for SSL in SE Alaska (Sigler et al. 2009), Kodiak SSLs tend to supplement year-round pelagic prey resources, such as walleye pollock, with seasonally abundant and energy-rich schooling prey, such as herring and capelin. But the major SSL prey species found in Kodiak differ markedly in their relative importance, with Pacific sand lance found in nearly as many scats as pollock and rockfish and Atka mackerel being insignificant diet items (Figure 5A; McKenzie and Wynne 2008).
Among Kodiak’s sympatric piscivores, the harbor seal (HS, *Phoca vitulina richardsi*) is most likely to have the greatest degree of dietary overlap with SSLs. Both have incredibly diverse diets and the top ten most frequently occurring prey items in Kodiak SSL scats clearly include many key prey species also found in Kodiak HS diets (Figure M5A). Although the diets of these pinnipeds clearly overlap, the relative significance (% frequency of occurrence, FO) of key prey species differed for HSs and SSLs. Dominant prey of SSLs generally include pelagic or demersal schooling species while the dominant prey of HS tend to be benthic or demersal non-schooling species such as Irish lords and greenling (Figure M5B).

To assess the degree to which diets of these sympatric pinnipeds overlap, we compared the relative abundance (RA: proportion of the total number of prey items made up of each prey type) of prey species in HS and SSL scats collected from the same regions and seasons. Difference in scat composition between HS and SSL was tested by permutation-based analysis of similarity (ANOSIM) using the ANOSIM routine in PRIMER (version 6, PRIMER-E Ltd). The ANOSIM test statistic, R, was computed for each pair of sample groups (HS vs. SSL) and then was used to calculate a p-value. If there is no difference between the two groups compared, R will be near zero. The level of significance is computed by the number of permutations giving an R value as large, or larger, than the observed R divided by 999 (set as the total number of permutation) (Table M4). Although the size of some *region x season* samples was limited, the greatest amount of dietary overlap between HS and SSL (where p>0.001) was found year-round in Western Kodiak scats and on Northern sites in the summer (Table M4).

In the *region x season* samples with greatest HS/SSL diet overlap, the most frequently consumed prey were species found to be seasonally abundant in those regions. Capelin was found in 60.4% of HS and 25.6% of SSL samples collected in summer on Northern sites. On Western sites, herring were found in 61.1% of HS and 43.7% of SSL samples collected in spring; salmon were found in 60.6% of HS and 26.1% of SSL samples collected in summer; sand lance were found in 22.9% of HS and 15 % of SSL collected in fall; and herring were found in 41.7% of HS and 22.1% of SSL samples collected in winter (Table M5).

Other upper level consumers share Kodiak’s prey resources with these pinnipeds. ATF are among sympatric predatory fish known to consume key prey of SSLs, including juvenile walleye pollock, capelin, (Yang 1995, Yang and Nelson 2005), and sand lance (Knoth and Foy 2008). ATF’s also appear to opportunistically exploit abundant prey resources, as evidenced by inter- and intra-annual shifts in diet and foraging behavior (Knoth and Foy 2008). Because ATF are currently the most abundant groundfish in the Gulf of Alaska, with a biomass of over 2 million metric tons (Turnock et al. 2005), there is potential for their dietary overlap with pinnipeds to become competitive if communal prey resources become limited.

Problems: The NOAA-mandated aircraft stand down and court-ordered vacation of the SSL research permit prevented us from accessing SSL haulouts to collect scats during four of the 12 quarterly scat collections planned from 2004-2006. Because GAP’s SSL diet methodology has been consistent over time however, we were able to address many of the project objectives by combining 2004-2006 scat data with those collected previously (1999-2005).

(5) Monitor long-term trends in sea lion diets.

Determining the diet of SSLs is key to understanding the potential for them to compete with other apex predators in the system (including commercial fishermen),...
should resources become limited. Because SSLs are known to opportunistically exploit abundant prey resources, future GAP studies should maintain periodic (quarterly) scat collections as a means of monitoring SSL diet resulting from changes in their prey base and environment.

(c) Protracted Weaning

Until recently, SSL pups were believed to wean during their first winter after birth. Data gathered from satellite-tagged and branded individuals, however, suggest that weaning may occur throughout the winter and spring after birth (as 6-12 month olds) and into subsequent years (Trites et al. 2006). Because it has been hypothesized that pups may be forced to rely on maternal nourishment longer (i.e., wean later) when adequate prey is difficult to obtain independently, it is important to monitor the weaning chronology of known-aged animals.

The effort by NMFS and ADFG to brand SSL pups on the rookery of their birth allowed us to subsequently monitor the behavior of known-aged animals during land-based observations on haulouts in the Kodiak area. During dedicated and opportunistic visits to haulouts in the Kodiak Archipelago, we have seen (at least once) 135 of the 434 (31.1%) pups branded on Marmot Island and 51 of the 559 (9.1%) pups branded on Sugarloaf since 2000.

(1) Document the number of known-aged SSLs seen on Long Island and other Kodiak area haulouts

Age at first reproduction: Branded females seen nursing their pup provided information on the onset of breeding and reproductive longevity of known-aged SSLs. Six females that were born and branded on MA were seen nursing a pup on LI haulout in subsequent years. Female T53 was seen nursing a pup in 2 different years, when she was 5 y.o. and 8 y.o. Three females (T124, T243, and T270) were seen as 6 year-olds nursing a pup on LI. Two other females were seen nursing a pup at 7 (T101) and 8 (T116) years of age. Because gestation takes approximately one year, the youngest of these mothers (T53) successfully bred at four years of age.

Natural Mortality: Two branded pups were found dead on area haulouts. Pup T106, born and branded on MA in June 2000, was found dead on Marmot in September 2000 from apparent SSL-inflicted trauma (multiple tooth marks, etc.). Pup X18, born and branded on Sugarloaf Island in June 2000 was found dead on LA haulout in Dec 2000, after becoming wedged between boulders on the haulout. Although absence from observation does not necessarily equal pup mortality, through 2008, 51 T-branded and 11 X-branded pups were never seen after their first year of life (YOYs), including the 2 mortalities mentioned above.

Longevity: To date, the oldest branded animal we have observed was 18 years old when observed on SO haulout in December 2005.

(2) Document the number of suckling animals and their approximate age and photograph all branded animals

Results and Conclusions: The size of young-of-the-year (YOY) pups was found to be so variable that we felt visual assessment of the age (YOY status) of non-branded animals was unreliable. Therefore, we only recorded suckling behavior of known-aged (branded) animals. During land-based observations, we documented the number of suckling animals and photographed all branded animals. Of 37 branded (known-aged) sea lions observed actively suckling to date, 35 (94.6%) were 5-11 mos old, one was 21.5 mos old and the oldest was 29 mos old (assuming born on 1 June). It is impossible to discern
whether a lone or sleeping pup is weaned or merely waiting for its mother to return from foraging, so calculating the age of weaning is not possible with periodic observation alone. Conversely, it is clear that at least two of the branded pups observed did not wean after their first year of life: one would be at least 2 and the other at least 3 years old if weaning the following May.

Problems: The NOAA-mandated air charter stand down (Dec 2004-July 2005) and court ordered vacation of SSL research permits, reduced our opportunity to access haulouts for land-based observation of branded animals. We requested and received a no-cost extension to continue brand-resight effort after branding and other operations were allowed to resume.

B) Harbor Seals

i) OBJECTIVES
   (a) Compare relative importance of prey species recovered from HS and SSL scats collected on juxtaposed sites.
   (b) Collaborate with ADFG in monitoring the trend of seal abundance within the Kodiak Archipelago. (2004 only)
   (c) Synthesize seal dive data collected in 2003 and compare to dive profiles of SSLs recorded by NMFS/NMML within the LICH study area.

ii) APPROACH

   HSs are pinnipeds whose diets are diverse, often reflect regional and seasonal availability of prey, and include many species also eaten by SSLs (Pitcher 1980, Sheffield et al. 1997, Jemison 2001). HS numbers declined more than 80% in western Alaska in the 1970’s and 1980’s, coinciding with noted declines in SSL numbers (Pitcher 1990). Unlike the slow recovery of SSL numbers in the Kodiak area, the number of HSs on eastern Kodiak haulouts has increased by as much as 5.6% annually from 1994-1998 (Small et al. 2003, Jemison et al. 2006). The overlapping diets but disparate rates of recovery from severe decline exhibited by these two sympatric pinniped populations raise questions regarding the potential for prey to be limited for SSLs. With this degree of overlap in diet composition and diversity, it would be reasonable to assume that growth in sympatric HS and SSL populations would have similar direction and trajectories as prey availability changed. The fact that HS numbers have increased since 1993 while SSL numbers have continued to decline in the Kodiak region suggests 1) the availability of prey is limited for SSLs but not HSs or 2) factors other than prey availability are regulating these pinniped populations in the Kodiak area. To explore the degree to which seasonal diets and foraging habits of HSs and SSLs overlap within the Kodiak Archipelago, we used a combination of scat analysis and dive-depth monitoring.

   (a) Compare relative importance of prey species recovered from harbor seal and SSL scats collected on juxtaposed sites.

Methods: We identified neighboring HS and sea lion haulouts within 3 Kodiak regions from which to collect scats on a quarterly basis 2004-2006 (Figure M5). Scat content indices have been shown to provide useful dietary information, given adequate sample sizes (Olesiuk et al. 1990b, Sinclair and Zeppelin 2002, Trites and Joy 2005). We attempted to access both HS and SSL sites in each region on the same day to compare prey use by these sympatric piscivores, assuming foraging by individuals on neighboring haulouts would have the greatest potential for overlap. Handling and processing methodology is described above (SSL objective 2). We tabulated and compared the frequency of occurrence of each prey item recovered from HS scats to those recovered from SSL scats to measure and compare the relative importance of prey items to these pinnipeds.

Results and Conclusions: From 2004-2006, 404 HS and 940 SSL scat samples were collected during eight sampling trips and stored frozen; they were subsequently
processed and analyzed during GAP 2008 (NOAA Grant NA08NMF4390533). Results of the Kodiak pinniped diet comparisons are detailed in the Final Report for the GAP 2008 project. To summarize those key findings:

- The diets of Kodiak HS and SSL are diverse, consuming many of the same prey species but with differing intensity.
- Kodiak HS diets: 36 different prey species were present in >1% of HS scats, 17 prey items were found in >5% of scats, and 6 prey species were found in >10% of HS scats (in order of FO: Irish lords, rock sole (*Lepidopsetta bilineata*), greenlings, Pacific cod, sand lance, and ATF).
- Kodiak SSL diets: 29 prey species were present in >1% of SSL scats, 14 prey items were found in >5% of scats, and Kodiak SSL diet was dominated by 6 prey items that each occurred in >23% of the scats with identifiable remains (in order of FO: Walleye pollock, ATF, sand lance, Pacific cod, herring, and salmon).
- Pacific sand lance, Pacific cod, and ATF are key prey items for both HS and SSL and were found in >10% of HS and SSL scats.

Problems: The problems associated with NOAA-mandated and court-ordered impediments to our scat collection efforts from 2004 to 2006 are detailed above in the SSL section. In addition, we found that collecting an adequately large sample of HS scats proved problematic. In the Kodiak region, SSL scats are typically substantial in size and deposited on bedrock/boulder haulouts. HS scats however are often fairly fluid and deposited primarily on sand beaches. Because scats that filtered into the sandy substrate were unusable, our sample of HS scats was always smaller than SSL scats during any collection. With small sample collections, we were unable to make direct site-to-site comparisons of HS and SSL prey use as originally proposed. To compensate for small per-collection samples sizes, we pooled diet data for each species by season in each region. Capitalizing on GAP’s longevity and collaboration with ADFG, we further strengthened our analyses by including HS scats collected in the Kodiak area by GAP or ADFG personnel outside our proposed 2004-2006 collection period. Including only the scats that contained identifiable remains, the combined dataset included 1565 HS scats and 3369 SSL scats collected 2000-2009 on haulout sites of the Kodiak Archipelago (Figure M5). A total of 1565 HS and 3369 SSL scats were collected on Kodiak area haulouts 2000-2009.

(b) Collaborate with ADFG in monitoring the trend of seal abundance in the Kodiak Archipelago

Wynne has collaborated with HS researchers of ADFG and NMML since 1993 in their efforts to document the abundance and distribution of HS numbers in the Kodiak Archipelago and monitor their population trend over time (Small *et al.* 1997)

Methods: During this project we continued this collaboration by conducting a series of replicate aerial surveys of HS haulouts on the east side of the Kodiak Archipelago in August 2004. These surveys, conducted during the seals’ annual molting, followed standardized survey protocol on sites included in ADFG’s HS Trend Route. Seals were counted from 35mm photographs taken of their haulouts.

Results and Conclusions: Four complete surveys of the Kodiak Trend Route were completed August 20-25, 2004. The daily total count of seals on these sits ranged from 4,556-6,915 and averaged 5,809 individuals. The raw data, daily counts, and photos were submitted to ADFG and NMFS for inclusion in their HS stock assessments.

(c) Synthesize seal dive data collected in 2003 and compare to dive profiles of SSLs recorded by NMFS/NMML within the LICH study area
Methods: In 2002 and 2003, we collaborated with ADFG in the capture and tagging of HSs on Middle Island, approx. 15 km southwest of Long Is SSL haulout. Details of that effort and results are presented in the GAP 2001-2003 final report (Harper and Wynne 2005). To summarize those key findings:

- Dive data were collected from five functional time-depth recorders (TDRs), one adult (and pregnant) female (March-July 2003) and four males (1 sub-adult and 3 adults, mid-October 2002 to mid-February 2003).
- Mean dive depths of seals in this study were shallow: both sexes spent most their time and dives in water <50m deep. The maximum dive depth recorded was 218m for the female and 274m for one of the males.
- Mean and max dive depths and durations recorded for the five seals varied:
  - 1 female, pregnant adult (26,476 individual dives): overall maximum dive depth was 218m but her AVERAGE maximum depth within a dive series was only 24m. Longest dives were made in shallowest depth bin (3-20m) and the use of shallow waters increased.
  - 4 males (113,247 individual dives): Two males dove deeper than 200m while two never dove deeper than 65m. The sub-adult male made consistently deeper dives than the adult males.

Results and Conclusions: Mean dive depths of seals in this study were shallow: both sexes spent most their time and dives in water <50m deep. This finding is consistent with dive depths previously recorded in Kodiak, where 94.7% of dives recorded were <50m (Hastings et al. 2001).

To date, dive data from SSLs tagged near Kodiak by NMFS have not been analyzed and/or available, preventing our direct comparison with Kodiak area HS dives as originally proposed. However, there was considerable overlap between our HS dives and those recorded for SSLs throughout Alaska. On average, the maximum depths to which our seals dove were similar to maximum depths reported for SSLs elsewhere in Alaska. Loughlin et al. (2003) found that SSL pups (7-10mos) in Alaska were capable of diving to 252m but that their mean maximum dive depth was 25.7m. Yearlings had a maximum dive depth of 288m but on average they dove to maximum depths of 63.4m (Loughlin et al. 2003). Adult females tracked in summer were found to dive to median and maximum depths of 21m and 150-250m, respectively; those tracked in winter dove deeper and longer (Merrick and Loughlin 1997). Sea lion dive depths were found to increase with age as their proficiency and physical capacity increased (Pitcher et al. 2005).

C) Baleen Whales
   i) OBJECTIVES
   The productive waters of the Kodiak Archipelago support seasonal and year-round foraging by a large but undocumented number of piscivorous whales, including fin (Balaenoptera physalus), humpback (Megaptera novaeangaliae), minke (Balaenoptera acutorostrata), and resident killer whales (Orcinus orca). To determine the role of these apex predators and their potential for competition with SSLs and other consumers, we need reliable species-specific estimates of their seasonal abundance, diet composition, and biomass consumption.

   (a) Abundance and distribution
   (1) Document the year-round presence and distribution of cetaceans observed during monthly aerial surveys of the study area
   (2) Document the number, behavior, and location of cetaceans with dedicated vessel surveys in Chiniak and Marmot Bays, May to September 2004-06
   (3) Collect identification photographs of humpback whales near Kodiak Island as a means of tracking movements of individual whales, generating a regional abundance estimate and monitoring feeding site fidelity
(4) Synthesize data gathered from 1999-2006 aerial and vessel surveys to define the seasonal distribution of cetaceans within northeastern Kodiak Island waters and their correlation to oceanographic and biological habitat parameters.

(b) Diet composition and consumption

(1) Determine dive depth targeted by foraging whales by acoustically tracking tagged whales while concurrently identifying prey fields through mid-water trawl and hydroacoustic sampling.

(2) Biopsy fin and humpback whales feeding in Kodiak waters and analyze the ratio of stable carbon and nitrogen found in their skin as a means of assessing their relative trophic position, diet, and origins.

ii) APPROACH

(a) Abundance and distribution

(1) Document the year-round presence and distribution of cetaceans observed during monthly aerial surveys of the study area.

Methods: Systematic aerial surveys were conducted to monitor the seasonal use of haulouts by SSLs. During these surveys, opportunistic sightings of cetaceans were documented. For each sighting, the species (if able to determine), location (latitude and longitude), number and general behavior were documented. Cetaceans were sighted during surveys conducted in March through September 2004, June, October and December 2005, and March, September and December 2006.

Results and Conclusions: Though cetacean sightings documented during aerial surveys were opportunistic, at least one cetacean was sighted in each of 13 surveys conducted between 11 March 2004 and 11 Dec 2006 and a total of 700 individuals were sighted (Table M6). Humpback whales accounted for the most sightings, followed by fin whales, gray whales and killer whales (Table M6; Figure M7). The peak number of sightings occurred in the late summer and early fall (Figure M7). The exception was the sighting of 150 humpback whales in December 2005. This was an unusually high number of animals to be sighted during a time period which is generally considered to be within the breeding season and when animals have migrated to lower latitudes.

Overall, the horizontal distribution of cetacean sightings seen in aerial surveys suggests some degree of habitat separation between species (Figure M8). In general, fin whales were more commonly seen on the west side of the island, while humpbacks and gray whales were more common on the east side. All three baleen whales species were sighted in Marmot Bay (Figure M8). However, since sightings were made opportunistically and the southern portion of the Kodiak archipelago was not surveyed, it is difficult to draw specific conclusions about habitat separation among these species.

(2) Document the number, behavior, and location of cetaceans with dedicated vessel surveys in Chiniak and Marmot Bays, May to September 2004-06.

Methods: Vessel surveys were conducted for the purpose of documenting relative abundance and distribution of fin and humpback whales within the northeastern waters of Kodiak Island. When whales were encountered during vessel surveys, the species, number, and location were documented. In addition, photographs of the ventral surface of humpback whale flukes and the right dorsal fin of fin whales were collected to identify individuals. When possible, the age class, sex and behavior of each whale were recorded at the time of photographing. Photographs were compared to previously photographed and catalogued whales to document the site fidelity and movement patterns of individuals.
Results and Conclusions: Vessel surveys showed a patchy distribution of humpback whales along the east side of the Kodiak archipelago between June and August 2004 to 2006 (Figure M9). Because surveys did not cover the northern portion of the archipelago in 2005 or 2006 and never covered the west side, conclusions about humpback whale presence in these areas cannot be made. However, vessel surveys did show consistent presents of humpback whales in both the southern portion of Marmot Bay and near Barnabas Gully in each year, suggesting these areas are represent important humpback whale habitat (Figure M9). Sightings of humpback whales clearly increased as the summer feeding season progressed with a peak in sightings occurring in August in each year (Figure M10).

(3) Collect identification photographs of humpback whales near Kodiak Island as a means of tracking movements of individual whales, generating a regional abundance estimate and monitoring feeding site fidelity.

Methods: Identification photographs of humpback whales collected between 1999 and 2006 were used to estimate regional abundance using mark-recapture methodology. Photographs were first assessed for quality in five categories; exposure, fluke angle, camera angle, focus and overall quality. Photographs not meeting minimal quality standards, as well as photographs of calves, were not included in abundance estimation (e.g., Calambokidis et al. 2008). Abundance was estimated using two approaches. The first was a closed population model; the Schnabel maximum likelihood estimator (MLE) (Seber 1982). The second was the Jolly Seber (JS) model (Seber 1982), which assumes an open population and allows for recruitment and mortality. In both models, each year was considered a sample period giving a total of 8 sample periods.

Results and Conclusions: Following assessment of humpback whale identification photographs for quality and distinctiveness, a total of 611 individually photographed whales were used for estimation of abundance and analysis of site fidelity, including residency and movements. Abundance estimates were 723 (95% CI 627,833) for the open Jolly Seber model and 1307 (1276,1340) for the closed Schnabel MLE (Figure M11). The MLE is likely an over estimation as it does not allow for the population to gain or lose individuals. Thus, the Jolly Seber is likely a more accurate estimate given that it does account such changes in the population, including births, deaths, and movement (immigration and emigation).

Movements between Kodiak and the Shumagin Islands, the other primary region of GAP whale research, were minimal. Movement between the two regions was documented for only 14 individuals between 2000 and 2005 (Table M7). Three individuals were sighted in both regions on the same year. Movements were not documented in 1999 and in 2006 as no surveys were conducted in the Shumagin Islands. Through matching of photographs with other regional catalogs, an additional 46 individuals were seen in Kodiak and other feeding regions within the Gulf of Alaska, including Lower Cook Inlet, Prince William Sound and the Barren Islands. This is a minimal degree of movement and on the order of 2 to 3%, which is expected between feeding aggregations of humpback whales (Baker et al. 1986, Calambokidis et al. 1996). Site fidelity to the Kodiak area is also reasonably high, with an average rate of resighting individuals of 20% (SD 8%). 120 individuals, or 1 in 5 whales, have been sighted in two or more years, with 24 being sighted in three or more years (Table M8). These data provide evidence that Kodiak represents a distinct feeding aggregation of humpback whales as has been hypothesized (Waite et al. 1999, Witteveen et al. 2007).

Humpback whale abundance was previously estimated at 157 (114, 241) based on photo-identification data from 2002 (Witteveen et al. 2007). This estimate was calculated for an area comprising approximately one quarter of the current study area. Thus, 157 was multiplied by four \( N_{2002} = 628 \) to get an estimate comparable to the
present estimate ($N_{2006} = 723$ from Jolly Seber above). A simple growth rate was calculated for the time frame between the two estimates as \((N_{2006} - N_{2002})/ N_{2006} \times 100\). The growth rate was 13.1%, which is considerably higher than the estimate rate of annual growth for the entire North Pacific humpback whale population of 6.8%, estimated as a result of the SPLASH (Structure of Population, Levels of Abundance and Status of Humpbacks) project (Calambokidis et al. 2008). While these rates are not directly comparable due to differences in spatial and temporal scales, the Kodiak area is clearly experiencing considerable population growth that may be greater than in other areas.

(4) Synthesize data gathered from 2000-2006 aerial and vessel surveys to define the seasonal distribution of cetaceans within northeastern Kodiak Island waters and their correlation to oceanographic and biological habitat parameters.

Problems: After initial data exploration and preliminary analysis, we discovered that the scale, both temporally and spatially, of oceanographic data was not compatible for correlation analysis.

(b) Diet composition and consumption

(1) Determine dive depth targeted by foraging whales by acoustically tracking tagged whales while concurrently identifying prey fields through mid-water trawl and hydroacoustic sampling

Methods: The foraging and diet composition of baleen whales was assessed, in part, through analysis of the dive behavior of tagged humpback whales. Tags attached to free-swimming humpback whales consisted of an acoustic time depth transmitter (ATDT, V22P continuous transmitter, VEMCO, Nova Scotia, Canada), which relayed dive depth to a vessel mounted hydrophone and receiver (VEMCO VR-60) in real-time. Tags were attached via 8 cm diameter suction-cup and deployed remotely using a crossbow. Tags also contained a VHF transmitter (MOD125, Telonics, Mesa, Arizona USA) in order to recover the tag after it was shed or to relocate the tagged whale in instances when the signal from the ATDT was lost.

Acoustic and mid-water trawl surveys were conducted concurrent to whale tagging efforts to assess local prey availability, distribution and relative abundance. Acoustic surveys estimated pelagic volume backscatter with a Simrad EK60 echo sounder using a hull-mounted split-beam 38 kHz transducer. Trawl nets (headrope/footrope length: 39 m; vertical opening: 20 m; 2.22 cm codend liner mesh) designed to target pelagic schooling fish were deployed for 10-20 min to determine the species composition and size distribution of the fish species responsible for patterns of acoustic backscatter within the study area. Whale dive profiles were compared to results from prey sampling to correlate depth of dive to prey layers and derive assumptions about targeted prey.

Results and Conclusions: ATDTs were successfully attached to foraging humpback whales on 5 occasions; 4 in 2004 and 1 in 2005 (Table M9). Prey surveys were conducted concurrent to tagging efforts in both years. The results of the 2004 study are detailed in Witteveen et al. (2008). Briefly, humpback whales were found to be diving to an average maximum depth of 106.2 m and the vertical distributions of dive depth and capelin were highly correlated ($r = 0.91, P < 0.001$). More importantly, the tagged whales seemed to be selecting capelin over juvenile walleye pollock within the same area (Witteveen et al. 2008). A vessel breakdown prevented additional attachments in 2005. However, a limited analysis was done with the small amount of data that was collected and results were similar to the 2004 study. The mean depth of humpback whale foraging dives (101.9m) was again shown to correlate to the distribution of fish ($r = 0.57, P = 0.008$). Data collection was not sufficient to determine if the whales were again selecting
capelin over juvenile pollock; however, capelin were the dominant forage fish in mid-water trawl catches (R. Foy pers. commun.).

(2) Biopsy fin and humpback whales feeding in Kodiak waters and analyze the ratio of stable carbon and nitrogen found in their skin as a means of assessing their relative trophic position, diet, and origins.

Methods: We quantified the ratio of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios present in humpback whale skin samples from 2004 to 2006. The abundances of nitrogen and carbon isotopes in animal tissues reflect the average composition of the animal’s assimilated diet (Deniro and Epstein 1978, 1981, Rau et al. 1983, Wada et al. 1987). In marine fauna, $\delta^{13}C$ indicates sources of primary productivity and, thus, locations of foraging (Fry 1981), while $\delta^{15}N$ is an excellent predictor of relative trophic position (Minagawa and Wada 1984). Results from isotopic analysis were used as an indirect means of assessing the diet composition and relative trophic level and of humpback whales. Trophic level (TL) was calculated as

$$\text{TL} = 2 + \left(\frac{\delta^{15}N_{\text{humpback whale}} - \delta^{15}N_{\text{primary consumer}}}{2.4}\right),$$

where $2$ is the relative position of the primary consumer and 2.4 is the average $\delta^{15}N$ enrichment per trophic level for marine mammals (Hobson et al. 1994, Post 2002). Primary consumers in this study were weathervane scallops and values of $\delta^{15}N$ were provided by Andrews (2010).

Finally, feasible compositions of humpback whale diets were modeled using a Bayesian mixing model (SIAR; Parnell et al. 2008) that utilized the stable isotope ratios of both humpback whales and potential prey species. Prey species used for this analysis were collected during GAP prey surveys between 2003 and 2005.

Results and Conclusions: Ratios of stable isotope signatures of skin samples were evaluated for 139 humpback whales. Humpback whales samples were collected between 2004 and 2006 in both Kodiak and the Shumagin Islands (Table M10). The overall mean values were $-17.9 \pm 0.05$ (SE) for $\delta^{13}C$ and $13.3 \pm 0.07$ for $\delta^{15}N$. Univariate analyses of variance (ANOVA) were performed to explore difference in stable isotope ratios with $\delta^{13}C$ and $\delta^{15}N$ dependent variables and area (Kodiak and Shumagin Islands) and year (2004, 2005, and 2006) as factors. Results showed that $\delta^{13}C$ was significant influenced by area ($F_{1,138} = 13.8$, $P < 0.001$) and year ($F_{2,138} = 14.1$, $P < 0.001$) but not the interaction between the two ($F_{1,138} = 3.1$, $P = 0.08$). In contrast, $\delta^{15}N$ showed no significant relationship with area ($F_{1,138} = 2.4$, $P = 0.12$), year ($F_{2,138} = 1.2$, $P = 0.30$), nor the interaction ($F_{2,138} = 1.3$, $P = 0.26$). The results for carbon are expected given that Kodiak and the Shumagin Islands represent different feeding locations. While the lack of a significant difference in $\delta^{15}N$ between areas suggests whales were foraging at similar trophic levels (TL), this result does not account for baseline values of nitrogen, which can show geographic variation (Post 2002). Comparison of calculated relative TL is therefore more informative (Table 5). The mean TL for Kodiak was higher than the value for the Shumagin Islands ($3.9 \pm 0.04$ (SE) vs. $3.7 \pm 0.04$ respectively) (Figure M12). ANOVA showed that TL was significantly different between areas ($F_{1,138} = 8.9$, $P = 0.003$), but not by year ($F_{2,138} = 1.2$, $P = 0.30$) or the interaction term ($F_{1,138} = 1.3$, $P = 0.26$). Therefore, by accounting for geographic differences in baseline $\delta^{15}N$, Kodiak humpback whales appear to be feeding higher trophically than the whales in the Shumagin Islands (Figure M12). These results could be interpreted as a diet higher proportionally in fish in Kodiak versus a diet proportionally higher in zooplankton in the Shumagin Islands.

Finally, stable isotope ratios of humpback whales and potential prey species were used in a Bayesian model to estimate feasible diet composition of humpback whales foraging in Kodiak between 2004 and 2006. In brief, models showed that humpback diets were likely comprised of juvenile walleye pollock, capelin, Pacific sand lance and euphausiids. Diets in 2004 were more diverse showing significant contributions...
by all species, while diets in 2005 and 2006 showed higher proportions of euphausiids (Figure M13). Complete results are detailed in Witteveen et al. (2011).

Combining results of tagging and stable isotope studies show that Kodiak Island humpback whales likely utilize both zooplankton and forage fish and may exhibit a preference for capelin over juvenile walleye pollock when both are available.

D) Killer whales

i) OBJECTIVES

Killer whales have been seen periodically in waters of Kodiak Harbor for decades, with photo-documentation since at least 1993 (K. Wynne, video). One pod known to visit Kodiak Harbor, (the "Kodiak Killers", Gulf of Alaska Transient Killer Whale Catalog (unpubl. data, C. Matkin pers. commun.)), includes an adult cow (AT126) and adult bull (AT127) that have distinctive dorsal fins that make repeated recognition, even by laymen possible. This and the fact they are easily visible from shore has led to their ‘popularity’ in Kodiak, where their presence is often announced on public radio. The fact they have been repeatedly observed and photographed attacking and (assumedly) consuming SSLs makes monitoring their presence, pod structure, and productivity of interest to those attempting to assess their role in limiting the recovery of SSLs in the western Gulf of Alaska (Matkin et al. 2002, Maniscalco et al. 2007).

Confirming and quantifying SSL predation events by transient killer whales is difficult (Maniscalco et al. 2007). However, the Kodiak Killers appear to specialize on preying upon sea lions commonly found on/near Kodiak’s processing plants, fishing vessels, and docks. Through opportunistic verbal reports and photo-documentation, it appears this pod of six orcas (currently) kills and consumed at least 4-6 SSL per year, primarily in late winter (January to April).

(a) Synthesize existing data on the presence, pod structure, and calf productivity of the "Kodiak Killer" whales.

Methods: GAP has collaborated with killer whale researcher Craig Matkin (North Gulf Oceanic Society) to monitor the presence and composition of this and other killer whale pods in the Kodiak area. Since 2000 we have submitted ID photos, collected biopsies, and archived opportunistic reports of killer whales whenever possible.

Results and Conclusions: The public visibility and popularity of the "Kodiak Killers" led to such a massive collection of sighting and SSL-attack reports as to overwhelm our ability to archive them in a meaningful way. Instead we focused our efforts on documenting particularly pertinent changes in the pod’s composition. Key findings since 2000:

• The pod consists of two adult females (AT126 and AT128) and an adult male (AT127) (Figure M14)
• Adult female AT128 has been seen in Uganik Bay (northwestern Kodiak) with other animals killing and eating sea otters
• Female AT128 gave birth to a calf in 2005 (catalog: AT128a) that died as a neonate. Another neonate was seen once (no photo) with the pod in 1998 but never again, implying another neonatal mortality
• Both females (AT126 and AT128) gave birth to calves (AT129 and AT130, respectively) in 2002.
• Calf AT129 was seen as a yearling with an apparent skin disorder in April 2003 but survived and was seen with obvious scarring in April 2005 (Figure M15).
• "Flopped-over “dorsal fins are rare in wild killer whales (Ford and Ellis 1999). Adult bull AT127 had a distinctively bent or twisted dorsal fin that, as our photos documented, ‘collapsed’ sometime between April and December 2005 (Figure M16).
II) SEABIRDS

i) OBJECTIVES

(a) Foraging ecology
(1) Determine diets of adult and chick tufted puffins, black-legged kittiwakes,
(2) Monitor colony size and productivity of black-legged kittiwakes, cormorants and
common murres in Chiniak Bay 2004-2005
(3) Monitor nestling growth rates for black-legged kittiwakes and tufted puffins in 2004
and 2005.
(4) Determine the relationship between nest attendance/foraging trip duration and
productivity (indirect measure of forage availability) in black-legged kittiwakes.

(b) Productivity
(1) Determine population indices and productivity measures for cliff-nesting kittiwakes
and ground-nesting glaucous-winged gulls.

(c) Develop Quantitative Fatty Acid Analysis (QFASA) as a tool for non-lethal assessment of
diets of tufted puffins.

(d) Stress and condition
(1) Determine the relationship between baseline plasma corticosterone concentrations of
black-legged kittiwakes in Chiniak Bay.
(2) Examine the relationship between the productivity of black-legged kittiwakes and the
baseline and stress-induced corticosterone levels of chicks.
(3) Determine the seasonal dynamics of corticosteroid binding globulin, total CORT, and
free CORT in free-living tufted puffin adults and to compare these parameters from
birds at colonies with high (2 years) and low (2 years) nestling growth and survival.

ii) APPROACH

(a) Foraging ecology
We focused research efforts on three of the most commonly occurring seabird species in
Chiniak Bay that utilize very different foraging strategies. Namely, we investigated the
foraging ecology of small and large surface feeders (small--black-legged kittiwakes
(Rissa tridactyla), large--glaucous-winged gulls (Larus glaucescens)) and off-shore divers
(tufted puffins (Fratercula cirrhata)). By focusing investigations on three species of
seabird that exhibit varying foraging strategies, we effectively sampled the 3-dimensional
forage strata from the surface (kittiwakes and gulls) to depths in excess of the dive
capability of SSLs (tufted puffins). We augmented data on seabird diets and foraging
areas by monitoring their population trends, breeding performance, nestling growth, diets,
and nest-site attendance as indicators of foraging conditions during the breeding season.
In addition, we set out to document reproductive parameters, and foraging areas of
several other species of seabirds that breed within the Long Island Critical Habitat study
area and occupy a variety of foraging niches. We also monitored population trends and
breeding performance of other offshore divers (common murres (Uria aalge)) and
nearshore divers (pigeon guillemots (Cepphus columba), pelagic cormorants
(Phalacrocorax pelagicus), red-faced cormorants (P. urile)).

(1) Diets of tufted puffins and black-legged kittiwakes

Methods:
 Tufted puffins: We used bill loads collected by burrow screening to estimate chick
diets and stable isotopes and fatty acid (FA) signatures to infer age- (adult vs.
nestling) and stage-dependent foraging niches of tufted puffins captured in Chiniak
Bay from 2003 to 2005. Samples were collected mainly during July and August. We
screened nesting burrows during dawn and dusk sessions that coincided with periods
of elevated rates of food delivery to nestlings. Screens prevented adults from
delivering meals to their chicks and prompted them to drop their bill loads at the
screen Individual prey items were identified to species, weighed to the nearest 0.1g,
and all intact fish were measured to the nearest 1mm.
Black-legged kittiwakes: Kittiwake diet samples were collected opportunistically from nestlings that voluntarily regurgitated when handled for other purposes. Kittiwake samples varied considerably in their state of digestion; therefore, fish and invertebrate prey items were identified from otoliths and other hard parts recovered by sorting through samples with the aid of a dissecting scope. Maximum lengths of fish otoliths were measured to the nearest 0.01 mm using a calibrated ocular micrometer built into the eyepiece of the dissecting scope. We estimated the fresh mass of individual fish from otolith measurements using mass-otolith regression equations derived from voucher samples of fish collected within the study area, and estimated the fresh mass of invertebrate prey items from voucher specimens collected in the Gulf of Alaska and Bering Sea.

We determined three metrics for each kittiwake and puffin diet samples: 1) total estimated mass of all prey items in the sample, 2) the proportion of total mass comprised by each prey species, and 3) the average size (mass) of individuals of each prey species. We pooled diet samples by colony and date (“collections”), computed average proportion and mass values for each species, and treated these averages as independent samples in statistical analyses.

Results and Conclusions: Tufted puffins: Whole blood $\delta^{15}$N values indicated a seasonal shift in trophic niche of adults: $\delta^{15}$N enrichment was consistent with a 0.47 to 0.68 increase in trophic level of feeding from pre-lay to late chick-rearing. Although incomplete turnover of blood cells from the pre-lay period likely contributed to intermediate $\delta^{15}$N values of incubating puffins, this was insufficient to account for differences between incubating and chick-rearing adults. Differences in $\delta^{15}$N and $\delta^{13}$C between chick-rearing adults and nestlings were small and inconsistent between years. Discriminant function analysis (DFA) using the 14 most abundant FAs classified individuals by reproductive stage and age within each year with a high level of accuracy (linear DFA: 93 to 99%; quadratic DFA: 80 to 92%). When all years were combined, accuracy of cross-validated classification remained high (linear DFA: 90%; quadratic DFA: 76%). There was significant inter-annual variability in the proportion of both sand lance and capelin in puffin nestling diets.

Based on burrow screen collections, stable isotopes and FA signatures, we conclude that foraging niches are stage-dependent in this species and suggest that chick-rearing adults do not typically feed at a lower trophic level than nestlings but likely consume a different array of prey species. Complete results and methods of tufted puffin diet studies can be found in Williams (2008a) and Williams and Buck (2010a, b)

Black-legged kittiwakes: Pacific sand lance and capelin accounted for 80-90% of diet samples of kittiwakes in every year of this study. However, there was significant inter-annual variability in the proportion of both sand lance and capelin in nestling diets of kittiwakes. In short, sand lance was significantly more abundant in 2004 relative to 2003 for kittiwakes and capelin exhibit opposite tends, being less abundant in 2004 compared to 2003 for kittiwakes. The size of both sand lance and capelin also varied significantly among years: sand lance were the smallest in 2004 and largest in 2005. For kittiwakes, capelin decreased in size from 2001 through 2004 and 2005. Sand lance and capelin make up the overwhelming majority of the diet of black-legged kittiwakes in Chiniak Bay in any given year although the relative proportion of each species varied from year to year. Moreover, prey size decreased with year of the study coincident with decreased overall productivity.
Methods: We canvassed the entire coastline and all off shore rocks and islets within Chiniak Bay for breeding colonies of cliff nesting black-legged kittiwakes, common murres (*Uria aalge*), thick-billed murres (*U. lomvia*), pelagic cormorants (*Phalacrocorax pelagicus*), red-faced cormorants (*P. urile*), and double-crested cormorants (*P. auritus*). Colony surveys adhered to standard protocols established by the Alaska Maritime NWR and were made from a 17’-long, open skiff at a distance of approximately 40-150 m using 8x or 10x binoculars and tally counters. Counts of adults were conducted within a daily census window of 1000 – 1800 h, when colony attendance is stable and maximized, and within a seasonal window that runs from mid-incubation to the initiation of fledging. Brood sizes of kittiwake and cormorant nests that contain small chicks represent minimum estimates only because they and are difficult to observe fully.

Results and Conclusions:

**Black-legged kittiwakes:** In 2004, we tallied 16548 adult kittiwakes and 8882 nests during a mid-incubation census of all 22 colonies in Chiniak Bay. The 2004 nest count indicated a decline of 32% from peak numbers in 2001 but was comparable to the nest count in 1975, the first year that kittiwake colonies were surveyed within Chiniak Bay. Sharp reductions in nest counts are associated with years of strong El Nino climatic events that bring warmer, wetter weather to the Gulf of Alaska. Kittiwakes experienced nearly complete breeding failure in 2004, one of the poorest years on record. Only 7 of 22 colonies fledged any young whatsoever and overall productivity was 0.01 chicks fledged/nest attempt. Successful nests fledged an average brood size of 1.11 young/nest. Complete results and methods of 2004 kittiwake population monitoring can be found in Kildaw et al. (2005a).

In 2005, we tallied 14722 adult kittiwakes and 9130 nests during a mid-incubation census of all 22 colonies in Chiniak Bay. Overall, kittiwakes experienced breeding failure in 2005. Only 13 of 22 colonies fledged any young whatsoever and overall productivity was 0.05 chicks fledged/nest attempt. It is noteworthy that 3 colonies (Svitlak I., Kekur I., and Gibson Cove) achieved moderate to good productivity (respectively: 0.21, 0.36, and 0.33 chicks/nest) despite widespread breeding failure. Bay-wide, successful nests fledged an average brood size of 1.17 young/nest. Complete results and methods of 2005 kittiwake population monitoring can be found in Kildaw et al. (2007a).

In 2006, we tallied 22518 adult kittiwakes and 13038 nests during a mid-incubation census of all 22 colonies in Chiniak Bay. This nest count represents a marked increase over the last two years despite bay-wide breeding failure of kittiwakes in 2006. Only 12 of 22 colonies fledged any young whatsoever and overall productivity was a dismal 0.01 chicks fledged/nest attempt. Successful nests fledged an average brood size of 1.22 young/nest. Complete results and methods of 2006 kittiwake population monitoring can be found in Kildaw et al. (2007b).

**Common murres:** In 2004, we tallied 101 and 63 adult common murres during mid-incubation and pre-fledging censuses, respectively. We observed no thick-billed murres in Chiniak Bay in 2004. Common murres were counted only at Cape Chiniak; however, small numbers were observed in the water near Veisoki Island and cliff-top observations indicate that 20+ adult murres breed in deep fissures and small caves in the north east corner of Veisoki I. Murres were observed brooding nestlings at both Chiniak I. and Veisoki I. during the pre-fledging census period of 2004. Complete results and methods of 2004 murre population monitoring can be found in Kildaw et al. (2005b).
In 2005, we tallied 149 adult common murres and no thick-billed murres during the mid-incubation census in Chiniak Bay. Common murres were counted only at Cape Chiniak, however, small numbers of adult murres were again observed in the water near Veisoki Island and cliff-top observations indicate that murres bred in deep fissures and small caves in the north east corner of the island. Complete results and methods of 2005 murre population monitoring can be found in Kildaw et al. (2007a).

In 2006, we tallied 218 adult common murres and no thick-billed murres, the highest number in 30 years. As was the case in prior years, common murres were observed only at Cape Chiniak and Veisoki Island. Complete results and methods of 2006 murre population monitoring can be found in Kildaw et al. (2007b).

Cormorants: In 2004, we observed a total of 289 adult pelagic cormorants and 165 nests scattered in several small colonies throughout Chiniak Bay. Counts in 2004 were among the lowest ever recorded and reflect a decline of 80% since peak counts of 800 nests in 1984. Productivity of pelagic cormorants was extremely poor this year: 0.03 young/nest attempt. Curiously, a small colony that formed this season on a navigational buoy near Blodgett Island was one of 2 locations that produced chicks. We tallied 27 adult red-faced cormorants and 9 nests in 2004. These counts are the lowest ever recorded and reflect a 98% decline since 1984 when 372 nests were tallied. No chicks or brooding adults were observed in red-faced cormorant nests this year. Complete results and methods of 2004 comorant population monitoring can be found in Kildaw et al. (2005b).

In 2005, a total of 340 adult pelagic cormorants and 219 nests were scattered in several small colonies throughout Chiniak Bay. Productivity of pelagic cormorants was low in 2005, 0.18 (SD 0.51) young/nest attempt. We tallied 23 adult red-faced cormorants and 6 nests in 2005. These counts are the lowest ever recorded. No chicks or brooding adults were observed for red-faced cormorants this year. Complete results and methods of 2004 comorant population monitoring can be found in Kildaw et al. (2007b).

In 2006, a total of 307 adult pelagic cormorants and 189 nests were scattered in several small colonies throughout Chiniak Bay. Productivity of pelagic cormorants was low in 2006, 0.20 (SD 0.29) young/nest attempt. We tallied 36 adult red-faced cormorants and 18 nests in 2006 all located in the vicinity of Long Island. Chicks were observed at Outer Long Island this season. Complete results and methods of 2006 comorant population monitoring can be found in Kildaw et al. (2007b).

In general from 2004-2006, productivity of kittiwakes, murres and cormorants was desperately low and can be characterized as abject breeding failure at most sub-colonies within Chiniak Bay. This observed decrease in productivity from the highs of the early 2000’s was likely precipitated by El Nino effects in late 2003 and 2004 that resulted in reduced forage abundance or quality within the three dimensional foraging range of these seabirds during their breeding season. Variability in sea surface temperature over the years likely exerted bottom up effects on seabird productivity in Chiniak Bay.

(3) Monitor nestling growth rates for black-legged kittiwakes and tufted puffins.

Methods: In 2004 and 2005, we used ladders and climbing ropes to access nests and obtain weights from nestling kittiwakes every five days (approx.) from hatching to roughly 30 days old. We estimated the growth rate of each chick by fitting a linear regression through mass measurements collected between 3 and 22 days of age, a
period for which the mass trajectory of even the most rapidly growing chicks was approximately linear. We restricted our analysis to chicks with at least 3 mass measurements within the linear window, to chicks that survived past 30 days of age, and to singleton chicks and alpha chicks from broods of two.

We accessed puffin chicks by excavating access holes into nest chambers that could not be reached from the burrow entrance and covered these access holes between visits to minimize disturbance. We weighed chicks every five days (approx.) from hatch until they disappeared from the burrow and estimated the growth rate of each chick by fitting a linear regression through mass measurements collected between 5 and 25 days of age, a window for which growth was approximately linear. We restricted our analysis to chicks with at least 3 mass measurements within the linear window, and to chicks that survived past 30 days of age.


Likely, the greater three-dimensional foraging range of puffins buffer them from localized low forage fish abundance experienced by the relatively nearshore and shallow diving kittiwake. Rapid growth rates observed in kittiwakes in 2003 were probably driven by the influx of large capelin into Chiniak Bay coincident with the chick-rearing period. Complete results and methods of chick growth rates can be found in Williams et al. (2008a, 2008b, 2008c, 2009), Brewer et al. (2008a, 2008b, 2009) and Fridinger et al. (2007).

(4) Determine the relationship between nest attendance/foraging trip duration and productivity (indirect measure of forage availability) in black-legged kittiwakes.

Methods: We used radiotelemetry to determine nest attendance and foraging trip duration of free-living black-legged kittiwakes, productivity plots to estimate laying, hatching and fledging success and applied multilevel, mixed, regression models to assess the hypothesis that the collapse from high to low breeding success was due primarily to changes in prey availability. Under this hypothesis, we predicted that longer foraging trips would be associated with reduced breeding performance in cohorts of kittiwakes—groups marked with radio-transmitters at the same colony in the same year.

Results and Conclusions: Chiniak Bay experienced high productivity from 2001 to 2003 and virtually no productivity from 2004 to 2005. In the absence of disease epidemics, increased human disturbance or predation, we separately modeled two response variables: foraging trip-durations made during the incubation and early chick stages. Multilevel mixed models revealed only weak variation at the cohort-level in either response variable; hatching success and fledging success accounted for none or less than 2% of the total variation in trip-durations made during the incubation and early chick stages, respectively. The majority of the variation in our response variables was at the observation (ca. 80–90%) and bird (or individual) levels (ca. 10–12%).

Our results expose the unreliability of using indirect evidence to implicate prey availability as the primary cause of widespread breeding failures in colonial seabirds. In the ecological literature, two types of inferences seem particularly vulnerable to indirect evidence: inferences following studies on species that are accepted or strongly promoted as bioindicators of changes in marine productivity such as the black-legged kittiwake, and inferences that implicate a fisheries-induced reduction in
prey availability to failed breeding. In light of these pitfalls, we recommend that long-term monitoring studies on kittiwakes and other seabirds carefully consider in their study designs and implementations multiple working hypotheses that might explain major changes in breeding success. Complete results and methods of foraging duration/nest attendance studies can be found in Breton et al. (2008).

(b) Productivity
We studied kittiwakes and glaucous-winged gulls breeding at colonies located on numerous sea stacks and islets within Chiniak Bay in the northeastern corner of Kodiak Island, Alaska. Kodiak Island is located in the Western Gulf of Alaska in a marine region that experienced "regime shifts" - dramatic changes in oceanographic conditions and food web structure - in 1977, 1989, and possibly 1998 (Anderson and Piatt 1999, Hare and Mantua 2000) that potentially effected seabirds and other apex predators in the region.

(1) Determine population indices and productivity measures for cliff-nesting kittiwakes and ground-nesting glaucous-winged gulls.

Methods: Fieldwork for kittiwake productivity was conducted May–August in 2004 and 2005 on colonies that ranged in size from < 10 to approximately 2000 nests. Colonies were accessed via daily excursions in open skiffs. We monitored black-legged kittiwakes at 3 levels of precision. We conducted "colony surveys" of all kittiwake colonies within Chiniak Bay to obtain information on population size and gross chick production. We also established multiple 'visual monitoring plots' at several colonies and visited these on a 5-day cycle to obtain more detailed information on breeding chronology and reproductive performance. Lastly, we used ladders and climbing ropes to reach kittiwake nests on a small number of 'access plots' on a 5-day cycle.

Field work for glaucous-winged gull productivity was conducted on seven colonies in Chiniak Bay May–August in 2004 and 2005. Reproductive success of glaucous-winged gulls was assessed by monitoring reproductive parameters of designated plots within known breeding colonies. We chose plots based on historical monitoring efforts, access, density, and proximity to other breeding seabird colonies. Briefly, we followed the fate of every glaucous-winged gull nest on pre-determined plots by visiting each plot every five days, weather permitting, from nest initiation to the date of failure or hatch. Clutch size is the maximum number of eggs observed in any nest. Nests that were depredated or disappeared during mid-lay cycle were included when calculating clutch size in this calculation. We calculated reproductive success as the proportion of nesting attempts in which at least one egg of the clutch hatched.

Results and Conclusions: The timing of kittiwake egg laying varied among years: laying was delayed by approximately 2 weeks in 2004 and 2005 vs. 2001-2003. Productivity of kittiwakes also varied significantly among years, but in the opposite direction than lay date: productivity was higher in 2001 and 2002 vs. 2004 and 2005 and was intermediate in 2003. Productivity in 2004 and 2005 approached zero and are among the lowest productivity years since monitoring of kittiwakes began in 1977 in Chiniak Bay.

Similarly, the timing of egg laying of glaucous-winged gulls in Chiniak Bay in 2004 and 2005 was delayed by approximately 2 weeks as compared to 2001 and 2002. Moreover, hatching success decreased from an average of ~120 chicks per plot in 2001 to less than 5 per plot in both 2004 and 2005. Although we could not follow chicks to fledging age, it is assumed that no glaucous-winged gull chicks fledged in

Marine foraging conditions in the near-shore of Chiniak Bay was poor in 2004 and 2005 and this poor foraging environment impacted breeding performance of glaucous-winged gulls and kittiwakes in a similar fashion; eggs were laid later and were less likely to hatch and overall productivity was at historic lows for both species. Complete results and methods of productivity studies can be found in Buck et al. (2007) and Kildaw et al. (2005a, 2008).

(c) Quantitative Fatty Acid Analysis

We set out to develop Quantitative Fatty Acid Analysis (QFASA) as a tool for non-lethal assessment of diets of tufted puffins. Fatty acid (FA) signature analysis is a powerful method to investigate foraging ecology and food web dynamics in marine ecosystems. However, use of FA signatures to qualitatively or quantitatively infer diets is potentially complicated by effects of nutritional state on lipid metabolism.

Methods: Estimation of diets using the QFASA model requires the use of calibration coefficients to account for predator metabolism of individual FAs. We conducted a captive feeding experiment to determine the effects of a 50% reduction in food intake on growth rate and adipose tissue FA signatures of tufted puffin nestlings, a species that routinely experiences food restriction during growth.

Results and Conclusions: FA signatures of chicks fed low- and high-calorie diets both exhibited a change in composition in response to the dietary shift with the direction of change in the composition of individual FAs matching the direction of change in the dietary FAs. Despite a growth rate in the restricted nestlings that was 38% of those in the well-fed group, rates of FA turnover were not different between high and low-calorie treatments, and turnover was close to, but not entirely complete, after 27 days on both high-calorie and restricted diets. FA signatures of tufted puffin nestlings were significantly affected by caloric restriction, but these effects were much less pronounced than those of dietary turnover, and calibration coefficients of puffins fed low and high-calorie diets were highly correlated. Our results demonstrate that changes in physiological state can affect FA metabolism.

QFASA is a powerful technique has proved useful in delineating spatial and temporal variability in diets, identifying the consumption of key species, and providing quantitative estimates of diet composition. Although consumer FA signatures are undeniably influenced by diet, they can also be affected by other factors including life history stage, diet quality, and physiological state. Our data, in combination with other published results indicate that the correct interpretation of FA data relies on accounting for factors that alter predator FA metabolism and controlling for variability in the lipid content and FA composition of prey. Efforts should also be made to incorporate uncertainty associated with predator metabolism into models designed for quantitative diet estimation. Complete results and methods of QFASA and SIA studies can be found in Williams et al. (2007, 2008b, 2009, 2010b).

(d) Stress and condition

In birds, activity of the hypothalamus–pituitary–adrenal (HPA) axis is reflective of predictable life history events and unpredictable environmental conditions (Wingfield and Ramenofsky 1997, Romero 2002). Activation of the HPA axis results in increased plasma concentrations of corticosterone (CORT), a steroid released by the adrenal cortex, which stimulates mobilization of stored energy reserves and elicits behavioral changes that promote survival (reviewed in Sapolsky et al. 2000). In the marine environment, climate-driven changes in primary productivity affect ecosystem structure and prey available to foraging seabirds—thus, seabird productivity is
shaped by marine resource availability. Although reduced prey availability is known to depress the reproductive output of seabirds (e.g., Suryan et al. 2002), the physiological response of breeding adults to such changes is currently unclear. Baseline levels of CORT have been shown to correlate with reproductive success and body condition in black-legged kittiwakes (Kitaysky et al. 1999, Buck et al. 2007) as well as with food availability in common murres (Kitaysky et al. 2007). Kitaysky et al. (2007) also found that maximum stress induced levels of CORT in murres were correlated with food availability in the recent past (one month prior). Because the reproductive output of seabirds is tightly correlated with prey availability (Suryan et al. 2002), these studies suggest that access to food may be one of the dominant factors affecting HPA activity in seabirds.

(1) Determine the relationship between baseline plasma corticosterone concentrations of black-legged kittiwakes in Chiniak Bay.

Methods: Throughout their breeding season over 5 consecutive years, kittiwakes were captured live at colonies scattered across Chiniak Bay and sampled for blood and body condition. Plasma samples were later analyzed for corticosterone concentration using modified Wingfield and Farner (1975) direct radioimmunoassy methods.

Results and Conclusions: During a 5-year period of declining kittiwake productivity in Chiniak Bay, we found increasing baseline corticosterone levels during both incubation and chick-rearing. Significantly lower baseline corticosterone levels were observed in the years with the highest kittiwake productivity and the least productive years exhibited the greatest baseline corticosterone levels in kittiwakes. Although we did not have access to measured food availability, declining kittiwake productivity was consistent with warming ocean temperatures and decreased availability of forage fishes to apex predators.

This study adds to the growing body of literature investigating the utility of baseline levels of plasma corticosterone as a predictive index of subsequent reproductive success of seabird colonies. We found a significant relationship between plasma corticosterone level and colony-wide productivity suggesting that corticosterone levels of blood samples collected from a relatively small subset of successfully breeding individuals at single time points in the breeding season can serve as a proxy for breeding performance across all colonies of the region. However, individual variability in plasma corticosterone levels of free-living Kittiwakes is high and thus precludes fine scale connectivity between corticosterone and colony-wide productivity. To elucidate the proximate drivers of the modulation of baseline corticosterone level of the individual, one would ideally need information about prey abundance, prey availability, foraging success, disturbance and predation rates. Complete results and methods of plasma CORT studies of adult kittiwakes can be found in Buck et al. (2007).

(2) Examine the relationship between the productivity of black-legged kittiwakes and the baseline and stress-induced corticosterone levels of chicks.

Methods: For this study, we captured free-living 12–15 day-old kittiwake chicks in a multi-year study in Chiniak Bay. Chicks were sampled for blood at 4 time-points (<3, 10, 30 and 50 min post-capture) for later analysis of corticosterone concentrations using modified Wingfield et al. (1992) direct radioimmunoassay methods and subsequently returned to their nests.

Results and Conclusions: Productivity decreased across years from relatively high levels in 2002, to very low levels in 2004 and 2005. Baseline corticosterone
levels of the chicks did not increase consistently across years. Stress-induced corticosterone levels were statistically indistinguishable in high productivity years but increased significantly in low productivity years. Complete results and methods of plasma CORT studies of kittiwake chicks can be found in Brewer (2008a, 2008b, 2009) and Fridinger et al. (2007).

The decline in kittiwake productivity coincided with warming ocean conditions, which, historically, are linked to declines in forage abundance for kittiwakes. Inconsistent changes in baseline corticosterone levels suggest some adult kittiwakes were able to buffer their chicks from poor foraging conditions. However, large increases in stress-induced corticosterone levels during the low productivity years indicate chicks were physiologically stressed for some period prior to sampling. Our results suggest that stress-induced corticosterone levels of kittiwake chicks are effective indicators of productivity in poor years, whereas the changes in baseline corticosterone levels across years are not as pronounced and therefore may not be as reliable.

(3) Determine the seasonal dynamics of corticosteroid binding globulin, total CORT, and free CORT in free-living tufted puffin adults and to compare these parameters from birds at colonies with high (2 years) and low (2 years) nestling growth and survival.

Methods: Free-living adult tufted puffins were captured at their burrows, weighed, measured and sampled for blood (<3, 10, 30 and 50 minutes post-capture) for later analysis of concentrations of CBG total and free CORT (Wingfield et al. 1992).

Results and Conclusions: At the high productivity colony, levels of CBG, total baseline CORT, free baseline CORT, and total maximum CORT were all higher prior to egg-laying than during late incubation and late chick-rearing. Levels of CBG were positively correlated with body condition index (BCI) and free baseline CORT was negatively correlated with BCI. Total baseline levels of CORT during chick-rearing were two to four times higher at the colony with low rates of nestling growth and survival. Complete results and methods of plasma CORT studies of tufted puffin chicks can be found in Williams et al, 2008a,b.

Our results demonstrate the need for long-term datasets to disentangle seasonal trends in CORT levels from trends driven by changes in environmental conditions. Given the negative effects associated with chronic elevation of CORT, our results indicate the cost of reproduction may be higher during years characterized by low productivity. We contend that elevated CORT in low productivity years provides evidence that reproductive costs reflect changing environmental conditions. However, more studies are needed to determine whether CORT and/or body mass (or BCI) are actually indicative of a cost to future reproductive output.

III) FISH & PREY
A) Prey Surveys
i) OBJECTIVES
The fish surveys were designed to compare fish distributions to oceanographic parameters that affect the east side of Kodiak Island. In doing so, the GAP study produced a unique seasonal view of the physical oceanographic structure affecting the shelf areas of Kodiak to relate trophodynamic interactions concurrently. The objectives of the prey surveys were to monitor the pelagic and demersal fish populations and zooplankton biomass in SSL critical habitat, to conduct a fisheries oceanographic assessment of Portlock Bank and the shelf break to determine the importance of oceanographic features on production and the biomass of prey species for apex predators, and to develop and carry out a survey in the Kennedy and Stevenson Entrance north of Kodiak Archipelago to assess the importance of the coastal current on downstream production of prey species around Kodiak.
ii) APPROACH
(a) LICH Monitoring
In 2004, the areas within 46.3 km of Long and Marmot Islands (Figure F1) were "monitored" such that trends in fish and zooplankton distribution or relationships to oceanographic conditions could be assessed and compared to previous years. Those data were used to integrate with other regional studies of the diets and habitat use by a SSLs, whales, sea birds, and fish. Those data were also compared to data collected on Portlock Bank to explore inshore-offshore relationships. Studies on temporal and spatial zooplankton species composition, abundance, and biomass are important to better understand interactions among trophic levels in the marine ecosystem.

Methods: In 2004, approximately four days of hydroacoustic and trawl surveying were conducted during each prey survey to assess relative seasonal abundance estimates and distribution of fish within 46.3 km of the Long Island and Marmot Island sea lion haulouts. The F/V Laura was equipped with commercial midwater and bottom trawling gear and an acoustic system using a hull mounted 38 kHz transducer. Hydroacoustic sampling included a total of 398.5 km parallel east-west transects spaced 11.12 km apart and out to the 46.3 km edge of designated SSL Critical Habitat around each island. Twelve predetermined locations within the survey area were sampled for demersal fish distribution.

Midwater fishes were surveyed using a Simrad EK60 echo sounder attached to a 38 kHz, 12-degree split beam transducer. Echo-integration of the acoustic signal was done using Echoview software that, combined with catch length and weight data, was used to estimate fish biomass. To determine the size and species of the target fishes, a small representative sample of prey was collected during 10-minute tows with a DanTrawl Bering Billionaire midwater net with a modified research codend. Demersal fish species were assessed by bottom trawling with a DanTrawl Fiska II with a small mesh cod end liner.

All fishes collected by bottom or midwater tows were separated by species and counted. From each tow, a random sample of up to 100 fish of each species (per size category) were measured; up to 30 of these were also weighed. A sample of up to 500 fish were collected and frozen for subsequent studies of species-specific quality (proximate analyses). Specimens that could not be positively identified to species in the field were frozen and returned to the University of Alaska, Fishery Industrial Technology Center campus in Kodiak for identification.

Zooplankton samples were collected during the Long island and Marmot Island surveys from 2002 to 2004. In 2004, "offshore" sampling stations were added in the Portlock Bank area (See Portlock survey below). Sampling stations were systematically distributed at regular intervals of ~15 km within Chiniak Bay and Marmot Bay area. A 0.75 m diameter, 130 µm mesh ring net was deployed vertically to a depth of 25 m at multiple stations to collect zooplankton specimens during the day. The depth of the tows was chosen based on the average maximum depth of the acoustic (38 kHz) scattering layer in this region. Upon retrieval, zooplankton samples were preserved immediately in 10% buffered formalin. In the laboratory, the samples were sequentially split using a Folsom splitter until the smallest subsample contained approximately 100 specimens of the most dominant taxa, then the plankton in the smallest subsample were identified, staged and enumerated, followed by analysis of subsamples of increasing size for less abundant taxa.
At each station, a Seabird Conductivity and Temperature at Depth (CTD) instrument was deployed to collect oceanographic data (salinity, temperature, light, and productivity) at each station. Casts were taken at 11 to 49 nearshore stations in 2002-2004. Fluorometry data was collected with a WETSTAR mini-fluorometer interfaced with the CTD.

Results: To determine species composition and relative abundance of fishes in critical habitat adjacent to Long Island and Long Island, acoustic and trawl surveys were conducted aboard the F/V Laura (16 May - 1 June 2004, 26 July - 8 August 2004). Bottom trawls were dominated by ATF, flathead sole, walleye pollock, Pacific cod, rock sole and eulachon (Thaleichthys pacificus). Catch-per-unit-effort was also calculated based on counts and biomass per km².

On average, > 95% of mid-water fish distributions occurred shallower than 200 m and > 65% occurred shallower than 100 m at the time of survey (Winter et al. 2009). Estimates of mean biomass density for major fish species groups showed that four species groups (pollock, ATF, cod, and soles) together comprised on average 80% of total biomass density in all surveys (May, July, November) and zones (0-10 and 10-20 nm around Long Island and Marmot Island). Average total biomass densities (all major species groups combined) were greater around Long Island than Marmot Island in May and November, but greater around Marmot Island in July. Seasonally, average total biomass in the entire survey area increased from May to July, then decreased to November.

Similar to previous studies in 2002-2003, high prey energy density concentrations by Marmot Island were primarily offshore suggesting that 0-10 nm inshore zones do not have higher forage potential than 10-20 nm offshore zones. Most prey species groups had lower energy content in May (post-spawning period) than in July and November (resting and developing periods). The four predominant species groups observed in this study; pollock, ATF, cod, and soles have relatively low mass based energy densities compared to capelin and salmon.

Zooplankton were sampled from 4 to 31 nearshore stations in 2002-2004 (Wang 2007). A total of 34 zooplankton taxa were encountered from 206 zooplankton tows. The most species rich taxonomic group collected was copepods (14 species). Oithona spp. was the only cyclopoid copeped found in our samples. Among the copepod taxa, small copepods such as Pseudocalanus spp., Oithona spp., and Acartia spp. were more abundant than large copepods such as Neocalanus spp., Eucalanus sp. and Calanus sp. in every sampling season. In general, zooplankton abundance was highest in August within each year while zooplankton biomass was highest in August in 2002 and 2003 and in May 2004. In 2004, total nearshore zooplankton abundance was significantly higher in August (4.43x 10⁴ individuals m⁻³) than in May (1.81x 10⁴ individuals m⁻³). Total zooplankton abundance was significantly higher in May 2003 than in May 2004, and zooplankton abundance was significantly higher in May 2002 than in May 2004. Zooplankton abundance in August 2003 and August 2004 was significantly higher than in August 2002. Zooplankton abundance was significantly correlated to S₂₅, T₂₅, F₂₅, and Φ in different months and years, but without consistent pattern.

Conductivity and temperature at depth were recorded at each site with a Seabird CTD Profiler. Average temperature above 25 m was about 1 °C greater in 2003 than in 2002 and 2004 and average salinity above 25 m was lower in 2003 than in 2002 and 2004. Average temperature above 25 m was lower in 2002 than 2004 and average salinity above 25 m was higher in 2002 than 2004.
The relative availability of prey near Long Island and Marmot Island was similar in 2004 when compared to the previous time period (2002-2003). Major prey species groups in all surveys were ATF, walleye pollock, cod, and other flatfish (soles). Correlations of average midwater prey energy densities with SSL counts at Long Island and Marmot Island haulouts indicate that prey availability may be an important factor in the choice of haulout sites by SSLs, and may provide some advantage at rookery sites.

The Long Island and Marmot Island survey revealed that the zooplankton community structure and oceanographic factors are highly variable on the shelf northeast of Kodiak Island, implying that the availability of prey for upper trophic levels such as commercially important fish, seabirds, and mammals may fluctuate on similar temporal and spatial scales. The overall numerical dominance of small copepods Pseudocalanus spp., Oithona spp., and Acartia spp. within the holozooplankton northeast of Kodiak Island was similar to data from UAF studies from the northern Gulf of Alaska study sites near Seward. It is notable that biomass of more oceanic Neocalanus spp. and Metridia pacifica biomass on Seward line were higher than in the Kodiak study area. However, biomass of the more neritic Pseudocalanus spp., Oithona spp. and Oikopleura spp. biomass were higher in the Kodiak than on the Seward line. Clione limacina biomass in Kodiak was higher than on the Seward line. Although zooplankton abundance in the Kodiak region may be a result of local production, zooplankton distributions may also be influenced by oceanographic currents and tides outside the immediate study area. Relatively higher abundance of small copepod species such as Pseudocalanus spp. and Oithona spp. in the Kodiak region could be due to higher plankton production from increased water column mixing. Temperature may have been more important in affecting zooplankton abundance than other factors in early spring because of the relationship between increased stratification in the surface layer and increased phytoplankton and zooplankton production. During summer months, salinity might become more important in affecting zooplankton abundance because of the larger influence of freshwater from snowmelt, glacial runoff, and precipitation on the Gulf of Alaska ecosystem. Therefore, the seasonal and interannual variability in these copepod taxa observed in this study may impact the abundances of these forage species in this region. Other commercial fishes, sea birds, and mammals that consume zooplankton could also be influenced by zooplankton abundance trends quantified in this region.

The correlations of zooplankton species composition with physical and biological factors were weak, suggesting that temperature, salinity, fluorometry, stratification, pycnocline depth, and station depth do not independently influence the aggregation of species on the northeast side of Kodiak Island. Correlations between oceanographic factors and the zooplankton community structure were weak in this study, likely a result of the complex interactions between physical processes and biological production on the western Gulf of Alaska shelf. Specifically, additional factors more complex than temperature and salinity such as bathymetry, dynamic currents, and variable climate forcing may be more influential in driving zooplankton community structure. Zooplankton advected from other regions may also play an important role in local zooplankton community structure and confound relationships with local environmental conditions. It is therefore not surprising that local physical features would not necessarily correlate strongly with zooplankton density in a small study area like this Kodiak study site where localized conditions may be more complex than the broader geographic area. Additional methods and results of the LICH surveys can be found in Xian (2007) and Winter et al. (2009).

(b) Portlock Bank and shelf break fisheries oceanography
To assess productivity and fish availability in this area, we assessed the larger scale fish distribution and related oceanographic features in shelf waters east side of Kodiak Island. In so doing, we produced a unique seasonal view of the physical oceanographic structure affecting the nearshore areas of Kodiak and the resources they support. Portlock Bank
and the shelf break (Figure F1) were surveyed to assess both the fish distribution and the physical oceanographic conditions in May and July in 2003 and 2004 to assess interannual differences and to establish the seasonal timing of oceanographic features. May represents “spring” conditions where productivity is at its highest and the freshwater driven Alaska coastal current is beginning to gain momentum. Conditions on the Banks northeast of Kodiak drive a source of production and may predict oceanographic influences on the northeast side of Kodiak. In addition to facilitating fish collection, transects were also used to survey marine birds and mammals in the area east of Kodiak. The shelf break (max z = 500 m) was surveyed to assess the pelagic fish distribution and physical oceanographic conditions in May and July 2003 and 2004. In both months, we were interested in relating the movement of off-shelf waters to the fish habitat closer to shore. Oceanographic conditions were compared to those found in the monitoring areas closer to shore and determine predictive linkages between the two environments. To understand the role of zooplankton in the food web, large scale environmental forcing has been assessed in the North Pacific Ocean and studies on spatial zooplankton community fluctuations have largely focused on inshore-offshore gradients. The shelf zooplankton community consists of a mixture of oceanic and neritic species due to the complex cross-shelf circulation patterns. Our goal of this project which was included in the original grant request and highlighted in the no-cost extension request in 2009, was to compare the communities and relate them to the general oceanographic patterns observed in the region.

Methods: Acoustic-trawl survey data from two consecutive years were used to examine the distributions of key pelagic fish species. The most prominent oceanographic feature in the area is the fronts between stratified and mixed waters due to enhanced tidal mixing over the Bank. We delineated the stratified fronts and quantified the relationship between horizontal distribution of key pelagic fish species and front positioning. Fish distribution patterns were also examined in relation to other oceanographic features, e.g. sea surface temperature fronts.

In May and August 2003, Portlock Banks (northeast of Kodiak) was surveyed to assess seasonal fish distribution and physical oceanographic conditions. In addition, the continental shelf break was surveyed to assess pelagic fish distribution and physical oceanographic conditions in May and July although weather prevented most stations from being sampled. In both months, we were interested in relating the movement of off-shelf waters into near-coastal fish habitat. The acoustic sampling was conducted on multiple parallel east-west lines equally spaced 18.5 km apart, covering a 12,201 km² area over Portlock Bank and a zig zag pattern over the shelf break. The vessel speed during all transecting was 7 knots (1000 rpms) and approximately 741 km were surveyed on each cruise. Midwater fishes were surveyed using a Simrad EK60 echo sounder attached to a 38 kHz, 12-degree split beam transducer. Echo-integration of the acoustic signal was accomplished using Echoview software that, combined with catch length and weight data, yielded estimates of fish biomass. To determine the size and species of target fishes, a small representative sample of fish was collected with a DanTraw Bering Billionaire midwater net with a modified research cod end. The midwater trawl was deployed opportunistically when we encountered pelagic fish assemblages to ground truth the hydroacoustic signals. Tow duration was dependent on the magnitude of acoustic signal, ranging from 10 to 25 minutes. Sampling stations were systematically distributed at regular intervals ~20 km near Portlock Bank area.

Methods for fish and zooplankton handling were similar to those used in nearshore surveys in 2002-2004 (see above). Zooplankton were sampled from 18 to 19 offshore stations in 2004 northeast of Kodiak Island. Temperature and salinity data of the entire water column were collected using a SeaBird19 CTD at systematically distributed stations spaced ~10 km apart in the Portlock Bank area. CTD data of August 2003 were
lost due to equipment failure. Fluorometry data was collected with a WETSTAR mini-
fluorometer interfaced with the CTD.

Three parameters were evaluated to estimate delineations of a structural front
across Portlock Bank: water column stability, remotely sensed nighttime sea surface
temperatures, and daytime sea surface temperatures (SST) recorded along the survey
transects. Water column stability was measured from CTD profiles taken during the
surveys. For each CTD profile, the stratification parameter \( \psi \) was calculated, which
represents the amount of work per unit volume (J m\(^{-3}\)) required to vertically mix the water
column. Remotely sensed SST (recorded by advanced very high resolution radiometer;
AVHRR) were downloaded from the NASA Jet Propulsion Laboratory website
(http://poet.jpl.nasa.gov) for the area and time period covered by each survey. Sea
surface temperatures along the transects were recorded at 5 sec intervals by a continual
data collecting thermostalinograph (TSG), attached to the hull of the survey vessel. For
each survey, statistical relationships among the three parameters \( \psi \) (from CTD),
nighttime SST RV (from AVHRR), and daytime SST gradient (from TSG) were tested by
pair-wise correlation analysis. Additional project methods and results relative to the
Portlock Bank data collections can be found in Wang (2007) and Montes-Hugo et al.
(2005).

Results and Conclusions: In August 2003, 8% of the survey area had significantly higher
aggregation of capelin than pollock. All capelin aggregation occurred within or north of
the 95% confidence interval of the front, and the Monte Carlo test for randomness
showed a marginally significant \( (p < 0.10) \) proximity between the aggregation and the
location of the front-line. No significant aggregation of pollock occurred in this survey,
although the averaged distributions of pollock showed zones of concentration in the
center and south. In May 2003, 19% of the survey area had significantly higher
aggregation of capelin than pollock. Of these capelin aggregation points, 78% comprised
one large patch dominating the north end of the survey area, and only 2% occurred south
of the 95% confidence interval of the front. Conversely, 7% of the survey area had
significantly higher aggregation of pollock than capelin, of which 73% occurred south of
the 95% confidence interval of the front. In May 2004, 31% of the survey area had
significantly higher aggregation of capelin than pollock. Monte Carlo testing showed the
capelin aggregations to be significantly correlated with the 95% confidence interval of the
front. In August 2004, the very low abundance of capelin resulted in 0.7% of the survey
area having higher aggregation of capelin than pollock. Depth distributions in May 2003
and 2004 showed higher proportions of pollock biomass in deeper water north of the
front-line than south of the front-line, despite relatively more deep-water area in the south.

Total offshore zooplankton abundance in the Portlock Bank area was significantly
higher in August 2004 (3.10x 10\(^{4}\) individual m\(^{-3}\)) than in May 2004 (1.03x10\(^{4}\) individual m\(^{-3}\); \(p=0.005, F=8.96, n=37\)). There was no significant difference between the nearshore
and offshore total zooplankton abundance in either May (\(p>0.05, F=3.47, n=35\)) or
August 2004 (\(p>0.05, F=1.03, n=40\)). Although there was no difference in species
diversity between the inshore and offshore study areas near Kodiak Island, the inshore
zooplankton abundance in various bays was higher than abundance at the shelf break.

CTD casts were taken at 40 offshore stations in 2004 northeast of Kodiak Island. Spatial patterns based on visual representation of the ordination clusters suggested
some discernable patterns with the nearshore stations clustered in the lower temperature
zone and the offshore stations clustered in the higher temperature zone of the study
area. Cloud cover limited the SST RV interpolations to 73% of the survey area in May
2003, 99% in August 2003, 44% in May 2004, and 82% in August 2004. Relationships
among the three parameters used to delineate the front-lines (\( \psi \), SST RV, and SST TSG)
were weak.
Data suggests that there is a linkage between the seasonal/interannual intensity of the Alaska coastal current and the frontal structures off of Kodiak Island. The oceanography on Portlock Bank showed a clear increase in water column stability from May to August in both 2003 and 2004. Stratification parameter values $\phi$ increased up to about 3 nm distance from the maximum likelihood front-lines, indicating that a front approximately 6 nm wide may be present. Based on available data in this study, the location of the front could not be mapped with high precision, but the 95% confidence intervals from CTD profile interpolations suggest that the entire elevation of Portlock Bank may represent a frontal zone.

Areal distributions in two of the four surveys showed significant relationships between capelin aggregations and the estimated location of the front. From May to August 2003, capelin aggregations spread southeastward through most of the study area, but appeared to be held from moving south past the frontal zone in August. Water column stability was weaker in May 2004 than in May 2003, perhaps causing the capelin to move through the area more rapidly. Alternatively, capelin in 2003 may have been more restrained from migrating inshore by the greater presence of pollock, compared to 2004 since pollock are potential predators as well as competitors to capelin. The relative spatial differences in May 2003 showed a pattern of capelin aggregating north-west vs. pollock aggregating south-east. Unlike capelin, the areal distributions of pollock did not change strongly between 2003 and 2004, other than the changes in abundance suggesting that pollock may experience less influence from variations in a frontal structure than capelin. By contrast, vertical distributions of capelin changed little from one survey to the next, while distributions of pollock went deeper in the water from May to August, in both 2003 and 2004. The analyses of survey data confirmed the utility of the geostatistical simulation method in assessing spatial distributions of fish in a dynamic environment. The geostatistical simulations gave good representation of the original survey data distributions, and were robust to variations in the simulation model.

The results of the study indicate that conditions on Portlock Bank may control the distributions and seasonal movements of pollock and capelin, contributing to the complexity of the near-shore fish community around Kodiak Island. Other species groups, including eulachon, rockfish and salmon, also showed large seasonal differences in abundance, and are likely influenced by the oceanography of Portlock Bank.

For zooplankton species, seasonal increases in abundance were more pronounced in the offshore waters compared to nearshore waters in 2004 likely due to the proximity of deep gullies that favor the movement of deeper water masses onto the shelf. Increases were expected due to their seasonal ontogenetic migration and advection onto shallower shelf waters. In the Portlock Bank region, this process may be enhanced through the interaction of the Alaskan Stream with the dynamic bathymetry on the Kodiak shelf. Additional methods and results specific to the Portlock Bank and shelf break surveys can be found in Xian (2007), Guo (2010), and Montes-Hugo et al. (2005).

(c) Nearshore
Nearshore waters immediately adjacent to haulouts and rookeries appear to be of particular significance to pre-weaned SSL pups and may represent biologically critical habitat. Several prey species found in these nearshore waters, including sand lance and other nearshore species, have been found to occur frequently in the scats of SSL using Chiniak and Long Island haulouts but are rarely caught in our LICH surveys. Because our LICH and offshore surveys use gear that precludes surveying shallow waters immediately adjacent to haulouts, we proposed to explore a number of nearshore survey techniques in June 2004 to determine the species composition and relative abundance of fishes present within 100 m of shore. Techniques for identifying fish prey species present included 1) deployment of beach and purse seines, 2) examination of seabird diets and/or 3) video imaging of prey schools associated with bird and whale aggregations.
Methods: Nearshore stations were occupied and periodically sampled with a beach seine while actively feeding seabird groups were sampled using a purse seine to capture prey. Approximately ten stations were sampled while approximately six foraging seabird aggregations were sampled.

Results and Conclusions: Systematically sampling nearshore stations and actively foraging bird aggregations proved to be a time consuming project that did not provide a sample size or species composition adequate to effectively quantify very nearshore forage fish in the GAP region. Nor were the sample sizes adequate to characterize the sand lance abundance (or index of abundance) in the region. Therefore, formal analyses were not pursued and additional sampling was not continued. However, samples collected during the nearshore surveys were used to augment seabird diet studies fulfilling the original objective to support seabird diet studies. Understanding the nearshore assemblages and the linkage of forage availability between the nearshore and mesopelagic regions of the study are remains a difficult aspect of the study.

(d) Upstream
In 2005 we moved our offshore fisheries oceanographic assessments north to an area upstream of Kodiak Archipelago. Previous studies on Portlock Bank have shown that the Alaska Coastal Current flow through this region is seasonally and inter-annually variable. The timing and magnitude of changes to the Alaska Coastal Current affect the stability of water flow to the east and west of Kodiak Island. This in turn affects the influence of offshore “oceanic” waters versus coastal freshwater driven waters on the nearshore environment. We hypothesized that understanding the variability in these fluctuations will help us better understand the production and available resources for upper trophic levels on the shelf area around the Kodiak Archipelago.

Methods: From 15 May to 28 May 2005, From 8 August to 17 August 2005, the area north of Kodiak Archipelago around the Barren Islands (Figure F2) was surveyed to assess both the fish distribution and physical oceanographic conditions. We acoustically cover an area 67 X 46 nm across the entrances of Cook Inlet and Shelikof Strait and encompassing Kennedy and Stevenson Entrance.

Results and Conclusions: We conducted acoustic and trawl surveys using the F/V Laura to determine species composition and relative abundance. The F/V Laura was equipped with commercial midwater and bottom trawling gear and an acoustic system using a hull mounted 38 kHz transducer. Hydroacoustic sampling included a total of 700 km mostly parallel transects spaced 17 km apart. Twenty-five midwater trawls were done to ground truth species composition and size class information to be applied to the acoustic backscatter data. Catches were dominated by capelin (32%) followed by larval fish (31%), walleye pollock (30%) and eulachon (5%). Approximately 1500 fish were measured for length and weight. Numerous samples were returned to Kodiak and frozen for more length and weight measurements. Conductivity and temperature at depth were recorded at each site with a Seabird CTD Profiler. Continuous surface temperature was recorded during the entire cruise with a Seabird TSG micro-45. Zooplankton were collected at each station with a 130 um mesh vertical ring net from a depth of 50 m.

The original intent of the upstream survey was to use interannual collections to compare differences in species composition relative to environmental variable. Unfortunately changes in funding and staffing in subsequent years precluded the upstream area as a GAP priority. Results from the southern portion of the upstream survey were analyzed in concert with nearshore data for fish distribution, and energetics. The results and conclusions of these data are included under objectives a and b under biochemical analyses.
B) Biochemical Analysis

i) OBJECTIVES

Biochemical studies were conducted as part of GAP to address the flow of energy in the shelf regions of Kodiak Island to accurately quantify the partition of resources available for apex predators.

(a) Fatty Acid Analyses

(b) Material and energy transfer in the Gulf of Alaska

ii) APPROACH

(a) Fatty Acid Analyses

Refining our knowledge in forage fish lipid dynamics is a necessary and effective step to improve the understanding of marine ecosystem functioning. Forage fishes serve as the main energy passageways between zooplankton and piscivorous fishes, marine mammals, and seabirds, and a significant portion of the conveyed energy is in the form of lipids. Variations in forage fish lipid content and fatty acid composition not only offer insights into forage fish life history and local plankton production, but also have profound implications on upper trophic level species. For these reasons, information on forage fish lipid dynamics has been used to investigate a variety of ecological questions, from fish community reorganization to marine mammal population decline. Fatty acids have also been used as natural biomarkers in marine ecosystems, because most dietary fatty acids are deposited in predator tissues with little modification. Fatty acids are structural moieties in most lipid molecules: fatty acids are typically esterified to alcohol groups (e.g., in glycerides) or amino groups (e.g., in sphingolipids). In marine plankton and fishes, fatty acids are commonly composed of 14 to 24 carbon atoms and up to six double bonds.

Relative to the GAP focus on SSL diets, scat and stomach content analysis are useful for qualitatively assessing most of the diet items, but have serious limitations that may bias the quantification of actual diets of the marine mammal. Fatty acids represent a large portion of the lipid component of organisms and are often conserved when ingested. Therefore, fatty acid analysis represents a tool for determining the origin of ingested food and a quantitative way of assessing prey items important to the diet of marine mammals.

Also to determine the importance of copepod derived energy in the GAP region, fatty acid analyses were used to test the relative accuracy of stomach content analyses. To date, calanoid copepods are the only known marine organisms capable of de novo biosynthesis of considerable amounts of 20:1 (20 carbon atoms and one double bond) and 22:1 fatty acids and fatty alcohols. In zooplanktivorous fishes, dietary fatty alcohols are efficiently oxidized into fatty acids while dietary fatty acids are directly absorbed with little alteration. As a result, both 20:1 and 22:1 fatty alcohols and fatty acids from copepods were deposited as 20:1 and 22:1 fatty acids in fishes. Preferential utilization of 20:1 and 22:1 fatty acids reduces the relative abundance of these fatty acids in predator lipids compared to in prey lipids. Thus, the presence and relative abundance of 20:1 and 22:1 fatty acids in forage fishes serve as indirect evidence for the importance of calanoid copepods as prey items for these fish species.

The specific objectives of this project included in the original grant request and highlighted in the no-cost extension request in 2009, were to collect pelagic and ground fishes within the GAP study region, determine protocol for lipid extraction and fatty acid assessment in coordination with other labs in the North Pacific collecting similar data, quantify fatty acid methyl esters from a representative sample of fish, and to compare seasonal and species specific variability in fatty acids found in fish near Kodiak Island. Another goal of this study was to provide fatty acid data of potential SSL prey to the Alaska Department of Fish and Game to drive a quantitative assessment model of SSL diets based on biochemical analyses. Unfortunately the Alaska Department of Fish and Game reallocated resources and did not complete this study. In this study, we assessed
lipid content and fatty acid composition of four locally important forage fish species, walleye pollock, Pacific herring, capelin, and eulachon, systematically sampled from embayments of the Kodiak Archipelago in the Gulf of Alaska. Forage fishes utilize these embayments as feeding and spawning habitats, and constitute critical food sources of local piscivorous fishes, marine mammals and seabirds.

Methods: Fishes were collected during acoustic-trawl surveys in four embayments of the Kodiak Archipelago, Alaska: Uganik, Tonki, Perenosa, and Paramanof Bay. A total of 81 midwater trawls were conducted in May and August of 2004 and 2005, November 2006, and April 2007. The trawl net was equipped with a modified codend of 10 cm mesh and 2.5 cm mesh liner. Sample length ranges were targeted to include stages in which fishes are expected to feed on both copepods and euphausiids. Trawls were deployed during daylight hours to groundtruth acoustic data collected to estimate fish biomass. For this study, we focused on four species that consistently dominated marine mammal diets and net catches: walleye pollock, Pacific herring, capelin, and eulachon. Zooplankton samples were collected concurrently for fatty acid analysis to ensure that copepod-originated fatty acids were not present in large amounts in other zooplankton taxa, particularly in euphausiids. Sampling gears included a triple-net Tucker Trawl (1 m² opening, 300 µm mesh), a bongo trawl (both 0.75 m diameter opening, 500 and 1000 µm mesh), and a ring net (0.75 m diameter opening, 130 µm mesh). The Tucker and bongo trawls were employed opportunistically and towed obliquely while the ring net was employed systematically at predesignated stations and towed vertically. On board, net contents were sorted into four groups: copepods, euphausiids including adults and juveniles, chaetognaths, and pteropods, which are known important prey taxa of forage fishes in the Gulf of Alaska.

Copepod-originated fatty acids were quantified for both fish and zooplankton samples. Lipids were extracted from individually homogenized whole fish, following the modified Folch method. Lipid content was calculated gravimetrically as percentage of whole-body wet weight. After lipid extraction, a total of 252 fish and 80 zooplankton samples were further analyzed for fatty acid composition. Fatty alcohols were only qualitatively accessed for both fish and zooplankton samples to confirm that copepods were the sole group with large amounts of 20:1 and 22:1 fatty alcohols.

Fish stomach content analysis was focused on the occurrence of copepods and euphausiids in order to compare with our fatty acid results. In the lab, fish were measured for total length to the nearest 0.1 cm and whole-body wet weight to the nearest 0.01 g. Excised stomach contents were weighed to the nearest 0.001 g, identified to the lowest taxonomic or developmental level possible and counted. To facilitate comparison between stomach content and fatty acid results, prey were combined into broad taxonomic and developmental categories. Euphausiids of different developmental stages were reported in two groups: 1) adults and juveniles, and 2) furcilia stages, calyptopis stages, and eggs. This taxonomic compromise conformed to the coarse level adopted in fatty acid analysis of concurrently collected zooplankton, which enabled direct comparisons of the two datasets.

Forage fishes were collected from Uganik, Tonki, Perenosa, and Paramanof Bay of the Kodiak Archipelago in May and August of 2004 and 2005, November 2006, and April 2007. Samples were captured using a midwater trawl (DanTrawl Bering Billionaire) with a codend of 10 cm mesh and 2.5 cm mesh liner. Samples were stored in air-tight containers at -20°C on board and, after each survey, vacuum-packed and stored in the lab at -30°C until analysis. Lipids were extracted from whole-body homogenates of 816 samples.
Fatty acid samples were also sent to multiple laboratories to compare methodology in Anchorage, Juneau, and Washington. Comparisons among labs were made and standards were equilibrated so that future comparisons could be made.

Results and Conclusions: Over 800 esterified lipid samples, including both pelagic and benthic fishes, were analyzed with a GC/FID (Gas Chromatograph/Flame Ionization Detector) and data was entered into a fatty acid database. Fatty acid contents of 20:1n-11/9 and 22:1n-11 varied in fish samples among species, months, embayments, and length categories. For example, values in walleye pollock collected in August 2004 were higher in Uganik Bay than in those of similar total length in Tonki Bay (p < 0.01). In all fish samples, 20:1 or 22:1 fatty alcohols were negligible. In zooplankton samples, fatty acid contents of 20:1n-11/9 and 22:1n-11 varied among taxonomic groups and months. In particular, values in euphausiids were expectedly low, with a maximum of 3.15% for 20:1n-11/9 and 3.38% for 22:1n-11. In addition, 20:1 or 22:1 fatty alcohols were found in large amounts in copepods, while they were negligible in euphausiids, chaetognaths, or pteropods. Both copepods and euphausiids were encountered in fish stomach contents, which satisfied the premise of our hypothesis. Stomachs were empty in 2.5%, 3.4%, 2.8%, and 4.4% of sampled walleye pollock, Pacific herring, capelin, and eulachon respectively. In 1,043 non-empty stomachs, adult and juvenile euphausiids (hereafter euphausiids) had the highest mean numeric percentage in all fish species, followed by copepods. All adult herring, capelin, and eulachon were entirely zooplanktivorous.

At the species level, lipid content in pollock was the lowest and in eulachon the highest among the four species (p < 0.001); there was no difference in lipid content between herring and capelin (p = 1.00). In comparison, fatty acid composition in the four species, pollock, herring, capelin, and eulachon, was different from each other (p < 0.001). Walleye pollock lipid content ranged from 0.62% to 9.86%. Dissimilarity coefficient of fatty acid composition among samples was moderately correlated with the differential in lipid content Pacific herring lipid content ranged from 0.53% to 26.62%). Dissimilarity coefficient of fatty acid composition among all the samples was significantly correlated with the differential in both lipid content and total length Capelin lipid content ranged from 1.09 to 20.48% and was not significantly different among months whereas eulachon lipid content ranged from 5.34% to 27.86%. Samples in April and May had lower lipid content than those in August and November Fatty acid composition was assessed for 20 eulachon collected in Uganik Bay in November 2006; only 20:5n-3 content was significantly correlated with lipid content.

Comparison between fatty acid and stomach content results displayed a re-occurring discrepancy: high contents of copepod-originated fatty acids were coupled with low numerical percentage of copepods in stomach contents. The scope and extent of the discrepancy varied among fish species. In walleye pollock, for example, fatty acid and stomach content results of most sample groups were in agreement. The recurring discrepancy between high contents (weight percentage of the 37 quantified fatty acids) of copepod-originated fatty acids and low numerical percentages of copepods in stomach contents of the four forage fish species suggests that dietary copepods were underestimated by stomach content analysis. The underestimation of dietary copepods by stomach content analysis can have profound effects on estimating prey consumption of forage fishes. Compared to stomach contents, fatty acid composition informs dietary information on a larger temporal scale and therefore is less affected by temporal oceanographic events. Such an event common in embayments is the pulsed elevation of meroplankton abundance, with each of these pulses typically lasting one to several days.

In conclusion, the results of this study demonstrate the need to use fatty acid analysis, in concert with stomach content analysis, to provide more diversified and reliable results on diet composition in order to refine our understanding of forage fish feeding ecology. Results of this study demonstrated relatively large intra-species
variations in forage fish lipid content and fatty acid composition. Seasonal variations in forage fish lipid content did not strictly mirror the annual cycle of prey availability, since they are expected to reflect changes in species-specific energy budgets that incorporate life history events. Considering the magnitudes of observed variations, it is apparent that the use of average values at the species level should be avoided when applying lipid data to ecological studies. The construction of forage fish lipid content and fatty acid databases, which are currently in great demand, should incorporate factors including, but not limited to, month, fish length, and location. We also demonstrated that fatty acid analysis can be used as a sensitive and informative tool, in combination with stomach content analysis, to refine our knowledge of forage fish feeding ecology. Additional methods and results regarding the fatty acid project can be found in Guo (2010).

(b) Material and energy transfer in the Gulf of Alaska
The goal of this study which was included in the original grant request and highlighted in the no-cost extension request in 2009, was to examine the material and energy transfer process between the zooplankton communities and forage fish in embayments around Kodiak Archipelago. Attributes of mesoscale (0.1 – 10 km) forage fish aggregations are key aspects in defining both short-term and long-term variations in prey availability for apex predator populations and thus the quality of feeding grounds for apex predators. Objectives were to determine major prey groups of forage fishes in embayments around Kodiak Archipelago, estimate taxonomic composition and relative abundance of local forage fishes and their major prey groups, examine proximate composition, lipid class profiles and fatty acid signatures of forage fish and their prey, examine the relationships between proximate composition, lipid class profiles and fatty acid signatures of forage fish and fish species, fish size and season, quantify the effects of major prey's chemical composition on forage fish's chemical composition, and examine the response time of dietary effects on forage fish body composition. We hypothesized that lipid content and fatty acid composition would vary significantly by month, fish length, and embayment. We also hypothesized that 1) patchiness of local forage fishes is species-specific and these patchy distributions form seasonal “hot spots” of feeding grounds for upper trophic level predators, and that 2) biomass of forage fish assemblages is an inadequate proxy for the amount of energy available to predators.

Methods: Forage fishes were collected from Uganik, Tonki, Perenosa, and Paramanof Bay of the Kodiak Archipelago in May and August of 2004 and 2005, November 2006, and April 2007. Samples were captured using a midwater trawl (DanTrawl Bering Billionaire) with a codend of 10 cm mesh and 2.5 cm mesh liner. We focused on four forage fish species that consistently dominated the net catches: walleye pollock, Pacific herring, capelin, and eulachon. Acoustic-trawl surveys were conducted during daylight hours on the chartered stern trawler F/V Alaskan, equipped with a Simrad EK60 echosounder system. Active acoustic backscatter data were collected through a hull-mounted 38 kHz split-beam transducer (calibrated for gain parameters and beam pattern characteristics), while the vessel followed transects at a nominal speed of 14.8 km hr⁻¹ (8.0 knots). A midwater trawl net (DanTrawl Bering Billionaire) with a modified codend of 10 cm mesh and 2.5 cm mesh liner was opportunistically deployed along transects to corroborate species and length composition of aggregations identified by the acoustic backscatter. A total of 18 and 20 trawls were conducted in May and August respectively. Acoustic backscatter data were processed using Echoview 4.80 (Myriax Software) to estimate fish density (km⁻²) and biomass (kg km⁻²) along transects.

Lipid content (%) and protein content (%) in whole-body wet mass were measured in order to compute energy content. Lipids were extracted from homogenates with the modified Folch method and afterwards lipid content was calculated. Lipids were extracted from whole-body homogenates of 816 samples. Lipid content (%) was calculated as the weight of extracted lipids divided by whole-body wet weight. Extracted lipids from 252 samples were analyzed for fatty acid composition. Weight values of the 37
fatty acids were standardized into compositional values, which were percentages of the total; these standardized values are hereafter referred to as fatty acid contents.

Results and Conclusions: In May, Pacific herring were not captured in Tonki, Shelf, and Perenosa, the three regions on the northeastern side the archipelago; eulachon were not encountered in Tonki and Uganik South; capelin and walleye pollock were found in all five regions. In August, herring were not captured in the Tonki and Shelf regions; eulachon, capelin, and pollock were encountered in all five regions. Compared to May, the numbers of area-units with positive fish densities generally increased. There was a seasonal shift in the location of energetic “hot spots”, when area units from all regions were compared.

In May, most of the area units with the highest energy densities were located in Uganik South; this was primarily due to the dense aggregation of herring. In August, the majority of the area units with the highest energy densities were found in Shelf as a result of high densities of capelin. In both months, energy content among length classes of the four species showed a large range. Within regions, species-combined biomass was not a good proxy for their energy density. About half (50.1% in May and 47.9% in August) of the standardized values of area-unit biomass underestimated or overestimated standardized energy density by more than 15.0%. Among regions, however, biomass was a fairly good quantitative measure of energy density. The proportional differential between standardized biomass and energy density was 15.6%.

Walleye pollock lipid content ranged from 0.62% to 9.86%. Samples in April and May had lower lipid content than those in August and November (p < 0.01). Correlations between lipid content and total length were positive in April and negative in November (p < 0.01). Fatty acid composition was different among months (p < 0.001). Pacific herring lipid content ranged from 0.53% to 26.62%. Correlations between lipid content and total length were negative in May 2004 and positive in August 2005 and November 2006 (p < 0.01). Fatty acid composition was different among months (p < 0.001) and dissimilarity coefficient of fatty acid composition among all the samples was significantly correlated with the differential in both lipid content and total length. Capelin lipid content ranged from 1.09 to 20.48% and was not significantly different among months (p = 0.27). Correlations between lipid content and total length were positive in August 2004 and 2005 and negative in May 2005. Fatty acid composition in May was different (p < 0.001) from that in August (2004 & 2005 combined) and contents of four and seven fatty acids were significantly correlated with lipid content in May and August respectively (p < 0.05). Dissimilarity coefficient of fatty acid composition among all the samples was significantly correlated with the differential in both lipid content and total length (p < 0.01, Rho = 0.36 and 0.15 respectively). Eulachon lipid content ranged from 5.34% to 27.86%. Samples in April and May had lower lipid content than those in August and November. Overall, lipid content in pollock was the lowest and in eulachon the highest among the four species; there was no difference in lipid content between herring and capelin. In comparison, fatty acid composition in the four species, pollock, herring, capelin, and eulachon, was different from each other (p < 0.001).

Horizontal distribution was patchier in Tonki and Uganik South than in other regions for all four forage fish species in both months. The consistently high patchiness of fish distribution in local embayments requires special consideration during survey planning. To retain reasonable precisions for estimating fish density, a relatively high degree of transect coverage should be applied in narrow embayments. The higher degree of patchiness in more enclosed areas may be attributed to a collective anti-predator strategy by the four species. There is little evidence suggesting that oceanographic features in narrow areas of local embayments are more heterogeneous than those in relatively open areas; hence habitat preference does not seem to be the driving force. In addition, the sampling periods did not coincide with the peak in spawning
of the four species. We demonstrated that biomass can be used as a proxy for energy density at certain spatial scales. Comparisons between standardized biomass and energy density values showed that biomass was a reasonable quantitative indicator of energy density among regions (region areas ranging from 51 to 508 km²), but not among area units within regions (each area unit being 0.034 km²).

Results of this study demonstrated relatively large intra-species variations in forage fish lipid content and fatty acid composition. Seasonal variations in forage fish lipid content did not strictly mirror the annual cycle of prey availability, since they are expected to reflect changes in species-specific energy budgets that incorporate life history events. Ontogenetic patterns in lipid content were species-specific. Ontogenetic patterns in lipid content were also specific to month. Isomers of 20:1 and 22:1 fatty acids have been extensively used as natural biomarkers to quantify the importance of calanoid copepods as prey for zooplanktivorous predators: higher 20:1 and 22:1 fatty acid contents indicate higher proportions of calanoid copepods in the diets. Considering the magnitudes of observed variations, it is apparent that the use of average values at the species level should be avoided when applying lipid data to ecological studies. The construction of forage fish lipid content and fatty acid databases should incorporate factors including, but not limited to, month, fish length, and location. We also demonstrated that fatty acid analysis can be used as a sensitive and informative tool, in combination with stomach content analysis, to refine our knowledge of forage fish feeding ecology.

The dense aggregations of capelin in August offer an ideal feeding opportunity for predators, which was supported by sightings of tens of thousands of piscivorous feeding seabirds in the northeast part of Shelf during the survey. In addition, co-occurring eulachon and pollock in Shelf happened to be of the lowest density among the five regions and were generally found in deeper waters than capelin; herring were not encountered in Shelf in August. The relative isolation from other species and dense aggregations over a large area make capelin potentially the dominate prey for apex predators. For SSL scats collected from sites around the Kodiak Archipelago from 1999 to 2005 the prey-specific numerical percentage of capelin was 91.9%, only slightly lower than Pacific sand lance among important prey; in contrast, both percentage frequency of occurrence and mean numerical percentage of capelin were much lower than those of sand lance. The high prey-specific value means that when encountered by sea lions, capelin are the preferred prey and tend to be consumed exclusively during the time frame over which scat results represent, typically two to three days. In comparison, herring, eulachon, and pollock were typically ingested in mixed diets. Therefore, the aggregative behavior of capelin may be an important factor in their relative importance in SSL diets. Capelin are also an important prey resource for humpback whales a local apex predator that prefer capelin over co-occurring pollock of similar sizes.

This study presents a comprehensive description of mesoscale distribution characteristics and energy density of pelagic forage fishes in coaster waters of the Kodiak Archipelago. Distribution was highly variable but consistently patchier in narrower embayments for all species. Dense aggregations were encountered after spawning periods and formed prey “hot spots” for piscivorous predators, exemplified by highly aggregated herring on the northwest side of the archipelago in May and dense capelin schools on the northeast side in August. Despite the difference in species composition, energy content of forage fish assemblages was similar among regions. Thus biomass of forage fish assemblages was found to be an adequate proxy for energy density at the scales of 10s to 100s km². Methods and results regarding the material and energy transfer study can be found in Guo (2010) and energy density specific to walleye pollock in Buchheister et al. (2006).
The large scale climatic regime shift that transpired in the North Pacific Ocean in the late 1970’s has had far reaching consequences for the marine ecosystem in the Gulf of Alaska. Following the 1977 regime shift, there was a proliferation of groundfish predators and a reduction in the prey available to other top-level predators in the system which may contributed to the decline in populations of SSLs, northern fur seals (*Callorhinus ursinus*), HSs, and several species of piscivorous seabirds. Although the exact mechanisms of these community shifts are unclear, the documented decline in shrimp and forage fish species has been attributed in part to predation by the increasing groundfish populations in the Gulf of Alaska. We looked at the trophic position and species interactions of ATF and spiny dogfish due to their extreme changes in population abundance relative to other apex predators in the GAP region.

(a) Investigating the trophic role of ATF as a top level consumer in the Gulf of Alaska.

(b) Variation in the trophic position of spiny dogfish (*Squalus acanthias*) in the Gulf of Alaska.

**ii) APPROACH**

(a) Investigating the trophic role of ATF as a top level consumer in the Gulf of Alaska.

In the Gulf of Alaska, the biomass of ATF has nearly tripled to over 2 million metric tons (mt) in the past 20 years (Turnock et al. 2005). Consequently, ATF are becoming an increasingly important component in the Gulf of Alaska ecosystem. Adult ATF are top-level fish predators and feed on forage fish species including capelin, juvenile walleye pollock, Pacific sand lance, and eulachon. Their diet overlaps with many top-level fish and marine mammal predators in the Gulf of Alaska. Predation is a major component in structuring prey populations in a marine ecosystem. In fact, predation mortality can comprise a major portion of the natural mortality rate for certain fish populations. Therefore, it is important to quantify the impact of predation by top level consumers such as adult ATF, on certain prey populations. This study will identify the major prey organisms, particularly commercially important species, found in the diets of adult ATF and will produce annual estimates of consumption by adult ATF of these species from 2000 – 2004. The main prey items eaten by ATF in the Gulf of Alaska are important forage species such as juvenile walleye pollock, capelin, and Pacific herring. Quantifying the removals by adult ATF will provide valuable information into the fluctuations of some key fish stocks.

This study will also produce initial estimates of the total fish biomass and energy flow to adult ATF in the Gulf of Alaska food web. Calculating the magnitude of these estimates will be useful in determining if predation by top level consumers is a dominant force driving the Gulf of Alaska food web. The specific goals of this research project were to:

- examine the seasonal and interannual variations in the diets of ATF in the study area
- provide estimates of the consumption of commercially important prey, by ATF, in the study area on a yearly scale;
- produce initial estimates of the flow of total fish biomass and energy to ATF in the Gulf of Alaska food web on an annual scale.

**Methods:** This study is based on the analysis of stomach contents of ATF collected during the GAP program in the nearshore waters of Kodiak Island in the western Gulf of Alaska from 2002 – 2004. Sampling stations were located within a 20 nm radius around Long Island and encompassed waters of Chiniak and Marmot bays. The sampling stations were randomly selected using depth and distance criteria from Long Island and were sampled twice annually, typically in early May and August, in 2002, 2003, and 2004. After each bottom trawl, a maximum of 20 ATF specimens were set aside for analysis depending on the catch size. In 2002 and 2003, only ATF ≥ 40 cm total length were collected; however in 2004 all size classes of ATF were collected to investigate ontogenetic dietary shifts. Stomach samples were preserved in 10% formalin–seawater solution and brought back to the laboratory for analysis of ATF feeding habits. In each
sample, intact prey organisms were counted, weighed (0.001 g) and measured (1.0 cm). Individual prey items were grouped into categories to analyze temporal and ontogenetic variations. Within year variations in ATF diet and feeding activity were assessed using stomach samples of adult ATF (> 40 cm total length) captured in the 100 – 200 m depth interval only in 2002 and 2003. In 2004, within year dietary variations were analyzed separately for the two ATF size classes (20 – 39 and ≥ 40 cm total length) in each depth interval (< 100 and 100 – 200 m).

ATF consumption was estimated from a bioenergetics model based on a balanced energy equation: C = (R + A + SDA) + (F + U) + (S + G) where C = consumption, R = respiration, A = active metabolism, SDA = specific dynamic action, F = egestion, U = excretion, S = somatic growth, and G = gonad production. Consumption was calculated as the proportion of energy needed to achieve observed growth after accounting for losses from each physiological process. ATF stock information was used to estimate ATF growth, mortality, and population structure. The model inputs describing ATF abundance and diet as well as water temperature and prey energy content inputs were generated from field data collected on the survey cruises for the present study. Generalized growth rates (g/g/d) for individual ATF length classes were calculated from published weight-at-age data. ATF diet composition data was generated from specimens collected within the study area during bottom trawl surveys in May and August of 2002, 2003, and 2004. ATF population estimates were generated using the area swept method for each depth strata (0 – 99 m, 100 – 200 m, and > 200 m) in the study area. Energy density values of ATF and their common prey items were determined for each sampling period from field collected specimens. For those species not captured during the survey cruises, energy density values were determined from literature values. Prey energy density values (kJ/g wet weight) were manually entered into the model and were calculated as Energy density (kJ/g) = (% lipid/ 100) × 36.43 + (% protein/ 100) × 20.1 where the energy equivalent values for lipid (36.43 kJ/g) and protein (20.1 kJ/g) were used. To better assess ATF prey consumption within the nearshore waters of Kodiak Island, AK, multiple model simulations were conducted to examine: 1) interannual variations in prey consumption by adult ATF ≥ 60 cm, 2) variations in prey consumption among 10-cm ATF length classes in 2004, and 3) total prey consumption by the estimated ATF population (≥ 20 cm) within the study area in 2004. In each model simulation, ATF prey consumption was calculated over an 84 day period representing the time from May to August for each study year. Separate model simulations were run for each depth interval (0-99, 100 – 200, > 200 m) within the study area.

Results and Conclusions: A qualitative analysis of stomach contents did not detect substantial differences in the diet between the sexes; therefore the diet composition data for the two sexes were pooled. Of the 742 ATF stomachs examined, 465 contained prey and 275 (37.0%) were empty. A total of 2,835 prey items were identified consisting of 40 different prey items. The predominance of pelagic prey in the stomachs including forage fish, pelagic shrimps, and euphausiids suggests ATF feed mainly in the water column. Fish were clearly the most important prey category and included at least 11 different species. Walleye pollock, Pacific sand lance, and capelin were the three most dominant fish prey on a weight and occurrence basis. Euphausiids, mostly of the Genus Thysanoessa, occurred in roughly 30% of the stomachs and comprised 17.7% by weight of the total stomach contents. Fish were clearly the most important prey category and included at least 11 different species. Walleye pollock, Pacific sand lance, and capelin were the three most dominant fish prey on a weight and occurrence basis. Euphausiids, mostly of the Genus Thysanoessa, occurred in roughly 30% of the stomachs and comprised 17.7% by weight of the total stomach contents. Shrimp were a relatively important prey and occurred in 12.0% of the ATF diets. Pandalus borealis and other pandalid shrimp were the most important shrimp species in the diets. Other prey items including miscellaneous mysids, copepods, and bivalves, were largely incidental and contributed relatively little by weight of the total stomach contents. ATF displayed substantial differences in diet composition among the years in each of the sampling periods. Interannual trends in stomach fullness and percent of empty stomachs suggest that ATF feeding activity decreased in 2004. The mean size of walleye pollock in the ATF diets differed among the years. In 2002, the diets of ATF (> 40cm) in May and August were similar in that walleye pollock and other fish
were the most dominant prey items respectively in each month. In each sampling month, these prey were the most frequently consumed and comprised the greatest portion of the diet (> 70% by weight combined). In 2003, there were also no substantial differences in the ATF diets between May and August. In 2004, there were substantial differences in the diet of ATF (≥ 40 cm) between May and August. For the larger ATF (≥ 40 cm), Pacific sand lance and euphausiids were the dominant prey items in each of the months. In May, there were substantial differences in the diets of the two ATF size classes (20 – 39 and ≥ 40 cm). In the deeper waters during May, the diets between the two size classes of ATF were fairly similar. The number of stomachs analyzed in order to reach an asymptote was highly dependent on the sampling month, ATF size, and depth collected. The number of stomachs needed in order to reach an asymptote ranged between 23 and 43 with a mean of 29.5. There were no noticeable trends in the number of stomachs analyzed to reach an asymptote between sampling months, ATF sizes, or depth intervals.

There were substantial differences in the daily consumption of prey by ATF (≥ 60 cm) among the study years. ATF (≥ 60 cm) had a significantly higher (P < 0.001) cumulative prey consumption rate in 2004 compared with previous years. In addition, these fish consumed capelin, euphausiids, other fish, and Pacific sand lance at a significantly higher rate (P < 0.001) in 2004. Conversely, the daily consumption (g/d) of walleye pollock was significantly higher (P < 0.001) in 2002 and 2003 compared to 2004. Total prey consumption by ATF ≥ 60 cm increased from around 61 mt in 2002 to over 160 mt in 2003 and 2004. In the shallowest depths (0-99 m) there were significant differences (ANOVA, 2 df, P < 0.001) in the daily prey consumption (for all prey groups) among the ATF length classes. In 100 – 200 m deep waters, there were also significant differences (ANOVA, 2 df, P < 0.001) in the consumption rates of prey (for all prey groups) among the ATF length classes. In general, the total prey consumption rates increased with increasing ATF size. The larger ATF generally consumed Pacific sand lance, walleye pollock, and other fish at a higher rate than smaller ATF. Conversely, smaller ATF consumed capelin at a relatively higher rate than ATF > 40 cm. Shrimps and euphausiids were generally consumed at the highest rates by mid-sized ATF (30 – 60 cm). In the shallowest depth interval (0 – 99 m), two ATF length classes (50 – 59 and 60-69 cm) constituted 64% of the estimated ATF abundance in the area and in turn accounted for the majority (74%) of the total prey biomass consumed among the various size classes. It was estimated that there were nearly twice as many ATF (≥ 20 cm) in 100 – 200 m waters compared to the shallower depths and these fish consumed 160 mt more prey. The results of sensitivity analyses indicated that individual food consumption estimates produced from the model are most sensitive to respiration parameters and associated temperature inputs.

The diet composition results indicate ATF eat mainly fish and crustaceans, such as euphausiids and shrimps, which is consistent with previous findings. In this study, benthic invertebrate prey such as mollusks, annelids, and echinoderms were incidental items in the ATF diets which is consistent with previous studies. The importance of a site specific species, such as Pacific sand lance, may have been obscured in previous studies which sampled far greater areas and habitats than this project. Consequently, Pacific sand lance appear to be a locally important prey item for ATF within Marmot and Chiniak bays. Interannual diet comparisons revealed several key shifts in the diets of adult ATF among the study years. Therefore temporal dietary shifts reflect changes in prey abundance and availability. The water temperatures of the study area were the freshest and warmest in 2003 possibly resulting in the low abundance of euphausiid larvae found in 2003. The shift to consuming mostly age 0+ walleye pollock in 2004 is another example of the trophic adaptability of ATF. Therefore, ATF maximize their net energy gain by consuming capelin rather than other prey at this time. The ability of ATF to take advantage of this energy rich food source when they are available, highlights their adaptive feeding behavior. It was found that the smaller ATF consumed significantly more euphausiids, shrimp, and capelin than larger ATF. Results of this study suggest that ATF
are generalist predators which feed mainly on pelagic prey such as zooplantivorous forage fish and euphausiids. These species are critical links between primary producers (phytoplankton) and higher trophic level predators and are consumed by many fish, marine mammals, seabirds, and whales in the Gulf of Alaska. Overall, the observed ontogenetic, temporal, and spatial dietary shifts in response to changing prey availability and quality highlights the adaptable feeding behavior of ATF.

ATF prey consumption estimates were largely influenced by predator abundance among the study sites. The interannual differences in ATF abundance may be correlated with the migratory behavior of ATF. The consumption estimates also reflected the temporal changes in ATF diet composition. Around Kodiak Island, capelin spawn on intertidal beaches during the spring and summer and it appears they became a more available or profitable food source when they were migrating nearshore to spawn. Conversely, euphausiids were generally more important in the ATF diets during May. The bioenergetics model developed had over 15 physiological parameters and field inputs that could ultimately affect the consumption estimates. Similar to previous bioenergetics modeling studies, the sensitivity analysis revealed that perturbations to the respiration parameters had a stronger effect on consumption estimates compared to changes in egestion and excretion parameters.

The results of this study indicate that the diet of ATF directly overlaps those of other top-level predators and that the prey removals may be substantial. The top prey items in the ATF diets used in the bioenergetics model are significant dietary components for humpback whales, SSLs, tufted puffins, Pacific halibut (*Hippoglossus stenolepis*), and adult walleye pollock. Within the study area, the consumption estimates indicate that ATF may be consuming a significant amount of prey including approximately 135 mt of euphausiids and 113 mt of Pacific sand lance during a 84 day period in 2004. In comparison, humpback whales around Kodiak Island are estimated to remove 1944 mt of euphausiids and 392 mt of Pacific sand lance for a 152 day feeding season. Methods and results regarding the arrowtooth flounder diet and energetics projects can be found in Knoth (2006) and Knoth and Foy (2008).

(b) Variation in the trophic position of spiny dogfish in the Gulf of Alaska. Spiny dogfish biomass estimates in the Gulf of Alaska based on bottom trawl surveys have indicated an increasing trend from 1990 until 2007. These dramatic changes in spiny dogfish biomass clearly demonstrate the need for a better understanding of the ecology and the life history patterns of this species. To date, little is known about the ecology of spiny dogfish in the Gulf of Alaska ecosystem; specifically, only one study exists that examined dietary patterns and thus trophic linkages of spiny dogfish in the Gulf of Alaska. Spiny dogfish are omnivorous opportunists that consume a wide range of prey items, including fishes, mollusks and crustaceans. Spiny dogfish are both an important prey item as well as competitor with SSLs. As spiny dogfish and other elasmobranch biomass has increased in the Gulf of Alaska in the past decade, the correlation to SSL declines needs to be addressed. Prior to a direct analysis, the importance of spiny dogfish in the Gulf of Alaska ecosystem needs to be determined. The goal of this study was to investigate the trophic status of spiny dogfish and to evaluate its role as a top-level predator in the Gulf of Alaska ecosystem. The specific goals of this research project are to:

- quantify number, biomass, fullness and frequency of occurrence of prey species in the stomach contents of individual spiny dogfish.
- assess stomach condition of spiny dogfish according to determination of fullness.
- determine trophic status of individual spiny dogfish with stable isotope analyses.

**Methods:** Spiny dogfish were collected in the northeastern Pacific Ocean off British Columbia and Alaska from 2004-2006. Specimens were obtained using baited long lines, trawls, setnets, and sportfishing gear (i.e., rod and reel) in the months from April to
September. For the isotope analysis, the second dorsal spine with attached white muscle tissue was removed. The majority of samples (n=451) were selected from 2005; however, in order to explore interannual variation in stable isotope signatures, additional samples from 2004 (n=20) and from 2006 (n=20) were selected and processed. To establish a trophic baseline, weathervane scallops (*Patinopecten caurinus*) were obtained from nine sites in the Gulf of Alaska (2005, n=1; 2006, n=8), ranging from Lituya Bay in the eastern Gulf of Alaska to the Shumagin Islands in the western Gulf of Alaska, and from two sites in the southeastern Bering Sea. Compared to proteins, lipids are depleted in $^{13}$C; as a result, the lipid content of a given tissue can influence carbon stable isotope values of that tissue. Here we used the C:N ratio as a proxy for lipid content to adjust for variable lipid content of samples. The C:N ratio was calculated from the %C and %N of each individual sample measured by the mass spectrometer.

**Results and Conclusions:** Weathervane scallop del$^{15}$N values varied significantly regionally between the Bering Sea and the Gulf of Alaska. Thus, a mean stable nitrogen value for the entire Gulf of Alaska (n=90) was calculated and used as the baseline nitrogen isotopic value to adjust spiny dogfish nitrogen values and calculate trophic position. A total of 186 males were sampled, ranging in length from 61 to 96 cm, and 305 females were sampled, ranging in length from 52 to 113 cm. Individual spiny dogfish del$^{15}$N values ranged from a minimum of 10.8‰ (Yakutat and NE Gulf of Alaska) to a maximum of 15.6‰ (Kodiak), while $^{13}$C values ranged from -23.1‰ (Yakutat) to -16.3‰ (BC). Lipid normalized del$^{13}$C' values ranged from -21.2‰ (Yakutat and NE Gulf of Alaska) to -16.8‰ (BC). For spiny dogfish ranging in length from 52 to 113 cm, both del$^{15}$N and del$^{13}$C were linearly related to length at most sites. Kodiak, PWS, NE Gulf of Alaska, and Yakutat had significant linear relationships between del$^{15}$N and spiny dogfish length. Variability in both the nitrogen and carbon stable isotopes indicated that spiny dogfish are feeding in different food webs and in potentially different habitats over the spatial range of this study. Differences in the type of food web used by spiny dogfish may be correlated to the difference between inshore and offshore habitats.

This study provided a preliminary assessment of the diet and trophic position of spiny dogfish in the northeastern Pacific Ocean. The significant range of nitrogen and carbon stable isotope values provides evidence that dogfish are occupying different trophic positions and potentially different habitats in this region. These data may indicate that dogfish range from a more pelagic, lower trophic position in the Gulf of Alaska and Yakutat to having a greater reliance on benthically derived prey of a higher trophic position in the more southern and, in some cases, enclosed habitats of Dixon Entrance, Howe Sound, and Puget Sound. Spiny dogfish in the northeastern Pacific Ocean exhibited ontogenetic changes in diet as exhibited with increases in trophic position with length. The results of this study support other findings from diet analyses that spiny dogfish prey is a function of size. Our results provide further insight that spiny dogfish not only are switching to larger sized and to a higher diversity of prey items, but are clearly accessing prey items that are of a higher trophic level. We hypothesize that the waters surrounding Kodiak are more productive than the EGO and provide a more abundant pelagic prey items for the smaller dogfish sizes. Diet studies have shown that dogfish are opportunists that prey on seasonally abundant prey. This opportunistic feeding behavior coupled with the results of this study suggest that dogfish may be capable of filling a wide range of feeding niches as their population increases.

It is unknown whether future physical and biological changes in the Gulf of Alaska ecosystem would support a long-term increase in the population of spiny dogfish. Spiny dogfish are a top predator in the Gulf of Alaska ecosystem and occupy a high trophic position along with many of the marine mammals, sea birds, and piscivorous fishes. Our results demonstrate that spiny dogfish have a range of trophic positions from at least 3.3 to over 4.2 in the Gulf of Alaska. In this range, spiny dogfish are competing with salmon, rockfish (Scorpaenidae), walleye pollock, and baleen whales and at the
maximum of this range spiny dogfish compete with some skates, sablefish (*Anoplopoma fimbria*), Pacific cod, and piscivorous seabirds. Therefore, large spiny dogfish are an important predator in the Gulf of Alaska ecosystem and share high trophic positions along with other top predators that include piscivorous seabirds and fishes. Methods and results regarding the spiny dogfish trophic level project can be found in (Andrews 2010) and Andrews and Foy (2010).

D) Fish Physiology and Ecology

i) OBJECTIVES

(a) Evaluate the effects of water temperature on Pacific cod performance as well as plasma endocrine, metabolic and osmoregulatory indices.

(b) Determine temperature effects on rates of metabolic recovery of Pacific cod.

(c) Evaluate the effects of temperature on swimming performance, metabolic rate and plasma constituents at rest and during activity of walleye pollock.

ii) APPROACH

The influence of ocean regime shifts on the relative abundance of groundfish is well documented. Current observations suggest that the warm regime of the Bering Sea and Gulf of Alaska may be reverting to conditions characterized by the pre-1977 cold regime. This regime, characterized by colder surface water temperatures, favored recruitment of forage species and a reduced biomass of groundfish in the Central and Eastern Gulf of Alaska. While the majority of reports have examined these changes in species abundance in the context of life history characteristics, food availability and predation, there is a lack of information describing changes in the physiology of species that occupy important positions in the trophic structure of the shelf around Kodiak. Most marine fishes are heterothermic ectotherms and thus are subject to changes in metabolic rate as a function in environmental temperature. Given the association of metabolic demands and environmental temperature, physiological tradeoffs must occur as these fish attempt to adapt to and function in a changed environment. These tradeoffs may manifest themselves in how forage is assimilated and partitioned into biologic needs such as growth and reproduction. We proposed to perform a series of tests, seasonally, that examined the swimming performance of walleye pollock and Pacific cod subjected to different temperature regimes, assessed alterations in metabolic demands associated with water temperature change, and linked these observations to intra-annual variations in organosomatic indices and plasma constituents.

(a) Evaluate the effects of water temperature on Pacific cod performance as well as plasma endocrine, metabolic and osmoregulatory indices.

**Methods:** Critical swimming speed (Ucrit) and rate of oxygen consumption of Pacific cod acclimated to 4 and 11° C were determined to assess the influence of water temperature on performance. The physiological effect of exercise trials on fish held at two temperatures was also assessed by comparing haematocrit and plasma concentrations of cortisol, metabolites and ions collected from fish before and after testing.

**Results:** The Ucrit of fish acclimated and exercised at 4° C did not differ from those acclimated and exercised at 11° C [1.07 body lengths (total length) s⁻¹]. While the standard metabolic rate of 11° C acclimated fish was 28% higher than that of 4° C fish, no significant difference was observed between fish acclimated at the two temperatures. Plasma concentrations of cortisol, glucose and lactate increased significantly from pre- to post-swim in both groups, yet only concentrations of cortisol differed significantly between temperature treatments. Higher concentrations of cortisol in association with greater osmoregulatory disturbance in animals acclimated at the lower temperature indicate that the lower water temperature acted as an environmental stressor.
Lack of significant differences in Ucrit between temperature treatments, however, suggests that Pacific cod have robust physiological resilience with respect to swimming performance within temperature changes from 4 to 11°C. In this study, the effect of acclimation temperature on metabolic rate of Pacific cod was not significant and the Q10 was below two. Such a response can be explained either by selection of temperatures in this study that were potentially outside the optimum for these fish or that Pacific cod are able to acclimate sufficiently to maintain metabolic rate across a 7°C temperature differential. Low water temperatures, however, may act as an environmental stressor affecting Pacific cod recruitment in the Gulf of Alaska and elsewhere. Although swimming performance of Pacific cod in this study was similar at 4 and 11°C, high resting levels of plasma cortisol and osmoregulatory disturbances observed here are suggestive of chronic stress in the animals maintained at lower temperatures. How such a chronic stressor would affect Pacific cod recruitment remains unclear and thus remains a topic of continued research. Complete methods and results of cod performance physiology can be found in Hanna et al, 2008a,b.

(b) Determine temperature effects on rates of metabolic recovery of Pacific cod.

In a previous experiment we found that Pacific cod, acclimated to two different temperatures (4°C and 11°C), showed no significant difference between Ucrit1 and Ucrit2 when swum to exhaustion twice with a one hour rest period in between swims (Hanna 2006) suggesting that one hour was an ample period for fish to recover between swim trials. Analyses of survey catch data indicate that Pacific cod preferentially inhabit waters slightly above 7°C. Paul et al. (1988) examined oxygen consumption rates of Pacific cod held at different temperatures and found differences in fish held between 3.5°C and 7°C but no differences in fish held between 7°C and 12°C. This suggests that these fish can acclimate to maintain metabolic rate between 7°C and 12°C but adjust their metabolic rate at temperatures between 3.5°C and 7°C. Thus, we set out to determine temperature effects on rates of metabolic recovery of wild-caught Pacific cod held at 2°C and 7°C.

Methods: To assess metabolic recovery we collected blood samples both before and after swim trials and after two and four hours of recovery. Samples were analyzed for hematocrit and plasma concentrations of cortisol, lactate, glucose, total protein, Na+, and Cl−. Because Pacific cod swum at different temperatures did not differ in their Ucrit1 and Ucrit2, we hypothesized that they would not differ in their rates of recovery.

Results: Concentrations of cortisol, glucose, and lactate significantly increased post-swim as compared to samples collected pre-swim irrespective of temperature treatment. For either temperature treatment, sample concentrations of cortisol, glucose, and lactate of cod remained elevated and did not return to pre-swim levels after four hours of recovery.

Because neither temperature group experienced any measurable amount of metabolic recovery in any variable we assessed, we cannot say that temperature does not affect rates of recovery. However, the temperatures chosen do not seem to affect short term recovery after exhaustion in Pacific cod. Differences in recovery rate seen in other studies occurred over wider temperature ranges than those examined in this experiment and included three temperature groups. Wilkie et al. (1997) acclimated Atlantic salmon to 12, 18, and 23°C and Galloway and Kieffer (2003) examined Atlantic salmon at 6, 12, and 18°C. To effectively demonstrate a temperature effect on recovery, one would need to greatly increase the observation time post-exhaustion. Thus, adding more and broader temperature treatments might help to elucidate a relationship between recovery rate and ambient temperature in Pacific cod. Complete methods and results of cod recovery studies can be found in Hanna et al 2008a.
(c) Evaluate the effects of temperature on swimming performance, metabolic rate and plasma constituents at rest and during activity of walleye pollock.

Swimming performance, metabolic rate, and plasma constituents were examined at rest and during activity of captive adult pollock in May of 2006. The impact of temperature on these parameters was evaluated by exercising the fish at three different water temperatures. Because temperature is known to impact biochemical reactions, it was believed that fish exercised at lower temperatures would demonstrate decreased swimming performance and metabolic rates than those at higher temperatures.

Methods: Swimming performance, metabolic rate, as well as endocrine and metabolic plasma indices, was examined in walleye pollock at 1.0, 4.5 and 8.5°C to determine the effects of water temperature on performance.

Results: Because pollock are such an important species ecologically, as well as economically, it is necessary to understand how climatic shifts may be impacting their populations. Reduced Ucrit2 suggests pollock recover from exhaustive exercise slower at extremely low temperatures. However, further work is needed on this topic to examine mechanisms that lead to the decreased Ucrit2 observed here. This, along with the metabolic and swimming performance data collected in this study, may be used to produce more accurate bioenergetics models that take into account temperature impacts on energy requirements as well as metabolic rates based on active fish. Combined with physiological data from prey species, this will allow us to better estimate energy requirements of populations impacted by environmental shifts. Complete methods and results of pollock performance studies can be found in Hanna et al 2008b.

IV) HUMAN COMPETITORS

During this reporting period one of our goals was to address the importance of human impact within our study area on the east side of Kodiak. Data sets regarding commercial catch locations, amount, and species composition were mined. Our goal was to assess the seasonal removals of fish species that are highly important to the diets of apex predators on the east side of Kodiak Island.

i) OBJECTIVES

(a) Trophic level of commercial groundfish removals in the Gulf of Alaska.

ii) APPROACH

(a) Trophic level of commercial groundfish removals in the Gulf of Alaska.

Trends in trophic level estimates of commercial fishery catches are used as ecosystem-based indicators for sustainability, but these estimates often do not incorporate species-specific interannual and ontogenetic feeding patterns. Changes in the trophic structure of an ecosystem can also be altered by climate changes; e.g., following a shift to a warm phase of the Pacific Decadal Oscillation in 1976/77. Therefore, it is essential to understand trophic patterns and interactions of key species to elucidate potential impacts of fishery removals on the ecosystem. This study provided a finer resolution of ontogenetic and temporal variations in the trophic position of four groundfish species in the central Gulf of Alaska, walleye pollock, Pacific cod, ATF, and Pacific halibut, using stable isotope analysis to assess total length and diet source.

Part one of this study was to examine the seasonal, interannual, and ontogenetic variability in the trophic role (both diet source and trophic level) of all four groundfish taxa, and to relate the observed patterns to prey availability and climate changes in the Gulf of Alaska. The specific objectives were to: 1) examine seasonal, annual, and size-class variation of total length for each species; and 2) compare trophic role among species. The second part of the study was to apply the nitrogen isotope data from part one to develop several Analysis of Covariance (ANCOVA) models to detect possible variations in the relationship between length and trophic level among years. Best-fit models were then used to estimate trends in mean total length and trophic level ranges of commercial catch using length-frequency data.
from onboard fishery observers for each of the target species. For a time series extending beyond the study period, linear regression models were used to estimate the mean trophic level of population biomass based on length frequency data and biomass estimates from triennial and biennial trawl surveys conducted by the NMFS and historical catch data during 1990-2009. Specific objectives were to: 1) estimate the mean annual trophic level and trophic level range of the commercial catch for walleye pollock, Pacific cod, ATF, and Pacific halibut; 2) estimate the mean annual trophic level and trophic level range of population biomass estimates; and 3) compare trophic level estimates based on SIA with published Ecopath-derived trophic level estimates.

Methods a: This study was located in the GAP study area on the northeastern side of Kodiak Island in the central Gulf of Alaska and fish were collected from the previously described midwater and bottom trawls. The highest concentration of sampling occurred within the 20-nm radius around Long Island and encompassed waters of Chiniak and Marmot bays. Sampling stations were randomly selected using bottom depth and distance from Long Island; stations were sampled up to four times annually, namely in March, May, August, and November during 2000 – 2004. For this study, a subsample of walleye pollock, Pacific cod, ATF, and Pacific halibut were selected for further analysis. Lipid extracted and bulk tissue samples were weighed to the nearest 0.2-0.5 mg dry weight on a Sartorius CP2P microbalance and enclosed in 3.5 mm x 3.5 mm tin capsules for stable isotope analysis (SIA). To account for differences in the isotope values of different fish tissue, all samples were run in triplicate. Stable nitrogen and carbon isotopes were analyzed at the Alaska Stable Isotope Facility, UAF, using a Costech ECS4010 elemental analyzer interfaced through a CONFLO III to a Finnigan Delta plus XP isotope ratio mass spectrometer (IRMS). Results were presented in delta (δ) notation in per mil (‰) calculated using the following formula:

$$\delta X = \left( \frac{R_{\text{SAMPLE}}}{R_{\text{STANDARD}}} - 1 \right) \times 1,000,$$

where X is $^{15}$N or $^{13}$C and R is the ratio of heavy to light isotope ($^{15}$N:$^{14}$N or $^{13}$C:$^{12}$C) for a given element. The IRMS precision values were 0.11‰ for $\delta^{13}$C and 0.23‰ for $\delta^{15}$N, based on the average standard deviation of replicates of peptone run every 10th sample (n = 319).

Delta $^{15}$N and lipid corrected $\delta^{13}$C values were analyzed to determine temporal, ontogenetic, and spatial variability in each species’ relative trophic level ($\delta^{15}$N), and the food web origin of the species’ diet (pelagic vs. benthic $\delta^{13}$C). For this study, we selected eulachon as a lower trophic level species for the baseline correction of $\delta^{15}$N values.

Size compositions of the commercial catch from 2000 through 2004 were provided by the NMFS Fisheries Monitoring and Analysis Division of the Alaska Fisheries Science Center base on observer data for walleye pollock, Pacific cod, ATF, and Pacific halibut for NMFS reporting area 630. Additionally, abundance and biomass estimates based on raw area swept and length-frequency data of walleye pollock, Pacific cod, ATF, and Pacific halibut were provided for the NMFS bottom trawl surveys over 1984 – 2007 for area 630. The total commercial catch weight (excluding discards and bycatch) and number for each of the species in area 630 were also provided for the same time frame. Parameters from best-fit models for each species were applied to the observed lengths for each year to estimate the trophic level based on length. These trophic level estimates were multiplied by the corresponding fraction of observed lengths to provide an estimated mean trophic level of commercial catch for each species for each year.

Results and Conclusions: For each of the target fish species, differences were found between the average lipid extracted and the average bulk tissue samples. As expected, $\delta^{13}$C values for lipid extracted tissues were significantly enriched relative to the bulk tissue samples for each of the four species, with values for $\Delta \delta^{13}$C ranging between 0.66‰ and 1.57‰. While the average difference between $\delta^{15}$N lipid extracted and the $\delta^{15}$N bulk was only...
approximately 0.1 trophic levels, the $\Delta \delta^{15}\text{N} \text{ (lipid extracted - Bulk)}$ was statistically significant for 3 of the 4 fish species, namely for walleye pollock, Pacific halibut, and ATF. The relative trophic level of Pacific cod and walleye pollock significantly changed with season. All species had seasonal differences in $\delta^{13}\text{C}$. The relative trophic level of each species significantly changed with year. Of the four target species, only Pacific halibut displayed a difference in $\delta^{15}\text{N}$ with depth. Significant differences were found between most species and species-size class combinations for $\delta^{15}\text{N}$ & $\delta^{13}\text{C}$.

To varying degrees, walleye pollock, Pacific cod, ATF, and Pacific halibut all exhibited interannual variations in the length-frequency distributions of the commercial catch and the population. Walleye pollock abundance was the most variable, with higher proportions of smaller fish from bottom trawl surveys in 1999, 2001, 2005, and 2007 and in catch length-frequency distributions from 2002 and 2003. For years within the time frame of the study, Pacific cod had the highest estimated mean trophic level of commercial catch by year, followed by Pacific halibut, ATF and walleye pollock, respectively. Over the years of the study within area 630, the percentage of walleye pollock in the catch declined, while the proportion of Pacific cod rose and the percentages of ATF and Pacific halibut remained relatively stable. The estimated trophic level of the population was the highest for Pacific cod, followed by Pacific halibut, ATF, and walleye pollock. This rank order corresponded with the trophic level estimates of commercial catch; however, the trophic level values for the overall populations were consistently lower, as expected because the population data contained a broader length range than the commercial catch data.

Walleye pollock, Pacific cod, ATF, and Pacific halibut all increased in trophic level with ontogeny, demonstrating that diet composition of these four groundfish species is a function of body size. These findings clearly demonstrate that using only a single trophic level for a given species is likely to lead to erroneous conclusions. Both walleye pollock and Pacific cod exhibited seasonal variations in trophic level. ATF, Pacific cod, and Pacific halibut were feeding at the lowest trophic level in 2003, regardless of their length. Walleye pollock also displayed interannual variation in trophic level; however, these changes in trophic level were influenced by total length. The four target groundfish species also differed in the diet source; specifically, walleye pollock had the most pelagic diet, followed by ATF, Pacific halibut, and Pacific cod. Annual climate changes affecting the strength and timing of the phytoplankton bloom, most likely propagate up through the food web influencing the survival and prey selection of higher trophic levels.

Estimates of mean trophic level based on the best-fit models, which allowed for year effects, nearly doubled the range of the mean trophic level estimates based on lengths alone, suggesting that accounting for temporal variations in diet may be important. Considering the longer time period, 1990 – 2009, the estimated trophic level of catch for each of the target species remained fairly stable; however, patterns arose when the species-specific annual trophic level ranges were examined. Most notably were the expansion and contraction of walleye pollock trophic level values after 1999, the lower trophic level values in 2008, and higher trophic level values in 2009 for ATF, and the disappearance of higher trophic level Pacific halibut with time.

Our results demonstrated that length seems to be the most important driver in estimating the trophic level of a given fish species. Ontogenetic differences in trophic level by far exceeded any interannual differences. Therefore, recruitment of small fish or the commercial removals of selectively larger fish seem to be driving species interactions more strongly than larger ecosystem-scale changes. In addition, it should be noted that while trophic level was mostly influenced by fish length, all target species also showed some temporal variation in their trophic level. Our results also suggest we are currently not fishing down the food web in the Gulf of Alaska and further support the sustainability of Alaska’s groundfish fisheries. Our results demonstrate that the use of catch length-frequency data could further improve estimates of the trophic status as an ecosystem-based indicator of sustainability and lead to
an earlier detection of potential declines in trophic level of a given fish species in the Gulf of Alaska. Additional methods and analyses relative to the ecosystem impacts of commercial removals on the GAP study area can be found in Marsh (2010) and Marsh et al. (in press).

<table>
<thead>
<tr>
<th>Date</th>
<th>LI</th>
<th>CH</th>
<th>UG</th>
<th>GP</th>
<th>CB</th>
<th>TH</th>
<th>IK</th>
<th>CU</th>
<th>LA</th>
<th>SO</th>
<th>SL</th>
<th>MA</th>
<th>DB</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/14/04</td>
<td>143</td>
<td>88</td>
<td>0</td>
<td>89</td>
<td>17</td>
<td>347</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/10/04</td>
<td>198</td>
<td>W</td>
<td>0</td>
<td>115</td>
<td>44</td>
<td>193</td>
<td>86</td>
<td>438</td>
<td>88</td>
<td>89</td>
<td>0</td>
<td>201</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>4/12/04</td>
<td>180</td>
<td>175</td>
<td>0</td>
<td>159</td>
<td>139</td>
<td>358</td>
<td>108</td>
<td>505</td>
<td>81</td>
<td>110</td>
<td>74</td>
<td>81</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>5/14/04</td>
<td>92</td>
<td>117</td>
<td>0</td>
<td>89</td>
<td>250</td>
<td>110</td>
<td>92</td>
<td>204</td>
<td>62</td>
<td>44</td>
<td>30</td>
<td>81</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>6/8/04</td>
<td>69</td>
<td>73</td>
<td>0</td>
<td>126</td>
<td>0</td>
<td>310</td>
<td>106</td>
<td>70</td>
<td>91</td>
<td>2</td>
<td>642</td>
<td>0</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>7/7/04</td>
<td>12</td>
<td>77</td>
<td>2</td>
<td>80</td>
<td>0</td>
<td>260</td>
<td>20</td>
<td>226</td>
<td>D</td>
<td>17</td>
<td>977</td>
<td>0</td>
<td>242</td>
<td></td>
</tr>
<tr>
<td>8/4/04</td>
<td>3</td>
<td>155</td>
<td>7</td>
<td>51</td>
<td>0</td>
<td>257</td>
<td>4</td>
<td>122</td>
<td>8</td>
<td>786</td>
<td>14</td>
<td>245</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/25/04</td>
<td>43</td>
<td>W</td>
<td>3</td>
<td>53</td>
<td>68</td>
<td>395</td>
<td>95</td>
<td>17</td>
<td>251</td>
<td>191</td>
<td>22</td>
<td>688</td>
<td>231</td>
<td></td>
</tr>
<tr>
<td>9/22/04</td>
<td>79</td>
<td>78</td>
<td>0</td>
<td>37</td>
<td>119</td>
<td>392</td>
<td>17</td>
<td>264</td>
<td>58</td>
<td>81</td>
<td>53</td>
<td>1088</td>
<td>87</td>
<td>26</td>
</tr>
</tbody>
</table>

No Surveys Dec 2004-May 2005: NOAA mandatory flight stand down

<table>
<thead>
<tr>
<th>Date</th>
<th>LI</th>
<th>CH</th>
<th>UG</th>
<th>GP</th>
<th>CB</th>
<th>TH</th>
<th>IK</th>
<th>CU</th>
<th>LA</th>
<th>SO</th>
<th>SL</th>
<th>MA</th>
<th>DB</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/8/05</td>
<td>165</td>
<td>169</td>
<td>0</td>
<td>135</td>
<td>137</td>
<td>415</td>
<td>100</td>
<td>317</td>
<td>42</td>
<td>70</td>
<td>67</td>
<td>129</td>
<td>62</td>
<td>0</td>
</tr>
<tr>
<td>6/19/05</td>
<td>43</td>
<td>189</td>
<td>0</td>
<td>75</td>
<td>5</td>
<td>132</td>
<td>139</td>
<td>82</td>
<td>2</td>
<td>1041</td>
<td>1</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7/28/05</td>
<td>17</td>
<td>172</td>
<td>9</td>
<td>30</td>
<td>0</td>
<td>379</td>
<td>79</td>
<td>385</td>
<td>199</td>
<td>8</td>
<td>890</td>
<td>8</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td>10/1/05</td>
<td>103</td>
<td>90</td>
<td>0</td>
<td>19</td>
<td>148</td>
<td>D</td>
<td>0</td>
<td>204</td>
<td>145</td>
<td>35</td>
<td>0</td>
<td>1177</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>12/1/05</td>
<td>250</td>
<td>18</td>
<td>0</td>
<td>53</td>
<td>114</td>
<td>347</td>
<td>36</td>
<td>146</td>
<td>21</td>
<td>144</td>
<td>0</td>
<td>360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/20/06</td>
<td>259</td>
<td>88</td>
<td>0</td>
<td>124</td>
<td>84</td>
<td>371</td>
<td>46</td>
<td>322</td>
<td>63</td>
<td>77</td>
<td>0</td>
<td>182</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>

No Surveys June 2006-Sept2006: NOAA research permit vacated

<table>
<thead>
<tr>
<th>Date</th>
<th>LI</th>
<th>CH</th>
<th>UG</th>
<th>GP</th>
<th>CB</th>
<th>TH</th>
<th>IK</th>
<th>CU</th>
<th>LA</th>
<th>SO</th>
<th>SL</th>
<th>MA</th>
<th>DB</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/7/06</td>
<td>81</td>
<td>60</td>
<td>D</td>
<td>45</td>
<td>W</td>
<td>226</td>
<td>301</td>
<td>171</td>
<td>45</td>
<td>877</td>
<td>38</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/11/06</td>
<td>230</td>
<td>47</td>
<td>0</td>
<td>72</td>
<td>52</td>
<td>254</td>
<td>51</td>
<td>121</td>
<td>110</td>
<td>110</td>
<td>0</td>
<td>293</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table M2. Summary of dedicated and opportunistic brand SSL resight effort by date and site, 2004-2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Site</th>
<th># brands</th>
<th>Effort Type</th>
<th>Year</th>
<th>Date</th>
<th>Site</th>
<th># brands</th>
<th>Effort Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>1/06</td>
<td>SO</td>
<td>1</td>
<td>S</td>
<td>2008</td>
<td>1/29</td>
<td>LI</td>
<td>1</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>5/3</td>
<td>LI</td>
<td>3</td>
<td>D</td>
<td>2008</td>
<td>3/08</td>
<td>DB</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>5/30</td>
<td>SO</td>
<td>3</td>
<td>V</td>
<td>2008</td>
<td>3/11</td>
<td>LI</td>
<td>2</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>9/24</td>
<td>SO</td>
<td>2</td>
<td>S</td>
<td>2008</td>
<td>3/11</td>
<td>LI</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>11/20</td>
<td>CU</td>
<td>1</td>
<td>V</td>
<td>2008</td>
<td>3/23</td>
<td>CU</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>12/14</td>
<td>LI</td>
<td>13</td>
<td>D</td>
<td>2008</td>
<td>5/30</td>
<td>SO</td>
<td>3</td>
<td>S</td>
</tr>
<tr>
<td>2005</td>
<td>3/16</td>
<td>CU</td>
<td>4</td>
<td>S</td>
<td>2008</td>
<td>5/13</td>
<td>CU</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>3/17</td>
<td>LI</td>
<td>6</td>
<td>S</td>
<td>2008</td>
<td>8/19</td>
<td>DB</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>4/28</td>
<td>CU</td>
<td>1</td>
<td>V</td>
<td>2008</td>
<td>11/4</td>
<td>LI</td>
<td>21</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>5/9</td>
<td>LA</td>
<td>2</td>
<td>S</td>
<td>2008</td>
<td>11/5</td>
<td>west</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>5/9</td>
<td>SO</td>
<td>1</td>
<td>S</td>
<td>2008</td>
<td>12/30</td>
<td>LI</td>
<td>12</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>6/02</td>
<td>CC</td>
<td>7</td>
<td>S</td>
<td>2009</td>
<td>3/2</td>
<td>LI</td>
<td>14</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>8/5</td>
<td>CU</td>
<td>2</td>
<td>V</td>
<td>2009</td>
<td>3/31</td>
<td>LI</td>
<td>13</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>9/14</td>
<td>LA</td>
<td>3</td>
<td>S</td>
<td>2009</td>
<td>5/1</td>
<td>LI</td>
<td>9</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>9/25</td>
<td>CU</td>
<td>15</td>
<td>S</td>
<td>2009</td>
<td>5/7</td>
<td>LI</td>
<td>7</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>12/21</td>
<td>LI</td>
<td>5</td>
<td>D</td>
<td>2009</td>
<td>10/3</td>
<td>west</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>12/22</td>
<td>CU</td>
<td>6</td>
<td>S</td>
<td>2009</td>
<td>11/26</td>
<td>west</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>12/23</td>
<td>SO</td>
<td>4</td>
<td>S</td>
<td>2009</td>
<td>12/28</td>
<td>LI</td>
<td>13</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>12/23</td>
<td>LI</td>
<td>7</td>
<td>S</td>
<td>2010</td>
<td>12/9</td>
<td>LI</td>
<td>21</td>
<td>D</td>
</tr>
<tr>
<td>2006</td>
<td>1/19</td>
<td>LI</td>
<td>4</td>
<td>D</td>
<td>2011</td>
<td>1/9</td>
<td>LI</td>
<td>17</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>2/14</td>
<td>CU</td>
<td>2</td>
<td>V</td>
<td>2011</td>
<td>1/26</td>
<td>LI</td>
<td>18</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>2/16</td>
<td>LI</td>
<td>1</td>
<td>D</td>
<td>2011</td>
<td>3/2</td>
<td>LI</td>
<td>19</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>3/22</td>
<td>SO</td>
<td>1</td>
<td>S</td>
<td>2011</td>
<td>3/18</td>
<td>LI</td>
<td>18</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>3/23</td>
<td>LI</td>
<td>3</td>
<td>S</td>
<td>2011</td>
<td>4/14</td>
<td>LI</td>
<td>19</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>3/24</td>
<td>CU</td>
<td>4</td>
<td>S</td>
<td>2011</td>
<td>5/12</td>
<td>LI</td>
<td>9</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>4/7</td>
<td>LI</td>
<td>9</td>
<td>D</td>
<td>2011</td>
<td>10/30</td>
<td>SO</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>5/15</td>
<td>LI</td>
<td>9</td>
<td>D</td>
<td>2011</td>
<td>10/31</td>
<td>LI</td>
<td>12</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>10/30</td>
<td>SO</td>
<td>1</td>
<td>S</td>
<td>2011</td>
<td>2/8</td>
<td>CU</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>10/31</td>
<td>LI</td>
<td>12</td>
<td>D</td>
<td>2011</td>
<td>4/28</td>
<td>LI</td>
<td>3</td>
<td>V</td>
</tr>
<tr>
<td>2007</td>
<td>2/8</td>
<td>CU</td>
<td>5</td>
<td>V</td>
<td>2011</td>
<td>4/28</td>
<td>DB</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>4/28</td>
<td>LI</td>
<td>3</td>
<td>V</td>
<td>2011</td>
<td>5/18</td>
<td>CU</td>
<td>2</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>5/18</td>
<td>CU</td>
<td>2</td>
<td>V</td>
<td>2011</td>
<td>7/11</td>
<td>DB</td>
<td>1</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>8/9</td>
<td>DB</td>
<td>1</td>
<td>V</td>
<td>2011</td>
<td>8/31</td>
<td>CU</td>
<td>4</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>8/10</td>
<td>CC</td>
<td>2</td>
<td>V</td>
<td>2011</td>
<td>10/1</td>
<td>MA</td>
<td>3</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>8/31</td>
<td>CU</td>
<td>4</td>
<td>S</td>
<td>2011</td>
<td>10/1</td>
<td>SO</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>10/23</td>
<td>LI</td>
<td>11</td>
<td>D</td>
<td>2011</td>
<td>11/7</td>
<td>LI</td>
<td>13</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>12/13</td>
<td>LI</td>
<td>3</td>
<td>S</td>
<td>2011</td>
<td>12/21</td>
<td>CU</td>
<td>1</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>12/21</td>
<td>CU</td>
<td>1</td>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table M3. Location of observations made thru 2007 of SSLs branded through 2004 on Marmot and Sugarloaf Island rookeries. Haulout site abbreviations: western = CU, CC, Uyak, Uganik; northern = LA, SO, MA; eastern = DB, LI, CH.

<table>
<thead>
<tr>
<th>Regional Haulout sites observed on</th>
<th>Rookery of Birth</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marmot (T)</td>
<td>Sugarloaf (X)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>% resights</td>
<td>n</td>
</tr>
<tr>
<td>West h.o.</td>
<td>20</td>
<td>20.83</td>
<td>18</td>
</tr>
<tr>
<td>North h.o.</td>
<td>39</td>
<td>40.63</td>
<td>19</td>
</tr>
<tr>
<td>East h.o.</td>
<td>62</td>
<td>64.58</td>
<td>14</td>
</tr>
<tr>
<td>in 2+ regions</td>
<td>16</td>
<td>16.67</td>
<td>3</td>
</tr>
<tr>
<td>Only West</td>
<td>10</td>
<td>10.42</td>
<td>12</td>
</tr>
<tr>
<td>Only North</td>
<td>25</td>
<td>26.04</td>
<td>14</td>
</tr>
<tr>
<td>Only East</td>
<td>45</td>
<td>46.88</td>
<td>12</td>
</tr>
<tr>
<td>Total Resights thru 2007</td>
<td>96</td>
<td>41</td>
<td></td>
</tr>
</tbody>
</table>

(when scat trips to all sites)

Table M4: Summary of ANOSIM R values and significant differences between HS and SSL scat samples collected in four Regions and four Seasons on Kodiak area haulouts, 2000-2009.

<table>
<thead>
<tr>
<th>REGION</th>
<th>SEASON</th>
<th>HS - n</th>
<th>SSL - n</th>
<th>R</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAST</td>
<td>SPRING</td>
<td>25</td>
<td>81</td>
<td>0.339</td>
<td>0.001</td>
</tr>
<tr>
<td>EAST</td>
<td>SUMMER</td>
<td>16</td>
<td>15</td>
<td>0.285</td>
<td>0.001</td>
</tr>
<tr>
<td>EAST</td>
<td>FALL</td>
<td>212</td>
<td>181</td>
<td>0.234</td>
<td>0.001</td>
</tr>
<tr>
<td>EAST</td>
<td>WINTER</td>
<td>112</td>
<td>515</td>
<td>0.124</td>
<td>0.001</td>
</tr>
<tr>
<td>NORTH</td>
<td>SPRING</td>
<td>5</td>
<td>159</td>
<td>0.45</td>
<td>0.001</td>
</tr>
<tr>
<td>NORTH</td>
<td>SUMMER</td>
<td>24</td>
<td>246</td>
<td>0.14</td>
<td>0.002</td>
</tr>
<tr>
<td>NORTH</td>
<td>FALL</td>
<td>24</td>
<td>691</td>
<td>0.196</td>
<td>0.001</td>
</tr>
<tr>
<td>NORTH</td>
<td>WINTER</td>
<td>89</td>
<td>421</td>
<td>0.214</td>
<td>0.001</td>
</tr>
<tr>
<td>SOUTH</td>
<td>FALL</td>
<td>255</td>
<td>43</td>
<td>0.161</td>
<td>0.001</td>
</tr>
<tr>
<td>SOUTH</td>
<td>SUMMER</td>
<td>621</td>
<td>75</td>
<td>0.151</td>
<td>0.001</td>
</tr>
<tr>
<td>WEST</td>
<td>SPRING</td>
<td>9</td>
<td>96</td>
<td>-0.03</td>
<td>0.562</td>
</tr>
<tr>
<td>WEST</td>
<td>SUMMER</td>
<td>30</td>
<td>116</td>
<td>0.137</td>
<td>0.004</td>
</tr>
<tr>
<td>WEST</td>
<td>FALL</td>
<td>43</td>
<td>220</td>
<td>0.152</td>
<td>0.002</td>
</tr>
<tr>
<td>WEST</td>
<td>WINTER</td>
<td>62</td>
<td>510</td>
<td>0.046</td>
<td>0.090</td>
</tr>
</tbody>
</table>
Table M5. Relative abundance (%RA) of prey families found in HS and SSL scats collected in five region x season categories where prey overlap was greatest (p>0.001). Shaded cells indicate sites and seasons in which these prey were of greatest abundance in scats of both HS and SSL in Kodiak.

<table>
<thead>
<tr>
<th>PREY</th>
<th>NORTH SUMMER</th>
<th>WEST SUMMER</th>
<th>WEST SPRING</th>
<th>WEST FALL</th>
<th>WEST WINTER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HS</td>
<td>SSL</td>
<td>HS</td>
<td>SSL</td>
<td>HS</td>
</tr>
<tr>
<td>Ammodytidae</td>
<td>9.72</td>
<td>3.41</td>
<td>5.56</td>
<td>2.48</td>
<td>8.89</td>
</tr>
<tr>
<td>Clupeidae</td>
<td>8.33</td>
<td>8.13</td>
<td>61.11</td>
<td>43.69</td>
<td>2.61</td>
</tr>
<tr>
<td>Gadidae</td>
<td>1.39</td>
<td>5.80</td>
<td>5.56</td>
<td>17.63</td>
<td>13.56</td>
</tr>
<tr>
<td>Osmeridae</td>
<td>60.42</td>
<td>25.81</td>
<td>0.00</td>
<td>0.52</td>
<td>0.00</td>
</tr>
<tr>
<td>Pleuronectiformes</td>
<td>7.64</td>
<td>21.78</td>
<td>25.00</td>
<td>8.86</td>
<td>7.50</td>
</tr>
<tr>
<td>Salmonidae</td>
<td>4.17</td>
<td>21.00</td>
<td>0.00</td>
<td>1.30</td>
<td>60.56</td>
</tr>
</tbody>
</table>

Table M6. Summary of the number of cetaceans sighted by species by date during aerial surveys. FW = fin whale, GW = gray whale, HB = humpback whale, KW = killer whale, UNK = unknown.

<table>
<thead>
<tr>
<th>Date</th>
<th>FW</th>
<th>GW</th>
<th>HB</th>
<th>KW</th>
<th>UNK</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/11/04</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4/12/04</td>
<td>9</td>
<td>42</td>
<td>1</td>
<td>25</td>
<td>0</td>
<td>77</td>
</tr>
<tr>
<td>5/14/04</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>6/8/04</td>
<td>9</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>7/7/04</td>
<td>33</td>
<td>0</td>
<td>51</td>
<td>0</td>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>8/4/04</td>
<td>18</td>
<td>15</td>
<td>134</td>
<td>20</td>
<td>0</td>
<td>187</td>
</tr>
<tr>
<td>9/22/04</td>
<td>52</td>
<td>0</td>
<td>26</td>
<td>0</td>
<td>0</td>
<td>78</td>
</tr>
<tr>
<td>6/19/05</td>
<td>0</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>10/1/05</td>
<td>8</td>
<td>2</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>12/1/05</td>
<td>0</td>
<td>19</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>169</td>
</tr>
<tr>
<td>3/20/06</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>9/7/06</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>5</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>12/11/06</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>135</td>
<td>92</td>
<td>414</td>
<td>56</td>
<td>3</td>
<td>700</td>
</tr>
</tbody>
</table>
Table M7. Movements of individual identified humpback whales between Kodiak (KOD) and the Shumagin Islands (SI) between 2000 and 2005.

<table>
<thead>
<tr>
<th>Whale_ID</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>011</td>
<td>SI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
</tr>
<tr>
<td>033</td>
<td>SI</td>
<td>SI</td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>034</td>
<td>SI</td>
<td></td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>050</td>
<td>SI &amp; KOD</td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
</tr>
<tr>
<td>061</td>
<td>SI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
</tr>
<tr>
<td>066</td>
<td>SI</td>
<td></td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>086</td>
<td>SI</td>
<td></td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>SI</td>
<td></td>
<td>KOD</td>
<td></td>
<td></td>
<td>KOD</td>
</tr>
<tr>
<td>118</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SI &amp; KOD</td>
</tr>
<tr>
<td>125</td>
<td>KOD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>SI</td>
<td></td>
<td>KOD</td>
<td></td>
<td></td>
<td>SI</td>
</tr>
<tr>
<td>169</td>
<td>SI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
</tr>
<tr>
<td>209</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
<td>SI</td>
</tr>
<tr>
<td>235</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>KOD</td>
<td>SI &amp; KOD</td>
</tr>
</tbody>
</table>
Table M8. Sighting records of individually identified humpback whales near Kodiak Island, Alaska that were sighted in more than three years between 1999 and 2006. X indicates a sighting in a given year.

<table>
<thead>
<tr>
<th>Whale_ID</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>Total Years Sighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>037</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td>038</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>6</td>
</tr>
<tr>
<td>039</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>048</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>050</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>074</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>076</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>081</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>083</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>088</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>090</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>099</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>105</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>107</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>109</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>112</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>149</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>177</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>192</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>283</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>288</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>Number Tagged</th>
<th>Total Number of Foraging Dives</th>
<th>Total Tracking Dive</th>
<th>Mean Max Dive Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>HB</td>
<td>4</td>
<td>62</td>
<td>16.7</td>
<td>106.2</td>
</tr>
<tr>
<td>2005</td>
<td>HB</td>
<td>1</td>
<td>10</td>
<td>3.4</td>
<td>101.9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5</td>
<td>72</td>
<td>20.1</td>
<td>104.1</td>
</tr>
</tbody>
</table>
Table M10. Mean values (±SE) of δ\textsuperscript{13}C, δ\textsuperscript{15}N and trophic level (TL) from humpback whale skin collected in Kodiak and the Shumagin Islands.

<table>
<thead>
<tr>
<th>Year</th>
<th>n</th>
<th>δ\textsuperscript{13}C</th>
<th>δ\textsuperscript{15}N</th>
<th>TL</th>
<th>n</th>
<th>δ\textsuperscript{13}C</th>
<th>δ\textsuperscript{15}N</th>
<th>TL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>29</td>
<td>-17.2±0.10</td>
<td>13.5±0.12</td>
<td>4.0±0.05</td>
<td>7</td>
<td>-18.0±0.23</td>
<td>13.4±1.2</td>
<td>3.6±0.11</td>
</tr>
<tr>
<td>2005</td>
<td>54</td>
<td>-18.0±0.07</td>
<td>13.4±0.15</td>
<td>3.9±0.06</td>
<td>24</td>
<td>-18.3±0.07</td>
<td>13.3±1.0</td>
<td>3.7±0.04</td>
</tr>
<tr>
<td>2006</td>
<td>25</td>
<td>-18.1±0.14</td>
<td>13.2±0.16</td>
<td>3.8±0.07</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Region Mean</td>
<td>108</td>
<td>-17.8±0.06</td>
<td>13.4±0.09</td>
<td>3.9±0.04</td>
<td>31</td>
<td>-18.2±0.07</td>
<td>13.2±1.0</td>
<td>3.7±0.04</td>
</tr>
<tr>
<td>Overall Mean</td>
<td>139</td>
<td>-17.9±0.05</td>
<td>13.3±0.07</td>
<td>3.9±0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure M1: Steller sea lion haulout sites in the Kodiak Archipelago. Two sites (▲) are seasonal haulouts not currently considered critical haulouts by NMFS.
Figure M2. Comparison of maximum counts (A) and multi-year mean counts (B) made on 13 Kodiak area sea lion haulouts made during aerial surveys in 1999-2003 (n=51) and 2004-2006 (n=17).
Figure M3. Comparison of seasonal and interannual counts of Steller sea lions made on key eastern (A), western (B), and northern (C) Kodiak haulouts, 1999-2006.
Figure M4. Age distribution of branded SSLs seen at least once on Kodiak are haulouts, Dec1999-May 2011.
Figure M5. 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 examine spatial differences in the diets of these pinnipeds.
Figure M6: A. 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. B. 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 M7. Number of cetaceans sighted by month during aerial surveys conducted between 11 March 2004 and 11 December 2006. FW = fin whale, GW = gray whale, HB = humpback whale, KW = killer whale, UNK = unknown.
Figure M8: Sightings of cetaceans recorded during aerial surveys conducted between 11 March 2004 and 11 Dec 2006. FW = fin whale, GW = gray whale, HB = humpback whale, KW = killer whale, UNK = unknown.
Figure M9. Sightings of humpback whales by year (2004-2006) recorded during vessel sightings.
Figure M10. Number of humpback whales sighted by year and by month during dedicated vessel surveys.

Figure M11. Estimates of abundance for humpback whales based on identification photographs collected between 1999 and 2006 near Kodiak Island.
Figure M12. Mean (±SE) values of the relative trophic levels (TL) for Kodiak (blue) and the Shumagin Islands (green) humpback whales.
Figure M13. Results of SIAR Bayesian mixing models for showing estimates (50%, 75%, and 95% credibility intervals) of diet compositions for humpback whales in all sampling years combined (a) and for 2004 (b), 2005 (c), and 2006 (d).
Figure M14: The current composition of the “Kodiak Killers” includes 2 adult females (AT126, AT128), their offspring born in 2002 (AT129, AT130), and AT128’s calf born in 2008 (AT150) (photo taken 01/25/10).

Figure M15: Photo-documentation of a severe skin disorder on yearling AT129 that was completed healed two years later.

Figure M16: Photo-documentation adult male AT127’s dorsal fin before and after its “collapse” in 2005.
Figure F1. Map of fish surveys sites. Lines represent transects on the east side of Kodiak Island. Circles represent bottom trawl locations at the monitoring sites. Stars represent the CTD and ring net monitoring sites.
Figure F2. Map of fish surveys sites in May 2005. Lines represent hydroacoustic transects north of Kodiak Archipelago. Circles represent stations with a CTD cast while “E” signs represent stations where both a CTD and vertical zooplankton net were cast.
Products

Mammals
Peer-reviewed Publications


Editor Reviewed Publications


Published Abstracts and Professional Presentations


Birds
Peer-reviewed Publications

• Williams, CT, Kitaysky, AS, Kettle, AB and Buck, CL. 2008. Corticosterone levels of tufted puffins vary with breeding stage, body condition index, and reproductive performance. *General and Comparative Endocrinology*. 58: 29-35.

Editor Reviewed Publications

Published Abstracts and Professional Presentations
• Buck, CL & CT Williams. 2005. Puffins as biological indicators of forage fish availability using fatty acid and stable isotope analyses to investigate the diets and trophic relationships of adult and nestling tufted puffins. Marine Science in Alaska.
• Whidden, SE, Williams, CT and CL Buck. 2006. Effects of radio transmitters on Tufted Puffin (Fratercula Cirrhata) reproductive success. The Seabird Group. 9th International Conference: Seabird populations under pressure. Aberdeen, Scotland.
• Williams, CT, Buck, CL, Kildaw, SD, Iverson, SJ. 2005. Seasonal and age related variation in fatty acid and stable isotope signatures in tufted puffins. Pacific Seabirds Vol. 31 Number 1. 31st Annual Pacific Seabird Group Meeting.
• Williams, CT, Buck, CL, Kildaw, SD, Iverson, SJ. 2005. Seasonal and age related variation in fatty acid and stable isotope signatures in tufted puffins. Pacific Seabirds Vol. 31 Number 1. 31st Annual Pacific Seabird Group Meeting.
• Williams, CT, Iverson, SJ and CL Buck. 2006. Fatty Acid and Stable Isotope Signatures Reveal Annual, Seasonal, and Age-Related Variability in Tufted Puffin Diets. Pacific Seabirds Vol. 32.
• Williams, CT, Iverson, SJ and CL Buck. 2006. Fatty Acid and Stable Isotope Signatures Reveal Annual, Seasonal, and Age-Related Variability in Tufted Puffin Diets. Pacific Seabirds Vol. 32.
• Williams, CT, Kildaw, SD, Breton, AR and CL Buck (2011) All seabirds don’t tell the same story: Productivity of Tufted Puffins and Black-legged Kittiwakes from 2001-2005 in Chiniak Bay, Kodiak, Alaska. Kodiak Area Marine Sciences Symposium, Kodiak, AK.
• Williams, CT, Kildaw, SD, Breton, AR and CL Buck. 2011. All seabirds don’t tell the same story: Productivity of Tufted Puffins and Black-legged Kittiwakes from 2001-2005 in Chiniak Bay, Kodiak, Alaska. Kodiak Area Marine Sciences Symposium, Kodiak, AK.


Completed Theses


Fish

Peer-reviewed publications


Published abstracts and presentations

Completed Theses
• Andrews, A. 2010. Spatial variability in trophic level of spiny dogfish (Squalus acanthias) in the northeastern Pacific Ocean using stable isotope analysis.
• Guo, L. 2010. Material and energy transfer from marine zooplankton to forage fish in subarctic waters: dietary effects on forage fish body composition
• Knoth, B. 2006. Investigating the role of ATF (Atheresthes stomias) as a top level consumer in the Gulf of Alaska.
• Loewen, M. E. 2007. Seasonal distribution, abundance, and characteristics of pelagic fish habitat in bays of Kodiak Island, Alaska.


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.

