

Exxon Valdez Oil Spill
Restoration Project Report

Cook Inlet Seabird and Forage Fish Studies

Restoration Project (APEX) 97163M
Annual Report

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Study History: Since the late 1970's, seabirds in the Gulf of Alaska have shown signs of food stress: population declines, decreased productivity, changes in diet, and large-scale die-offs. Small-mesh fishing trawls conducted during the past 30 years reveal that a major shift in fish community composition occurred in the late 1970's: some forage species (e.g., capelin) virtually disappeared, while predatory fish (e.g., pollock) populations increased markedly. Restoration Project 97163M was initiated as part of APEX in 1995 to characterize relationships between seabird population dynamics, foraging behavior, and forage fish densities in lower Cook Inlet--the area in which most seabirds were killed by the EVOS. CISeaFFS is a collaborative project of the Alaska Biological Sciences Center and the Alaska Maritime National Wildlife Refuge, with major funding and logistic support from the EVOS Trustees (APEX), the MMS, USGS, USFWS, ADF&G, University of Alaska Fairbanks, Oregon State University and the University of Washington.

Abstract: From 1995 through 1997, populations, productivity, diets and foraging behavior of 6 seabird species (murre, kittiwake, guillemot, puffin, cormorant, gull) were studied at three seabird colonies in lower Cook Inlet (Chisik, Gull and Barren islands). Oceanographic measurements, seabird and hydroacoustic surveys, trawls, and beach seines were conducted in waters around (<40 km) each colony. In all years, offshore and southern waters of Cook Inlet were dominated by juvenile walleye pollock and capelin, important prey for murre and puffins. Nearshore waters were dominated by sand lance, which were consumed by seabirds (e.g., kittiwakes, guillemots, murre) in proportion to their local abundance. Acoustically-measured forage fish biomass, beach seine CPUE and trawl CPUE were lowest around Chisik Island, moderate in Kachemak Bay, and highest around the Barren Islands. Correspondingly, seabird breeding success in all years ranged from relatively low in the Chisik Island area to relatively high in the Barren Islands area. Populations of seabirds at Chisik Island continued a long-term decline, whereas populations at Gull and Barren islands are stable or increasing. Behavioral studies revealed that seabirds worked harder (longer foraging trips, less "free" time) at colonies where nearby fish densities were lower. Breeding success at all three colonies varied between years, with 1996 being the best year for production, and 1995 and 1997 being slightly worse for seabird breeding success. There was little evidence for adverse effects of the 1997 El Niño event on seabirds, and water temperatures through summer were similar to those observed in 1996.

Key Words: Cook Inlet, murre, kittiwake, guillemot, forage fish, diet, pollock, capelin, sandlance, reproduction, growth rate, hydroacoustic, trawl, seine, *Exxon Valdez*, Kachemak Bay.

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COOK INLET SEABIRD AND FORAGE FISH STUDIES (CISeaFFS)

INTRODUCTION

Some seabird populations in the Gulf of Alaska have declined markedly during the past few decades (Hatch and Piatt 1995; Piatt and Anderson 1996). Whereas human impacts such as those from the *Exxon Valdez* oil spill can account for some proportion of these declines (Piatt et al. 1990c; Piatt and Naslund 1995), natural changes in the abundance and species composition of forage fish stocks have also affected seabird populations (Decker et al. 1994; Piatt and Anderson 1996). Marine fish communities in the Gulf of Alaska changed dramatically during the past 20 years (Anderson et al. 1994). Coincident with cyclical fluctuations in sea-water temperatures, the abundance of small forage fish species such as capelin (*Mallotus villosus*) declined precipitously in the late 1970's while populations of large predatory fish such as walleye pollock (*Theragra chalcogramma*) and cod (*Gadus pacifica*) increased dramatically. Correspondingly, capelin virtually disappeared from seabird diets in the late 1970's, and were replaced by juvenile pollock and other species in the 1980's (Piatt and Anderson 1996). Seabirds and marine mammals exhibited several signs of food stress (population declines, reduced productivity, die-offs) throughout the 1980's and early 1990's (Merrick et al. 1987; Piatt and Anderson 1996). Similar trends in oceanography, seabird population biology and prey availability have been noted in the Bering Sea, although the cycle there appears to be offset by 4-5 years from events in the Gulf of Alaska (Decker et al. 1994, Springer 1992).

Factors that regulate seabird populations are poorly understood, but food supply is clearly important (Cairns 1992b). In many cases, anthropogenic impacts on seabird populations cannot be distinguished from the consequences of natural variability in food supplies (Piatt and Anderson 1996). Thus, 'management' of seabird populations remains an uncertain exercise. For example, how can we enhance recovery of seabird populations lost to the *Exxon Valdez* oil spill if food supplies in the Gulf of Alaska limit reproduction? Would commercial fishery closures reduce or increase food availability to seabirds? What are the minimum forage fish densities required to sustain seabirds?

We are attempting to answer some of these questions by studying seabird and forage fish interactions in lower Cook Inlet. Upwelling of oceanic water at the entrance to Cook Inlet creates a productive marine ecosystem that supports about 2-3 million seabirds during summer. More seabirds breed here than in the entire northeast Gulf of Alaska (including Prince William Sound) and concentrations at sea (up to 90 kg/km²) are among the highest in Alaska (Piatt 1994). For these reasons, the greatest damage to seabirds from the *Exxon Valdez* oil spill occurred in lower Cook Inlet (Piatt et al. 1990).

Pilot studies were initiated in 1995. The overall objective was to quantify and contrast seabird-forage fish relationships at three seabird colonies in lower Cook Inlet: Chisik Island, Gull Island (Kachemak Bay), and the Barren Islands. The abundance and species composition of forage fish schools around each colony were quantified with hydroacoustic surveys, mid-water trawls, and beach seines. At each colony, we measured breeding success, diet composition, and foraging effort of several seabird species including: common murre, black-legged kittiwakes, pigeon guillemots, pelagic cormorants, glaucous-winged gulls, tufted puffins and horned puffins.

In 1996, this research program was refined and expanded. For example, we increased hydroacoustic sampling of nearshore habitats, tried some new fishing techniques (bottom trawls, pair trawls, cast-nets), increased study effort on some species of seabirds (pigeon guillemots, puffins, cormorants) and forage fish (sandlance), and increased coordination of seabird studies at the three colonies (for example, we synchronized feeding watches and census counts with respect to breeding phenology).

In 1997, we increased benthic trawling and added SCUBA transects for benthic fishes near guillemot colonies, increased study effort on pigeon guillemots, added nearshore sampling for zooplankton, phytoplankton and nutrients (in collaboration with Peter McRoy, UAF), measured physiological stress in adult and chick seabirds, initiated banding of adult murre and kittiwakes to assess adult survival, and further increased coordination of seabird studies at the three colonies using protocols developed in collaboration with other principal investigators in the EVOS/APEX program.

OBJECTIVES

The overall objective of this study is to quantify components of seabird reproductive and foraging biology at colonies while simultaneously measuring the distribution, density and species composition of forage fish schools in adjacent waters. It has been hypothesized that these components are non-linear functions of prey density and sensitive to different thresholds of prey density (Piatt 1987, Cairns 1987, 1992a,b). Data collected in this study will allow us to characterize response curves and thresholds for several different seabird species and then go on to test other hypotheses about seabird-forage fish relationships. For example, is seabird recovery from the *Exxon Valdez* oil spill limited by current forage fish densities? Do different seabird species have different thresholds to prey density? Can some species adjust foraging effort to compensate for fluctuating prey densities? Can seabirds compensate for differences in prey quality? Do weather and oceanographic conditions influence prey distribution and therefore seabird foraging success? None of these hypotheses can be addressed without a clear understanding of the underlying functional and numerical responses.

1997 ANNUAL REPORT

The following Annual Report summarizes our 1997 research efforts, including some preliminary 1997 results, and includes some compilation of findings over the entire study period (1995-1997). We are in the process of synthesizing and publishing detailed results of studies to date (below), and so this Annual Report contains only selected highlights of these studies. Details of work at the Barren Islands in 1997 are found in separate reports, although some data from the Barrens are summarized here.

RESULTS

OCEANOGRAPHY

The summer of 1997 was notable for an onset of the strongest El Niño event ever observed in the Pacific Ocean. Surface waters in Alaska were also warmer than normal, possibly owing to teleconnection effects of El Niño rather than direct effects of warm El Niño water transport to

Alaska. By July, sea surface temperatures in the Gulf of Alaska were 2-3 degrees above average. However, surface waters become mixed with deeper, cooler water as currents drive up onto shallow banks around Kodiak Island and into the shallow entrance to the Cook Inlet estuary. Temperature data loggers which continuously record temperature were again deployed in Lower Cook Inlet. Continuous temperature recordings have now been obtained from Gull Island during summer of 1995, and without a break since March of 1996 (**Figure 1**). We observed almost no difference in sea surface temperatures in Kachemak Bay between 1996 and 1997 until about August of 1997 when temperatures increased to about 2 degrees warmer than in 1996, and remained warmer through September (**Figure 1**). In June, two temperature data loggers were deployed at both Chisik and the Barren Islands. These loggers were retrieved in September. In July, two temperature data loggers were deployed at 10 and 100 m South of Hesketh Island in Kachemak Bay and will record temperature until August 1998. In August, temperature data loggers were re-deployed at Gull Island and Sixty Foot Rock in Kachemak Bay and will record temperature at 5 m until July 1998.

Temperature and salinity (CTD) profiles of the water column were collected in conjunction with mid-water trawls (96 CTD casts), and bottom trawls (40 CTD casts) in Cook Inlet in 1997. Two CTD transects across Kachemak Bay that were established and sampled in May and August 1995, and February, May and August 1996 (Abookire and Norcross, unpub. data) were modified and sampled 3 times in the summer of 1997 (33 CTD casts). On 23 July, temperature and salinity profiles were collected on a CTD transect that was established and sampled in 1996 across Cook Inlet to Chisik Island (7 CTD casts), and during 29 July on a CTD transect that was established and sampled in 1996 across the entrance to Cook Inlet near the Barren Islands (6 CTD casts). The profiles show that oceanographic habitats near each of the colonies are dissimilar (**Figure 2**). In the upper part of lower Cook Inlet between Kachemak Bay and Chisik Island, waters are vertically mixed except for shallow stratification near Chisik (upper panel, **Figure 2**). The cold mixed water off Kachemak represents the intrusion of mixed oceanic from the Gulf of Alaska. Inner Kachemak Bay is strongly stratified in the upper 15 m owing to fresh water outflow (middle panel, **Figure 2**). Waters near the Barrens are weakly stratified, with a lens of warm, lower salinity water (lower panel, **Figure 2**). This stratification is lost north of the Barrens owing to upwelling and mixing on the relatively shallow estuary shelf of lower Cook Inlet. The combination of intruding dense oceanic water in the east, outflow in the west of fresh water from further up the Inlet, and strong tides, keep the upper Inlet well mixed. Property gradients are strongest from east to west.

Approximately 1000 Advanced Very High Resolution Radiometer (AVHRR) images were reviewed for the 1997 field season. Raw images were run through an automated script that clipped out the Cook Inlet study area, estimated cloud cover, and dropped images with less than 20% cloud free pixels. A visual review of the remaining images reduced further the number analyzed to 369. These "better quality" images were then calibrated and georeferenced. These data will be used to compare with 303 images archived from 1996, and 125 images from 1985-1990. The long time-series of images will allow us to look at interannual variation, including past ENSO events. The high temporal resolution of sampling in 1996 and 1997 will allow us to examine seasonal variations and effects of tides and currents in Cook Inlet on temperature regimes in different areas of the inlet.

NUTRIENTS, PHYTOPLANKTON AND ZOOPLANKTON

A permanent sampling site was established in Eldred Passage (59 30.47, 151 28.22). This site was sampled for phytoplankton and water nutrients on 9 occasions from 15 April to 15 August. This site is in fairly shallow water (60 m) and is generally well mixed. It was selected for its sheltered location near the Kasitsna Bay Lab. Samples of nutrients and phytoplankton were collected at the surface, and at 5, 10, 25, and 50 m. Preliminary analysis of nutrient samples shows a steady depletion of nitrates from our first sample in mid-April to the phytoplankton bloom that occurred in mid-May. CTD casts and a vertical zooplankton tows were also conducted at this site. Zooplankton biomass peaked on 2 June. About 140 zooplankton samples taken during fishing operations in Cook Inlet and from Eldred Passage have been archived for later analyses (volume and species composition).

On 27 June a cross-inlet transect was established between the Homer Spit to the middle of Lower Cook Inlet (12 stations). This transect was designed to traverse 3 distinct bodies of water identified from AVHRR satellite derived sea-surface temperature images. At each station, samples of nutrients, phytoplankton, and zooplankton were taken. Additionally, CTD, fluorometry, and PAR data were collected at all sites. Preliminary analysis of nutrient samples indicates that nutrient concentrations were high in the turbulent, mixed waters to the west of Kachemak Bay, whereas nutrient levels were low in stratified waters within Kachemak (**Figure 3**). Correspondingly, phytoplankton concentrations were highest in Kachemak and lowest in the mixed water offshore. There was an abrupt transition between low- and high-production waters (**Figure 3**), which correlates with the front between mixed and stratified waters.

FISH SAMPLING

Beach Seines

Between the months of February and August, 217 beach seine sets were conducted in Kachemak Bay. Five permanent study sites were visited once each month until May and then twice each month through summer. Additional sites in Eldred Passage (3) and Seldovia Bay (3) were sampled twice each month throughout summer to assess availability of Pigeon Guillemot food. A total of 102,195 fish were caught in the 217 seines. As in previous years, beach seine catches were dominated by sand lance which comprised 78% of the total catch (compared to 81% and 71% in 1976 and 1996, respectively). Sand lance occurred in 54% of sets (compared to 41% and 51% in 1976 and 1996, respectively). Notable changes in community structure were observed in 1997 (compared to previous years 1976, 1995, and 1996). Large numbers of first-year capelin ($n=5836$, 6 % of total catch) were present during the summer compared to only 1 fish in all 3 previous years of study. First-year ling cod numbered 330 individuals and occurred in 15% of seines compared to only 7 fish in all 3 previous years of study. More than 500 fish comprising 10 species have been individually frozen and archived for energetic, stable isotope, and genetic analyses. At Chisik Island, 18 beach seine sets were conducted on 3 different beaches throughout summer. Catches were dominated by salmonids, pricklebacks, and herring. Sandlance were also dug from beaches on 7 occasions from 2 sites. All Chisik fish collections were frozen and archived. Beach seining was also conducted throughout summer at the Barren Islands. Catches were similar to those in 1996 (i.e., dominated by sand lance), and more cod were taken in 1997. As in 1996, seine catches were highest at the Barrens and lowest at Chisik Island (**Figure 4**, comparison of July data only).

Mid-water Trawls

To assess the relative abundance and species composition of forage fishes in lower Cook Inlet, midwater trawling was continued in 1997. Aboard the ADF&G R/V Pandalus, 21 stations were fished from June 20 to 25, and 43 stations were fished from July 19 to August 2, 1997. Fishing efforts were concentrated around the Barren Islands, Gull Island, and Chisik Island. Prior to fishing at each station, a CTD (conductivity, temperature, and density) was deployed to record temperature and salinity data at depth and zooplankton samples were collected and preserved for future analysis. All fishes were identified, counted, measured to the nearest mm fork length, weighed for total mass by species, and a subsample of fishes were weighed individually. Fish data were standardized to catch-per-unit-effort (CPUE) of 1 km distance trawled.

Midwater trawl catches were greater in 1997 than 1996 ($F=4.82$, $df=1$, $p=0.0315$), and different among the three areas ($F=3.40$, $df=2$, $p=0.0389$) with highest catches at the Barren Islands and lowest at Chisik Island (**Figure 4**). Species diversity was lowest at the Barren Islands (Shannon-Wiener= 0.74, species richness=12), and catches were dominated by walleye pollock offshore and Pacific sand lance nearshore. Gull Island catches were dominated by gadids and Pacific sand lance (**Figure 5**). Percentages of walleye pollock and Pacific sand lance were high in both 1996 (31% and 54% respectively) and 1997 (33% and 47% respectively). Pacific cod, Pacific herring, salmonids, and capelin were also captured, and species diversity at Gull Island was relatively high (Shannon-Wiener=1.23, species richness=25). Species diversity was greatest at Chisik (Shannon-Wiener=1.25, species richness=31), and catches were mixed with species Pacific sand lance, salmonids, walleye pollock, longfin smelt, capelin, eulachon, Pacific herring, and Pacific sandfish (**Figure 5**).

Benthic Trawls and SCUBA

SCUBA diving and bottom trawls were used in 1997 to assess the abundance and species composition of benthic fishes within foraging range of Pigeon Guillemot colonies in Kachemak Bay. Twenty SCUBA transects were conducted from August 19 to 26 near Seldovia and Moosehead Point, two separate Pigeon Guillemot colonies. Each transect covered 30m³ and the depth, time, substrate, and habitat were noted at the beginning, middle and end of each transect. All fishes encountered in 1 m³ preceding the diver were identified and recorded on underwater paper according to three size classes: 0 - 8 cm, 8-15 cm, and > 15 cm. Bottom trawling occurred on July 3, 14 and August 6 at Halibut Cove (2 stations), Moosehead Point (3 stations), Yukon Island (3 stations), and Neptune Bay (2 stations). Additionally, on August 14, 1997, three stations were established and sampled around the outer Seldovia colony. A 3.05 m plumbstaff beam trawl equipped with a double tickler chain was towed at all stations from a 9.3 m aluminum Munsen skiff. Standard tow duration was five minutes, and depth range of stations did not exceed 25 m. All fishes were identified to species, counted, and measured to the nearest mm fork length; however, only fishes with length 80 to 150 mm were analyzed for Pigeon Guillemot diet availability. Fish data were standardized to catch-per-unit-effort (CPUE) for an area of 1000 m².

Total abundance of benthic fishes in 1997 around Pigeon Guillemot colonies in Kachemak Bay increased with date and was greater on 6 August than on 3 or 14 July ($F=3.88$, $df=2$, $p=0.0227$) (**Figure 6**). Common taxa in bottom trawls were flatfishes (36%), ronquils (22%), sculpins (11%), gadids (11%), and pricklebacks (10%). Bottom trawl data from Kachemak Bay did not reflect a

difference in fish species composition among Pigeon Guillemot colonies ($F=0.8550$, $df=12$, $p=0.5966$). However, SCUBA data imply benthic fish communities at Moosehead Point and Seldovia are only 26.8% similar (Renkonen percent similarity index). The Moosehead fish community is dominated by gunnels and greenlings, and pricklebacks dominate at Seldovia.

Hydroacoustic Surveys

Most at-sea hydroacoustic surveys were conducted from the R/V Pandalus, a 23m stern trawler operated by ADF&G. On the first Pandalus cruise (20-25 June), a general survey of Kachemak Bay and waters near Chisik Island were conducted over 6 days. This was a shakedown cruise to test the BIOSONICS DT4000 hydroacoustic equipment, and to refine the mid-water trawling methods. On each day, a search was made for significant hydroacoustic signs of fish. When found, these schools were fished with the trawl, and another hydroacoustic record of schools was taken as schools were trawled. In total, 30 hydroacoustic files were archived while searching, and more obtained during the 23 trawls for fish. CTD casts (39) were taken at the beginning and end of most tows. No bird observations were made during this cruise.

On the second R/V Pandalus Cruise (19 July - 8 August) all nearshore and offshore transects (ca. 1200 linear km) that were established in 1995 and 1996 in core study areas of Kachemak Bay, Chisik Island, and the Barren islands were surveyed hydroacoustically and with mid-water trawls. Transects were broken into segments as determined by the need to stop and trawl significant fish aggregations. Most of the transects were completed from the R/V Pandalus (15 days), but some nearshore transects were completed with the R/V David Grey (5 days). The transects are broken into 100 acoustic data files, and there are 51 fishing files and 2 searching files, for a total of 153 hydroacoustic data files for the cruise. Good hydroacoustic data were obtained on most of the common fish species caught by trawls. Bird observations were recorded for all transects and during all trawls using DLOG, an automatic bird data entry program with Rockwell GPS position data for each observation. A CTD cast was usually made after every tow. On the few occasions when we fished an area more than once, we did not duplicate the cast. An additional 13 casts were made along 2 transects across the inlet, for a total of 60 CTD casts. All accessible hydroacoustic files have been echo-integrated and saved as bitmaps. All transects, trawl locations and CTD casts have been plotted using GIS software (CAMRIS). In Kachemak Bay, hydroacoustic surveys were conducted from the R/V David Grey on 7 days (7-12 July, 17 July) searching for good fish sign and attempting to catch fish with an Isaacs-Kidd midwater trawl. In total, hydroacoustic data were recorded during 18 search transects, 16 trawls, and 2 cast-netting attempts. The hydroacoustic data have all been integrated, but analysis is still in progress.

SEABIRDS

Common Murres

In 1997, we continued our third year of monitoring the productivity, populations, and behavior of common murres (*Uria aalge*) breeding at Gull and Chisik/Duck Islands in lower Cook Inlet. At Gull Island, about 6,000 murres nest in sub-colonies on open cliff-faces and cliff-tops among 5700 pairs of other seabirds. Seabird populations at Gull Island have increased or remained stable in the past 20 years (Zador et al. 1997). at Duck Island, about 3500 murres nest in sub-colonies on cliff-faces and on cliff-tops, open or partially-to-completely over-hung by woody elderberry (*Sambucus*

racemosa) shrubs. Seabird populations at Duck and Chisik have declined during the past 20 years (Zador et al. 1997).

Two to three people monitored murre activity from June through early September at each island. Observations of bird behavior, nest status, and prey items were made through spotting scopes and binoculars from small temporary and permanent blinds erected before the birds began to lay eggs; viewing distances varied from 1 - 500 m. Population trends were monitored on plots at both islands by conducting replicate counts through the season. Hatching success, productivity, and phenology were determined by observing 11 productivity plots with 6 - 20 nest sites each every 1 - 5 days. We considered chicks last seen at age 15 days or older to have fledged. Chick growth assessed from single measurements of 23 - 26 chicks. Fledging weights and wing lengths were measured on 38 - 123 chicks captured after they left the colony and before they reached the water. Adult nest attendance, chick-feeding rates, and foraging trip durations were determined in 6-7 dawn-to-dusk watches of 7-11 nest sites conducted weekly, conditions permitting, throughout the incubation and chick-rearing stages. Fish brought to the colonies by adults were identified to the lowest possible taxonomic level through binoculars, and their sizes were estimated in relation to adult bill length. Adults were captured with noose poles and banded with numbered stainless steel bands and unique 4 color combination plastic bands.

We counted a maximum of 3500 murrelets at Duck and 6068 murrelets on Gull. Average numbers of murrelets in population plots were 128.7 ± 13.9 birds ($n = 3$ plots) at Duck and 344.2 ± 6.5 birds ($n = 10$ plots) at Gull. The first murrelet chicks were seen on 30 July at both islands. The median hatch date at Duck was 7 August (range: 30 July - 2 September) and at Gull was 9 August (range: 30 July - 22 August). There was no significant difference in hatching success or productivity between islands. Hatching success at Duck was 0.75 ± 0.05 chicks hatched per egg ($n = 11$ plots) and at Gull was 0.82 ± 0.05 chicks hatched per egg ($n = 8$ plots). Productivity at Duck was 0.63 ± 0.04 chicks fledged per egg ($n = 11$ plots) and at Gull was 0.56 ± 0.08 chicks fledged per egg ($n = 8$ plots).

Non-brooding adults spent significantly less time at their nest sites at Duck than at Gull. At Duck, average adult attendance was 66.8 ± 1.3 bird-minutes per hour ($n = 7$ watch days) and at Gull, 77.3 ± 1.4 bird-minutes per hour ($n = 6$ watch days) ($t = 2.3$, $df = 11$, $p = 0.039$). There was no significant difference between islands in chick feeding rates. Chicks at Duck were fed 0.23 ± 0.03 fish per hour ($n = 3$ watch days) and at Gull were fed 0.30 ± 0.03 fish per hour ($n = 3$ watch days). Adult trip durations were significantly longer at Duck than at Gull. Adults at Duck returned with fish after an average of 182 ± 16.1 minutes away ($n = 111$ trips) and at Gull, 111.1 ± 14.6 minutes away ($n = 62$) ($t = 3.0$, $df = 171$, $p = 0.003$).

Osmerids were the most common fish delivered to chicks at Duck (61.2% of 603 identified fish) and at Gull (42.5% of 193 identified fish). Sandlance and salmonids comprised 15.4 and 13.3% of the chick diets at Duck. Sandlance, gadids, and herring comprised 19.7, 19.2, and 14.5% respectively of the chick diets at Gull. Chick growth was similar at each island. At Duck chicks were 4.92 ± 0.14 grams per mm wing length ($n = 23$ chicks) and at Gull were 4.65 ± 0.13 grams per mm wing length ($n = 26$). However, chicks fledged significantly lighter and smaller at Duck than at Gull. The average fledging weight at Duck was 229.3 ± 2.6 grams ($n = 123$ fledglings) and at Gull was 248.9 ± 4.6 grams ($n = 38$ fledglings; $t = 3.6$, $df = 159$, $p < 0.001$). The average fledgling's wing length at

Duck was 71.95 ± 0.6 mm ($n = 123$ fledglings) and at Gull was 80.0 ± 0.9 mm ($n = 37$ fledglings) ($t = 6.2$, $df = 158$, $p < 0.001$). A total of 131 adult murres at Duck and 50 adult murres at Gull were banded. All fledglings captured at Gull were banded with a single plastic color band.

Analysis and synthesis of data collected in 1995-1997 are in progress (see "publications" below), and will eventually include data from the Barren Islands. General trends (**Table 1**) for murres at Gull and Chisik/Duck islands are as follows: Numbers of murres in population plots at Duck have declined in the three years of our study (1996: 162 birds, 1995: 199 birds), while those at Gull have remained stable (1996: 327 birds, 1995: 364 birds). First and median chick hatch dates at Duck were similar to those in 1996 (28 July and 10 August) and at Gull were 4 days later than in 1996 (3 and 13 August). Hatching success and productivity at both islands declined from 1996 values (Duck: $0.82 \pm .04$ chicks hatched per egg, 0.78 ± 0.04 fledged chicks per egg; Gull: 0.92 ± 0.03 chicks hatched per egg, 0.87 ± 0.05 chicks fledged per egg). Murres had the lowest productivity in 1995 (0.44 fledged chicks per egg at both islands). Non-brooding adults spent more time attending nest sites in 1997 than in the previous two years. Average attendance was lowest in 1996 (Duck: 62.9 ± 0.49 bird-minutes per hour; Gull: 68.9 ± 0.81 bird-minutes per hour) and closer to 1997 values in 1995 (Duck: 65.4 ± 0.59 bird-minutes per hour; Gull: 75.4 ± 1.65 bird-minutes per hour). Attendance was always higher at Gull than Duck. Chick feeding rates at Duck were lowest in 1996 (0.17 ± 0.02 fish per chick per hour) and similar between 1997 and 1995 (0.22 ± 0.07 fish per chick per hour). In contrast, chick feeding rates at Gull were highest in 1996 (0.35 ± 0.06 fish per chick per hour) and similar between 1997 and 1995 ($.31 \pm 0.03$ fish per chick per hour). At Duck, adult trip durations were an average of 1 hour longer in 1996 (242.9 ± 20.6 minutes) when chick feeding rates were lowest, but at Gull, average adult trips durations have remained approximately 2 hours in all three years. Chick diet composition at Duck was similar to that observed in 1996. At Gull, osmerids comprised a greater proportion of the diet, outnumbering gadids, which were the most common fish in 1996 (26.6% of 109 fish observed). Considering data pooled over 1996 and 1997, diets of chicks and adults were significantly different at each colony (**Figure 7**), and both adult and chick diet composition differed significantly from what was available according to trawl samples in each area (**Figure 7**; $p < 0.001$ in all Chi-square tests). It is clear that murres prefer to feed chicks osmerids while selecting sandlance or gadids for themselves. Chick growth rates at Duck increased over 1996 values (3.93 ± 0.12 grams per mm wing length) but remained the same at Gull (4.25 ± 0.19 grams per mm wing length). This was the first year we collected fledging weight and wing lengths, so comparisons between years are not yet possible.

Black-legged Kittiwakes

Productivity data were collected every one to three days in 10 plots at Chisik and in 11 plots at Gull. An index of productivity (chicks per active nest) was completed during mid incubation and late chick rearing. Nest structures and adults were counted on 8 population plots at Chisik and 12 plots at Gull ten times throughout the breeding season. Nests with known-age chicks and banded or marked parents were observed for attendance data, feeding rates, and foraging trip lengths. Three dawn to dusk watches with three nests each (for a total of 9 "nest days") were conducted at Chisik and four watches with eight nests each (32 "nest days") were conducted at Gull. Growth rate data were collected every four days from hatch to 30 days of age from 8 chicks on Chisik and 45 chicks on Gull. Adult kittiwakes ($n=71$) were banded with metal USFWS bands at Chisik, and 71 adults and 51 chicks were banded at Gull. All adults were additionally banded with a unique combination of

color bandettes and were weighed and measured. Mass, wing length, tenth primary length, and head-plus-bill length were recorded. Chick regurgitants were collected throughout the chick rearing period either opportunistically or were induced through throat massage. All mean values are reported ± 1 standard error. Values were compared between islands with t-tests and all reported differences are significant.

In 1997, kittiwakes at Chisik exhibited reproductive failure, producing only 0.02 ± 0.01 chicks per nest ($n=10$ plots containing a total of 140 nests). In contrast, kittiwakes at Gull Island produced 0.64 ± 0.11 chicks per nest ($n=11$ plots containing a total of 300 nests). Productivity was significantly higher at Gull ($t = -5.343$, $df = 19$, $p = <0.001$). The index of productivity estimate for Chisik and Gull Island was 0.005 chicks per nest, and 0.46 chicks per nest, respectively. Reproductive failure occurred at Chisik during chick rearing, since the mean clutch size and hatching success at each island were similar. Mean clutch size at Chisik was 1.53 ± 0.04 eggs per nest ($n=9$ plots) and at Gull 1.57 ± 0.07 eggs per nest ($n=11$ plots). At Chisik 0.44 ± 0.10 eggs laid hatched ($n=10$ plots) and at Gull 0.48 ± 0.07 eggs laid hatched ($n=11$ plots). The median hatch date at Chisik was 9 July ($n=51$ nests) and at Gull was 6 July ($n=159$ nests). The hatch range for Chisik (4 July - 18 July) differed from Gull (29 June - 25 July). Median egg laying at Chisik was 14 June ($n=64$ nests) and at Gull was 9 June ($n=262$ nests) based on a 27 day incubation period. Assuming chicks fledge at 32 days, median fledging at Chisik was 6 August ($n=2$ nests) and at Gull was 7 August ($n=141$ nests).

The mean number of adult kittiwakes and nests counted in plots at Chisik in 1997 was 555 ± 43 birds and 427 ± 33 nests ($n=10$ counts). These are the lowest numbers recorded since monitoring of the colonies began in 1986 by Mike Nishimoto (Zador et al. 1997). The mean number of kittiwakes counted in plots at Gull Island was 1177 ± 25 birds ($n=10$ counts). The mean number of nests in the same plots was 738 ± 36 nests ($n=10$ counts). We counted a total of 13,341 nests on Chisik on 19 June, and 4435 nests on Gull on 26 and 27 June. The total number of nests at Gull decreased from 5152 in 1996. Overall, it appears that kittiwake populations continued their decline at Chisik Island, but populations at Gull Island are now stable (**Figure 8**).

The mean foraging trip length (defined as time spent away from the nest site by the off-duty kittiwake) for kittiwakes at Chisik Island was 294.1 ± 50.6 minutes ($n=8$ trips). At Gull Island the mean trip length was 191.7 ± 11.5 ($n=74$ trips). Foraging trips at Gull were significantly shorter than at Chisik ($t=2.657$, $df=80$, $p=0.01$). The mean amount of time that nests were not attended by either parent at Chisik was 136.0 minutes ($n=1$ "nest day") and at Gull 55.5 ± 51.2 ($n=4$ "nest days"). During the linear growth phase (6-22 days of age), the average growth rate of all chicks at Chisik was 14.45 ± 1.57 grams per day ($n=8$ chicks). The average growth rate for all chicks at Gull was 14.83 ± 0.56 ($n=45$ chicks). Singleton chicks at Gull gained 15.90 ± 0.71 grams per day ($n=27$ chicks), Alpha chicks gained 13.85 ± 1.22 grams per day ($n=9$ chicks), and beta chicks gained 12.60 ± 1.03 grams per day ($n=9$). Mean weights and wing lengths were calculated for all chicks that fledged at each island. The mean fledging weight at Chisik was 445.5 ± 41.62 grams and mean wing length was 222 ± 10.03 mm ($n=2$ chicks). At Gull Island, the mean fledging weight was 384.4 ± 5.74 grams and mean wing length was 228 ± 3.61 mm ($n=42$ chicks). Kittiwake chicks at Chisik were fed 0.15 ± 0.04 meals per nest per hour for one chick nests ($n=4$ days) and 0.17 meals per nest per hour for two chick nests ($n=1$ day). Chicks at Gull were fed 0.19 ± 0.03 meals per nest per hour for one chick nests ($n=4$ days) and 0.24 ± 0.02 meals per nest per hour for two chick nests ($n=4$ days).

In 1997, kittiwake chick diets at Chisik were mainly composed of Pacific sand lance (67 % by biomass) but also included other prey items such as Pacific sandfish and sculpins (n=8 regurgitations). Chick diets at Gull were also dominated by sand lance (76 % by biomass). The remainder of chick diets at Gull (by percent biomass) included euphausiids (3%), capelin (1%), and other fish species (20%) (n=79 regurgitations). Considering data pooled over 1995 to 1997, diets of chicks and adults were significantly different at each colony (**Figure 9**), and diet composition differed significantly from what was available according to trawl samples in each area (**Figures 5 and 9**; $p < 0.001$ in all Chi-square tests). Diets of adults and chicks did not contrast as much as murre (above), although adults at the Barrens ate far more gadids than they fed to chicks (**Figure 9**).

Pigeon Guillemots

We studied the effects of food availability and nestling diet composition on Pigeon Guillemot reproductive success at four colonies in Kachemak Bay (Moosehead Pt., Yukon I., Inner Seldovia Bay, Outer Seldovia Bay) in 1997. We conducted both a one-time shoreline survey and repetitive counts at the larger guillemot colonies in Kachemak Bay. Our one time count was conducted along most of the south shore of Kachemak Bay between 9-12 June following the methods of Sanger and Cody (1994). We counted a total of 634 guillemots, a higher count than those obtained in 1996 (467) and 1995 (518). We conducted repetitive colony counts to make possible robust statistical interpretations of population trends. We counted guillemots on shore and within 100 m of land during morning high tides at 16 census areas established in 1996. Eight or nine replicate counts were made at each area. We detected no area-wide changes in population from 1996: mean counts were significantly higher in 1997 than 1996 at two areas, and significantly lower at two areas (t-test, $P < 0.05$).

We observed provisioning adults with telescopes from blinds, conducting 10 all-day watches at four different colonies. We identified meals to the lowest possible taxon, estimated meal size relative to bill length, and recorded delivery time and the elapsed time that an individual rested on the water with a fish before delivering. We collected 48 chick meals to verify species identification and length estimates. Meals were collected either by intercepting adults with mist nets placed over burrow entrances or as discarded items in nests in the course of other field activities. Each meal was weighed, measured, identified and frozen for proximate composition analysis. Data compiled from all years of study (1995-1997) reveal that different study colonies are characterized by very different chick diets (**Figure 10**). Indeed, spatial variance in diets far exceeds temporal variance we have observed in 3 years (Litzow et al. *in prep.*). In 1997, schooling fish again comprised most of the diet at Moosehead Pt. (74%), and formed only a small proportion of the diet (0% - 15%) at the other three main study colonies. The proportion of schooling fish in the diet increased markedly from 46% to 74% at Moosehead Pt., but declined from 21% to 15% at Outer Seldovia Bay (**Figure 11**).

We visited nests every five days post-hatch, when possible, to measure flattened wing chord and weigh chicks with spring-loaded scales. A total of 84 chicks were weighed and measured at least once, and 48 chicks were followed to fledging. We weighed and measured a subset of 32 chicks 1-2 d before fledging in order to estimate fledge weight. Chick growth was compared between high-sandlance and low-sandlance areas using three methods: estimated fledge mass, linear phase growth, and slope of transformed mass and wing chord. We defined the linear phase of growth as 8-18 days and computed the slope of the regression of mass on wing chord for individuals that were

measured at least twice during this phase. Finally, we transformed our data by taking the square root of mass and the square root of the natural log of wing chord. This transformation linearized the relationship between mass and wing chord and satisfied the assumptions of regression for normally distributed residuals and equal variance across the full chick-rearing period. We used the slope of the regression of transformed mass on transformed wing chord to compare chick growth rates. Mean chick mass 1-2 d pre-fledge was 447 ± 37 g ($n=32$), mean growth rate during the linear phase was 17.7 ± 5.3 g/d ($n=18$), and the mean transformed slope was 29.5 ± 3.2 ($n=37$). There were no significant differences in these parameters between chicks from colonies with high and low proportions of sandlance in the diet (t-test, $P > 0.05$).

In order to minimize nest abandonment due to disturbance, we began checking known nest sites late in the incubation phase, during the third week of June. New nests were discovered throughout the summer, and we checked nests every five days through the nesting cycle. Reproductive success (chicks fledged/nest) was estimated with the Mayfield Method to account for nests that failed before we found them. Mean clutch size was 1.78 ± 0.42 eggs/nest ($n=37$), and did not vary significantly between high and low schooling fish colonies (t-test, $P > 0.05$). Estimated bay-wide reproductive success was 0.70 chicks fledged/nest ($n=58$ eggs, $n=66$ chicks). Reproductive success was slightly higher at low schooling fish colonies (0.77 chicks fledged/nest, $n=27$ eggs, $n=46$ chicks) than the high schooling fish colony (0.58 chicks fledged/nest, $n=32$ eggs, $n=21$ chicks). This difference was largely due to higher rates of nest predation at Moosehead Pt.

Glaucous-winged Gulls

On Gull Island, Glaucous-winged Gulls began laying eggs on or before June 1. Productivity plots were checked every 2 - 10 days through June and July. We monitored 60 nests in 5 plots with 8 - 19 nests in each. Mean hatching success in these plots was 0.61 ± 0.07 chicks hatched per egg laid. The median hatch date was July 1. Mean clutch size was 2.46 ± 0.17 eggs per nest. We counted 1222 individuals on the island during one census in mid-June. On Duck (Chisik) Island, Glaucous-winged Gulls ($n=24$ nests) had a mean clutch size of 2.33 eggs/nest, and a hatching success of 0.46 chicks/egg. First chicks were observed on 22 June, and median hatching was on 27 June. Population plots (2) were counted 10 times. Chick regurgitations were obtained from 8 chicks.

Puffins

On Duck (Chisik) Island, 60 Horned Puffin nest sites were followed every 4 days from incubation, and 13 more nests (chicks) were found at later dates. First chicks appeared between 17-21 July. Diurnal attendance patterns were studied on 3 days, and seasonal attendance patterns assessed from daily counts between 27 June and 4 September. Populations plots (6) were counted daily from 14 June to 14 August, and 6 whole island censuses yielded a maximum count of 2335 puffins. About 100 chick meals were obtained from netting adults, pick-ups, and visual identifications. Chick feeding rates were obtained from all-day watches (3) of 5-7 nest-sites. Chick growth rates were obtained from 17 chicks measured every 4 days. On Gull Island, individual growth rate data were obtained from 5 Tufted Puffin chicks. Some puffin chick meals and phenology data were collected opportunistically from sightings of adult puffins carrying fish.

Cormorants

On Gull Island, 20 Pelagic Cormorant nests were monitored every 3-17 days throughout the summer. Productivity in 13 nests was 1.23 ± 0.34 chicks per nest. An index of productivity from all 70 nests on the island was 0.93 chicks per nest. The breeding population was estimated at 140 individuals based on a census of nests in late June. On Duck (Chisik) Island, only 3 of 15 active Double-crested Cormorant nests produced chicks (6 total). No Pelagic Cormorants or active nests of this species were observed all summer.

PHYSIOLOGICAL STRESS AND FOOD SUPPLY

In contrast to adult birds, dependent chicks confined to a nest are limited in their ability to respond to food shortages. Starved adult birds increase plasma levels of corticosterone-- a steroid hormone released by the adrenal glands in response to stress-- which in turn can stimulate foraging behaviour, trigger irruptive migration, induce abandonment of reproduction, and mobilize stored energy resources to fuel increased locomotory activities. These responses can improve adult survival during food shortages. Similar increases in corticosterone occur in dependent chicks deprived of food, but little is known about the behavioural response of chicks to food stress.

What's a chick to do when stressed by lack of food? In the Black-legged Kittiwake (*Rissa tridactyla*)-- a cliff-nesting gull with a maximum brood of 3 chicks-- a hungry chick has only two behavioural options to improve its chances of survival: Either eliminate nest-mates (siblicide) or intensify its begging for food. Here we present evidence that elevated levels of corticosterone in chicks stimulates food-begging behaviour, which in turn elicits a behavioural response from adults that results in increased food provisioning of chicks.

We conducted our experiment on free-living Black-legged Kittiwakes at Gull Island in lower Cook Inlet, Alaska. At 6 nest sites, experimental chicks were implanted subcutaneously with a 25 mm sealed silicon tube filled with enough crystallized corticosterone to raise blood plasma concentrations above base levels but below maximal stress-response levels (Kitaysky, unpubl. data). At 6 control nests, chicks were implanted with empty tubes. Rates of chick-begging and feeding of chicks by adults were monitored over a 2 day period after treatments.

Chicks with subcutaneous corticosterone implants more than doubled their rate of begging (Kruskal-Wallis ANOVA: $H=8.49$, $P<0.01$) over controls with empty implants (**Figure 12**). Parent kittiwakes responded to the increased begging of chicks by nearly doubling their rate of food provisioning (independent samples t-test: $t=3.97$, $P<0.01$).

These results reveal a physiological mechanism for the regulation of chick begging behaviour and provide insight into the behavioural regulation of parent-offspring feeding interactions. A recent study showed that Blue-footed Booby (*Sula nebouxii*) chicks release corticosterone in response to short-term food deprivation. We have taken this a step further to show that elevating plasma corticosterone can initiate a behavioural cascade that increases chick begging behaviour, stimulates adult foraging behaviour, and ultimately increases adult feeding of chicks. Thus, chicks can regulate their own food supply by modifying the behaviour of their parents. Adults respond almost

immediately to changes in chick begging behaviour, implying that elevation of corticosterone would be a highly adaptive short-term response of chicks to food deprivation.

If food supplies were limiting, and parents could not increase feeding rates in accord with demands of their chicks, then brood reduction would be a secondary means of preventing total reproductive failure during food shortages. As in Blue-footed Boobies, older kittiwake chicks eliminate their younger siblings when food is in extremely short supply. Before reaching this point, however, it seems that begging behaviour would offer some evolutionary advantages over aggressive behaviour. Begging behaviour probably requires less energy and entails less risk of personal injury than aggressive behaviour. Further, survival of younger siblings could increase inclusive fitness of a begging individual. Experiments to evaluate the effect of corticosterone on aggressive behaviour of chicks would be revealing. We would predict that corticosterone levels required to induce aggressive behaviour should be much higher than levels needed to induce begging behaviour.

SEABIRD RESPONSE TO FOOD SUPPLY

We are attempting to define relationships between seabird population dynamics and food supply. For any species, this relationship can be characterized by quantifying components of the "numerical (population) response" and "functional (foraging) response" of seabirds to variations in prey density (Holling 1959; Murdoch and Oaten 1975; Piatt 1987). The "numerical response" includes components of population biology such as adult survivorship, clutch size, and reproductive success. The "functional response" includes components of foraging such as feeding rate, time spent foraging, and foraging range.

For individual seabirds, the functional response incorporates all parameters relating to the capture of prey. Studies have demonstrated or hypothesized that these parameters are non-linear functions of prey density that operate over time-scales of hours to days, and spatial scales of meters to kilometers. For example, foraging time declines with increasing prey density (Cairns et al. 1987; Monaghan et al. 1989, 1994) allowing more free time for other activities (Burger and Piatt 1990). Similarly, as prey densities increase, foraging ranges may contract by 10's of km (Cairns et al. 1990; Monaghan et al. 1994) resulting in a considerable reduction in foraging energy expenditure (Cairns et al. 1987) and greater prey harvests in the vicinity of colonies (Cairns et al. 1990).

Numerical response parameters for seabirds are, in the absence of stochastic mortality events (e.g., oil mortality), a direct function of food availability over longer time scales (months and years) and larger spatial scales (100's to 1000's of kilometers). Thus, population change in seabirds reflects day-to-day foraging success integrated over reproductive time-periods and the area over which populations are distributed (Cairns 1987, 1992a,b; Piatt 1987).

The numerical and functional responses of individual species to changes in prey density are almost always non-linear, frequently sigmoidal, and species-specific with regard to absolute density thresholds (Holling 1959; Murdoch and Oaten 1972; Piatt 1990; Piatt and Methven 1991). In other words, some seabird species may prosper at low levels of prey density while others require much higher densities (Piatt 1987, 1990). Cairns (1987) further hypothesized that components of the numerical and functional response in individual species of seabirds are sensitive to different levels

(thresholds) of prey density. For example, adult survivorship is probably quite high over a wide range of medium to high prey densities, but at some low, critical level, adult survival diminishes rapidly. In contrast, when seabirds are constrained to forage locally during the breeding season and food demands are high (for both adults and chicks), then moderate to high prey densities are required to maintain high breeding success.

Some species may be able to buffer against variation in their numerical and functional response by adjusting their foraging effort as prey densities fluctuate (Piatt 1987, 1990; Burger and Piatt 1990; Uttley et al. 1994; Monaghan et al. 1994). Other species may have little buffering capacity because they are pushed to their limits even under normal circumstances (Goudie and Piatt 1991; Hamer et al. 1994). Thus, in some species (e.g., murre), chick feeding rates or breeding success may not be affected over a wide range of prey densities because adults simply spend more time foraging to compensate for the change in prey density. Components of numerical and functional responses which may be buffered are therefore less sensitive indicators of prey fluctuations (Burger and Piatt 1990).

In point of fact, functional and numerical responses have not been demonstrated for any seabird species. After 2 years of collecting data at 3 different colonies simultaneously, we have acquired just enough data to take a preliminary look at seabird responses to varying prey densities (**Figure 13**). In this example, we used beach seine catch data as a proxy for prey abundance until the hydroacoustic data are completely analysed. As predicted, kittiwakes appear to show a non-linear numerical response to food abundance (note log scale), and the relationship was best fit ($r^2=0.77$) by a sigmoidal function. In contrast, murre production was relatively insensitive to differences in food supply between colonies, presumably because of their ability to buffer against prey variability. As noted above (*Common Murres*), however, attendance patterns differ significantly among colonies in Cook Inlet. Mean attendance (bird-min per hour) was a linear function of food abundance (**Figure 13**) and provides a more sensitive indicator of food stress. After another field season, we will have enough data to begin examining in more detail the various responses of seabird biology and behavior to variations in prey density.

PUBLICATIONS

Although field work will continue in 1998 and 1999, we are attempting to publish some of the basic results from the first three field seasons to lay the groundwork for later publications that will take a more synthetic approach. The following manuscripts comprise some of the products we hope to submit before the end of this fiscal year (FY98). Listed here are only those papers for which manuscripts have been completed and are submitted or currently under revision before submission. Included here are products (indicated by *asterisk) that are related to APEX interests and/or were prepared by investigators partially under financial support of APEX. We anticipate that all of the following will have been submitted for publication before 31 May, 1998:

Zador, S.G., J.F. Piatt, A. Kettle, Ann Harding, and A. Abookire. 1998. Can the diet of Common Murres be used to assess forage fish stocks? Mss. submitted to **Marine Ecology Progress Series**.

- Kuletz, K. and J.F. Piatt. 1998. Marbled Murrelet chick production and juvenile nursery areas in Kachemak Bay, Alaska. Mss. under revision for submission to **Wilson Bulletin**.
- Abookire, A.A., J.F. Piatt and M. Robards. 1998. Near shore fish communities in two oceanographically distinct regions of an Alaskan estuary. Mss. under revision for submission to **Canadian Journal of Fisheries and Aquatic Sciences**.
- Kitaysky, A., J. Wingfield, and J. Piatt. 1998. What's a chick to do? Hormonal regulation of foraging behavior in Black-legged Kittiwake chicks. Submitted to **Nature**.
- *Speckman, S.G., A. Springer, and J.F. Piatt. 1998. Attendance patterns of Marbled Murrelets at sea: Implications for population monitoring. Under revision for submission to the **Journal of Wildlife Management**.
- *Piatt, J.F., D.C. Schneider, and D.A. Methven. Response of mobile marine predators to their prey. Mss. under revision for submission to **Canadian Journal of Fisheries and Aquatic Sciences**.
- *Piatt, J.F., D.C. Schneider, and D.A. Methven. Functional and aggregative response of coexisting marine predators. Mss. submitted to **Science**.
- Harding, A. and J.F. Piatt. 1998. Attendance patterns and monitoring of Horned Puffins in Cook Inlet, Alaska. Mss. under revision for submission to **Colonial Waterbirds**.
- Nielsen, A., J.F. Piatt, A. Kettle, and Tom van Pelt. 1998. Diets of Black-legged Kittiwakes in relation to prey availability in Cook Inlet, Alaska. Mss. under revision for submission to **Polar Biology**.
- *Kitaysky, A.S., G.L. Hunt, Jr., Flint E.N., Rubega M.A., and M.B. Decker. 1998. Does reproductive performance reflect population size in high latitude seabirds? Mss. under revision for submission to **Behavioural Ecology**.
- Litzow, M.A., J.F. Piatt, A.A. Abookire, M. Robards and A.K. Prichard. 1998. Variability in Pigeon Guillemot Diet and Nearshore Fish Communities at Kachemak Bay, Alaska. Mss. submitted to **Canadian Journal of Zoology**.
- Litzow, M.A., J.F. Piatt, and J. Figurski. 1998. Hermit crabs in the diet of Pigeon Guillemots at Kachemak Bay, Alaska. Submitted to **Colonial Waterbirds**.
- Robards, M.D., J.F. Piatt, and G.A. Rose. 1998. Maturation, fecundity and intertidal spawning of Pacific Sand Lance (*Ammodytes hexapterus*) in the northern Gulf of Alaska. Mss. submitted to **Marine Biology**.

Robards, M., J.F. Piatt, and A. Abookire. 1998. Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet, Alaska. Mss. submitted to **Fishery Bulletin**.

Zador, S., and J.F. Piatt. 1998. Time-budgets of Common Guillemots (*Uria aalge*) at a declining and increasing colony in Alaska. Submitted to **Condor**.

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Table 1. Trends in murre populations, productivity, and breeding behavior at Chisik and Gull Islands, 1995 - 1997.

<u>Parameter</u>	<u>Duck Island</u>		<u>Gull Island</u>	
	<u>1995 -> 1996</u>	<u>1996 -> 1997</u>	<u>1995 -> 1996</u>	<u>1996 -> 1997</u>
Populations	Decline	Decline	Decline	Increase
Phenology	n/a	No Change	n/a	Late
Hatching Success	n/a	Decline	n/a	Decline
Productivity	Increase	Decline	Increase	Decline
Attendance	Decline	Increase	Decline	Increase
Chick Feeding Rates	Decline	Increase	Increase	Decline
Adult Trip Durations	Increase	Decline	No Change	No Change
Chick Growth Rates	n/a	Increase	n/a	No Change

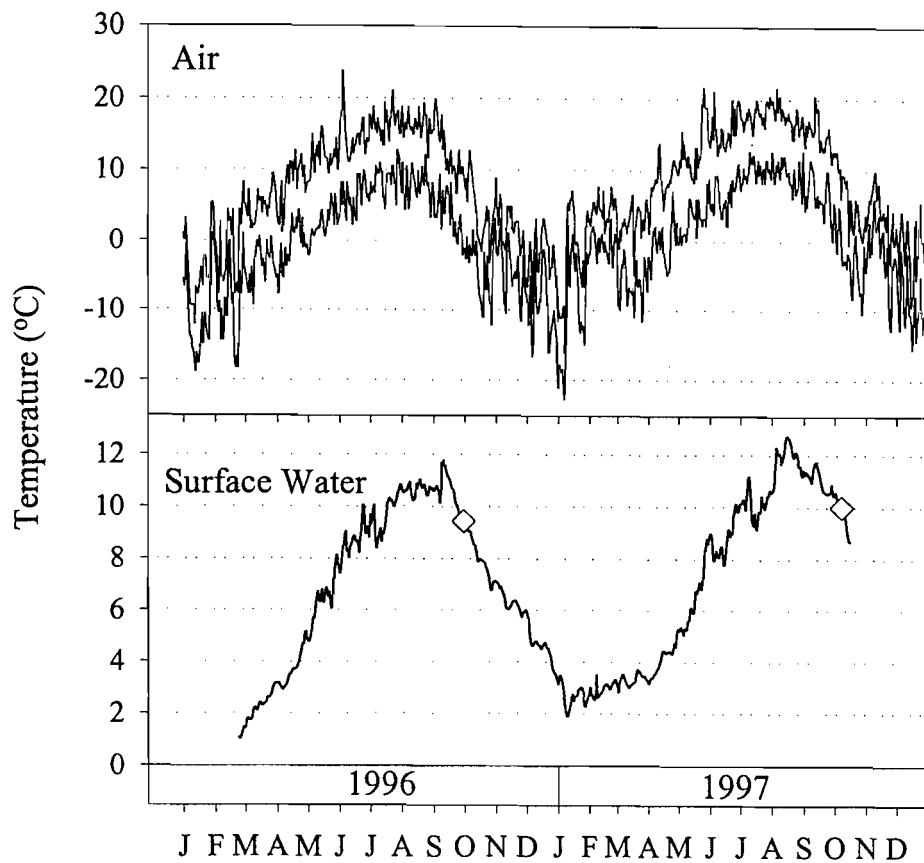


Figure 1. Air temperature (daily maximum and minimum) and sea surface temperature (at 5 m below low low water) in Kachemak Bay, Alaska, 1996-1997. Note there was little difference in SST trends between 1996 and 1997 until August of 1997, when temperatures increased and stayed about 2 degrees higher through to October. Diamonds on SST lines indicate timing of spawning of sand lance in Kachemak Bay.

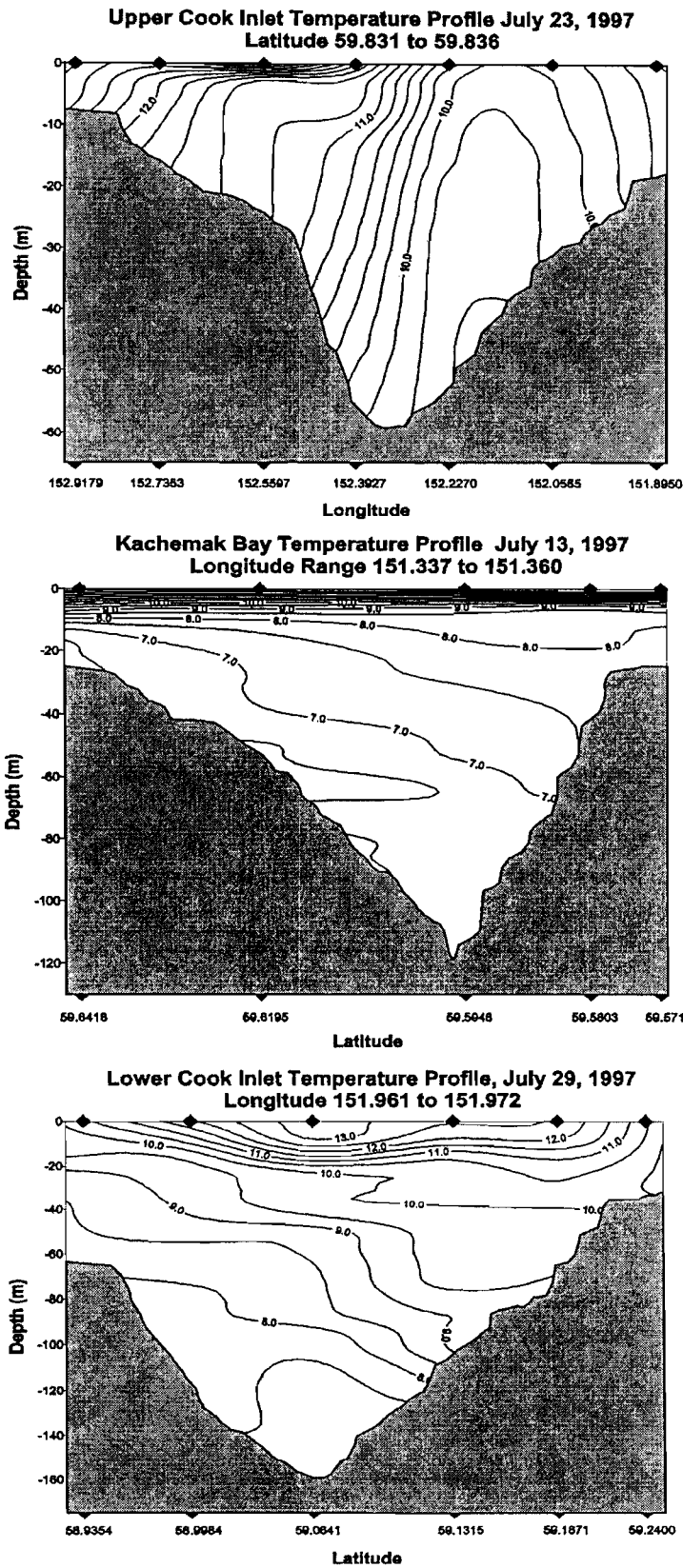


Figure 2. Cross-sections of water temperatures in lower Cook Inlet: From Kachemak Bay to Chisik Island (upper panel); North to South across outer Kachemak Bay (middle panel); and North to South from the Kenai Peninsula to the Barren Islands (lower panel).

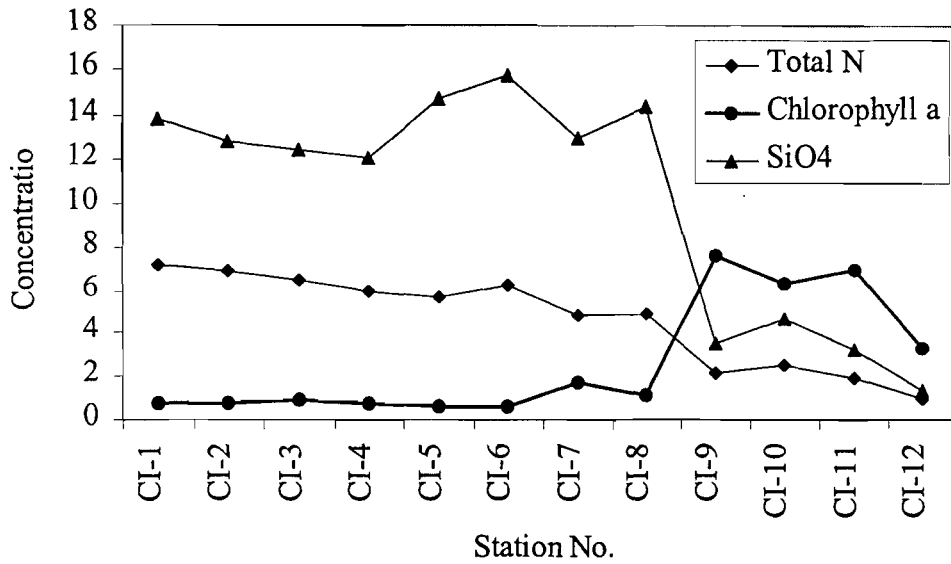


Figure 3. Nutrients and phytoplankton production on a transect across lower Cook Inlet. Low nutrients and high phytoplankton (stations C-9 to C-12) were found in stratified waters of Kachemak Bay (Fig. 2, middle panel). High nutrients and low phytoplankton (stations CI-1 to CI-8) were found in turbulent, mixed waters further offshore in the plume of upwelled water entering lower Cook Inlet (like those shown in Fig. 3, upper panel, right-hand side).

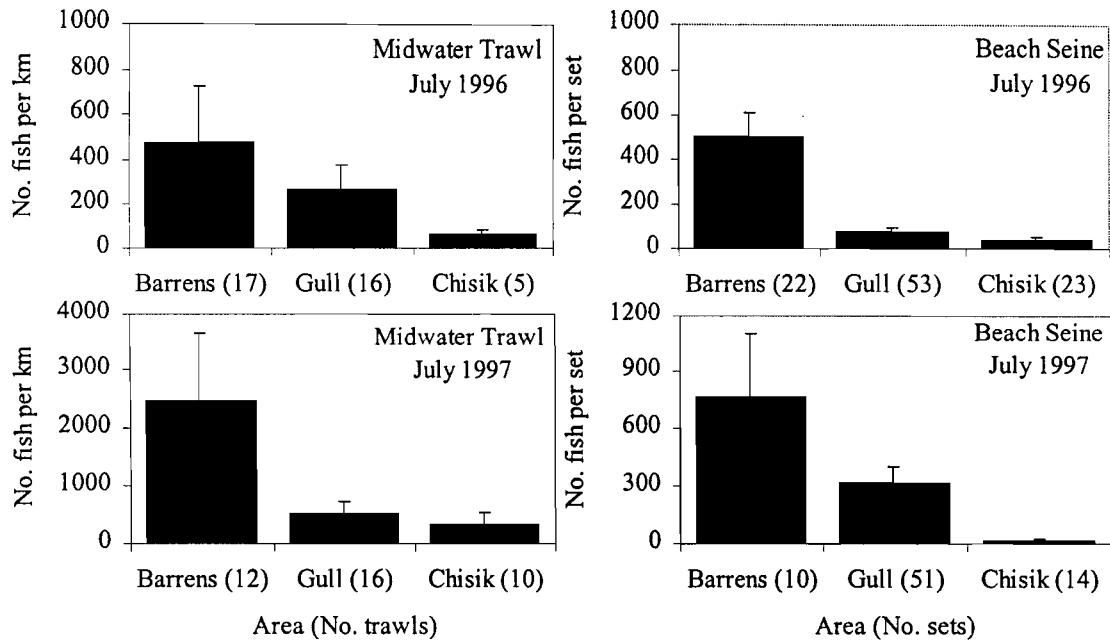


Figure 4. Catch-per-unit-effort (CPUE) of fish in mid-water trawls and beach seines at 3 study areas in lower Cook Inlet, 1996-1997. Trawl CPUE is standardized per km of distance towed. Only data from the month of July are included in this analysis. Note increase in CPUE for both trawls and seines between 1996 and 1997.

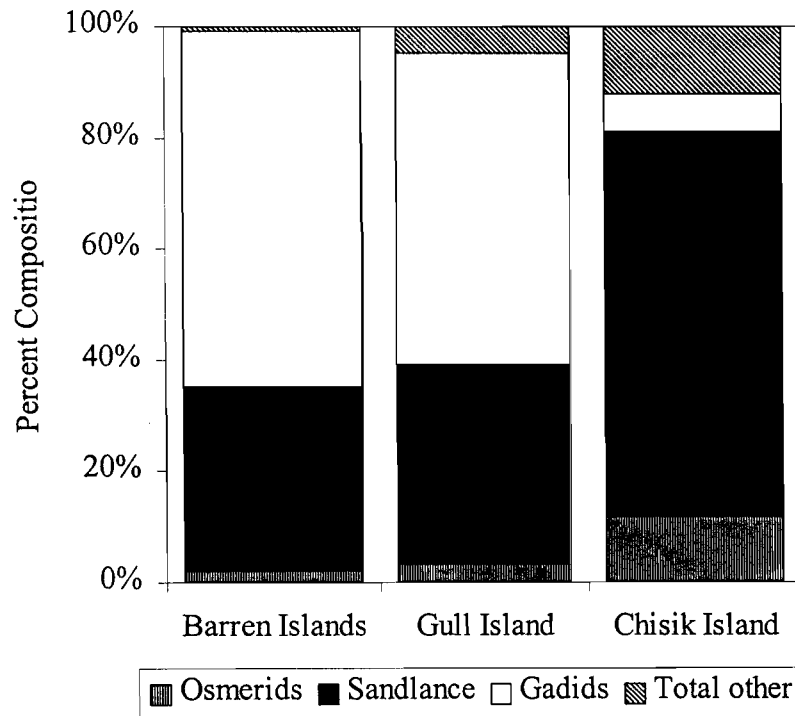


Figure 5. Fish species composition available to seabirds in each study area. Data pooled for 1996 and 1997 (n=76 trawls). Percent composition was determined by pro-rating trawl catch composition by total foraging area within each study area (stratified into inshore and offshore zones).

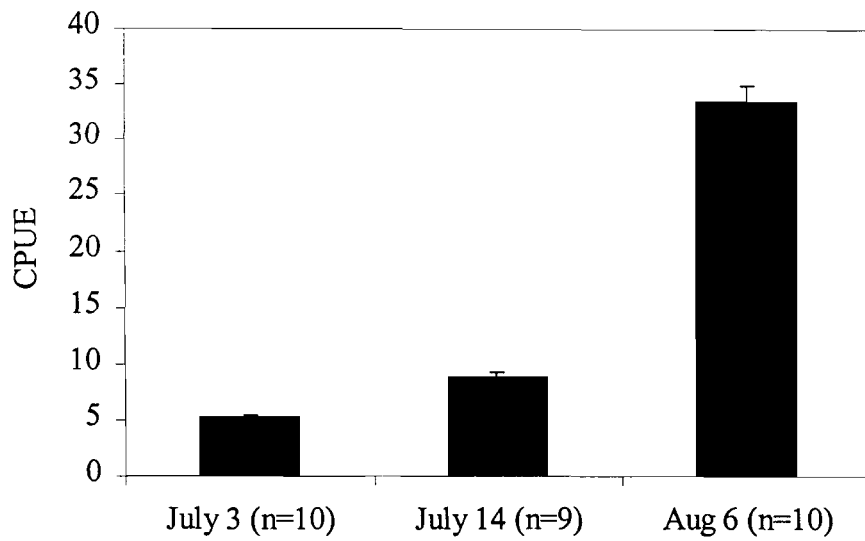


Figure 6. Seasonal variation in bottom trawl catches in Kachemak Bay, 1997. Includes only forage-sized fishes (80-150 mm). Catch-per-unit-effort (CPUE) was standardized for 1000 m² area trawled. Shown are mean values with standard error bars. Sample size in parantheses.

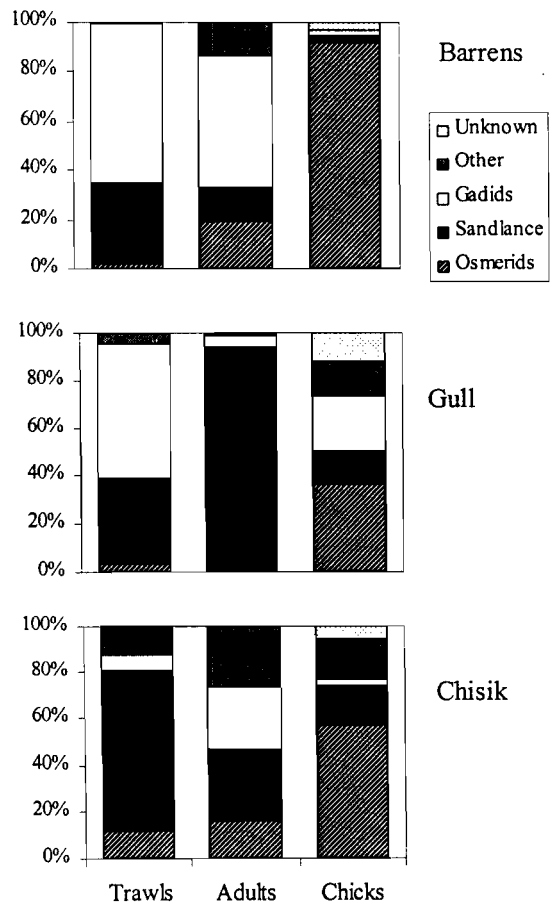


Figure 7. Diets of Common Murre chicks and adults, and fish availability (from mid-water trawls), at Barren, Gull and Chisik islands. Data pooled from 1996 and 1997.

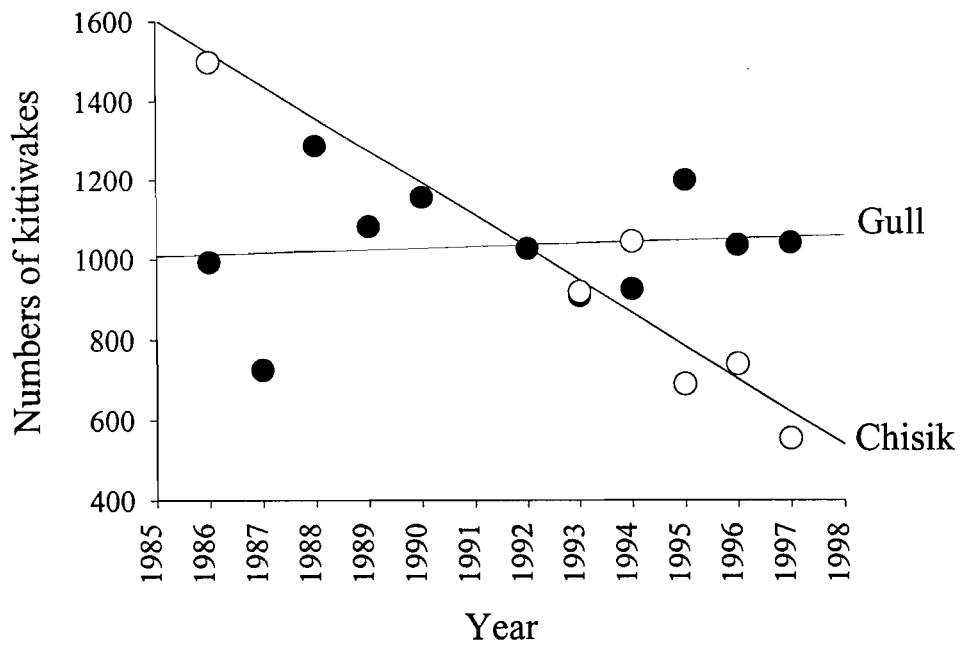


Figure 8. Kittiwake population trends at Gull and Chisik islands. Data from standardized plot counts only. Whole-island counts conducted prior to 1985 show a marked increasing population trend at Gull Island, and a decreasing trend at Chisik similar to that observed above.

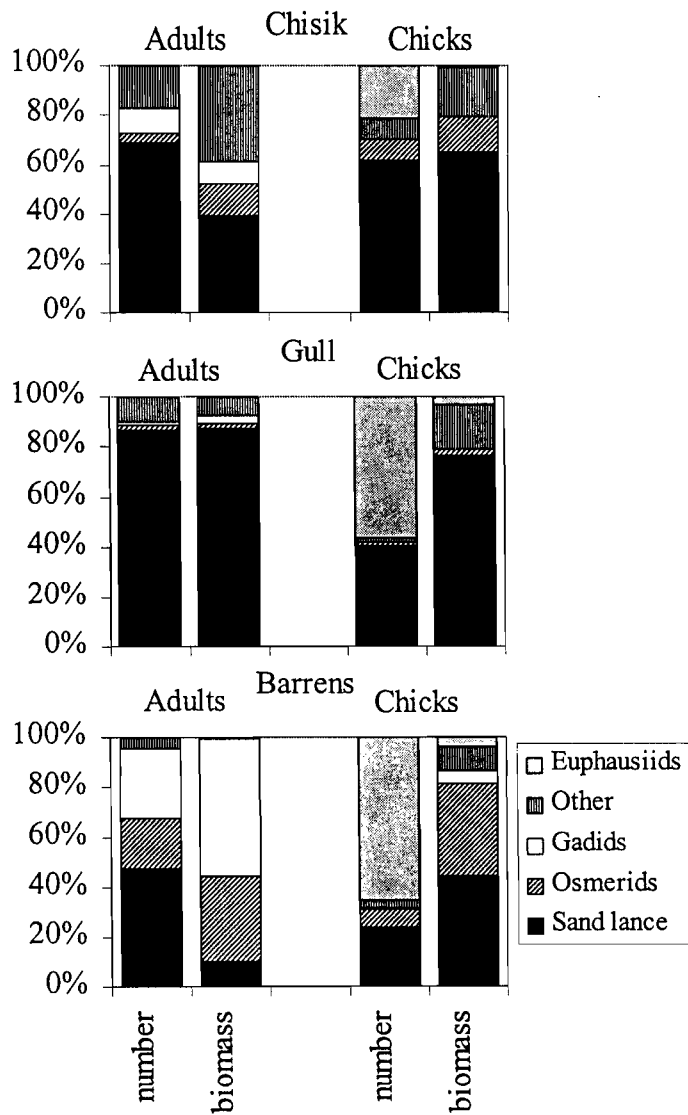


Figure 9. Diet of adult and chick Black-legged Kittiwakes at Chisik, Gull and Barren islands, Cook Inlet. Data from 1996 and 1997 are combined and expressed as percent total number or biomass in diet. See Fig. 5 for comparison with forage fish availability as determined by mid-water trawls.

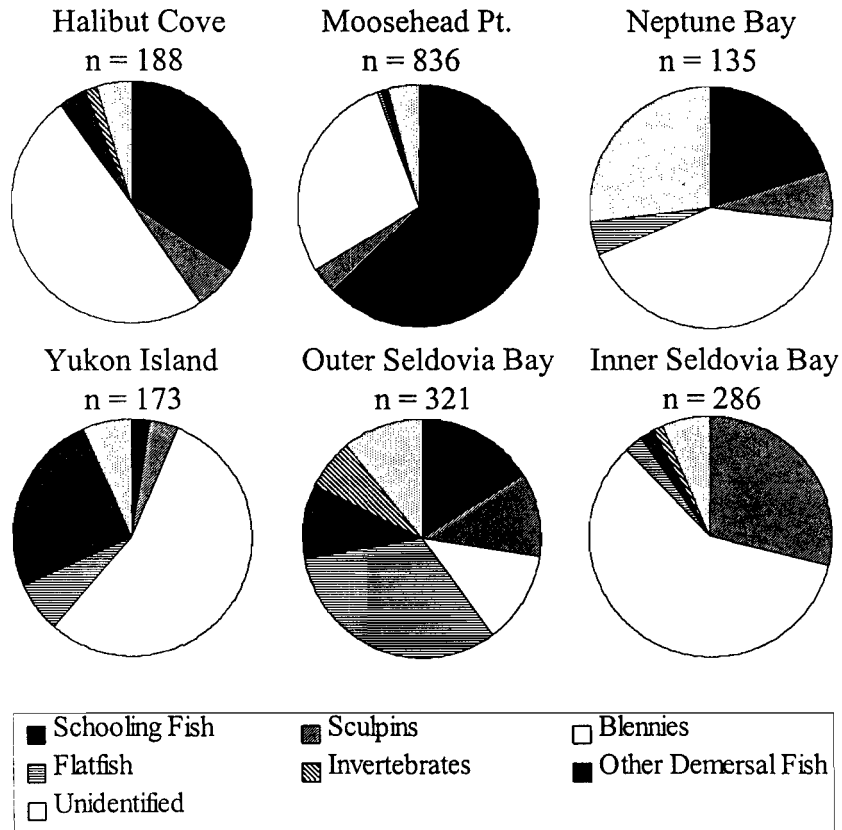


Figure 10. Pigeon Guillemot nestling diet at six colonies in Kachemak Bay. Data from 1995-1997 combined. "Other Demersal Fish" category includes unidentified demersal fish. Schooling fish are almost entirely Pacific Sandlance.

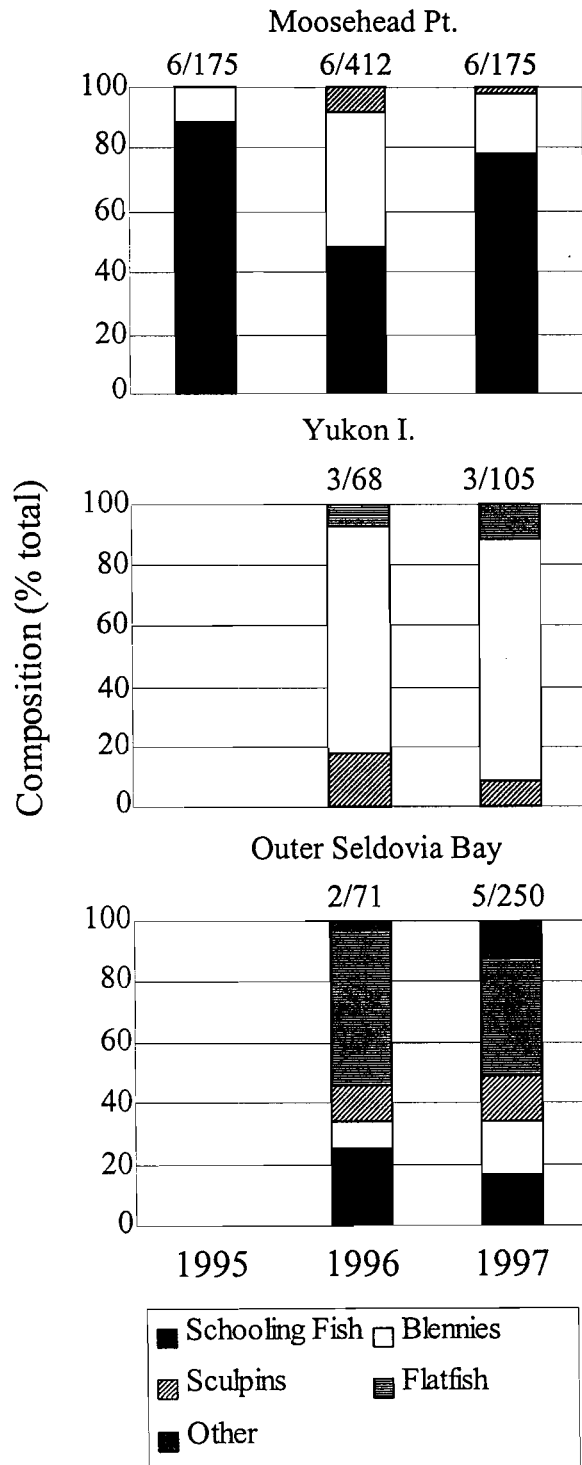


Figure 11. Interannual variation in diet of Pigeon Guillemots at 3 colonies in Kachemak Bay, Cook Inlet. Sample sizes indicated above bars (no. nests/no. prey items).

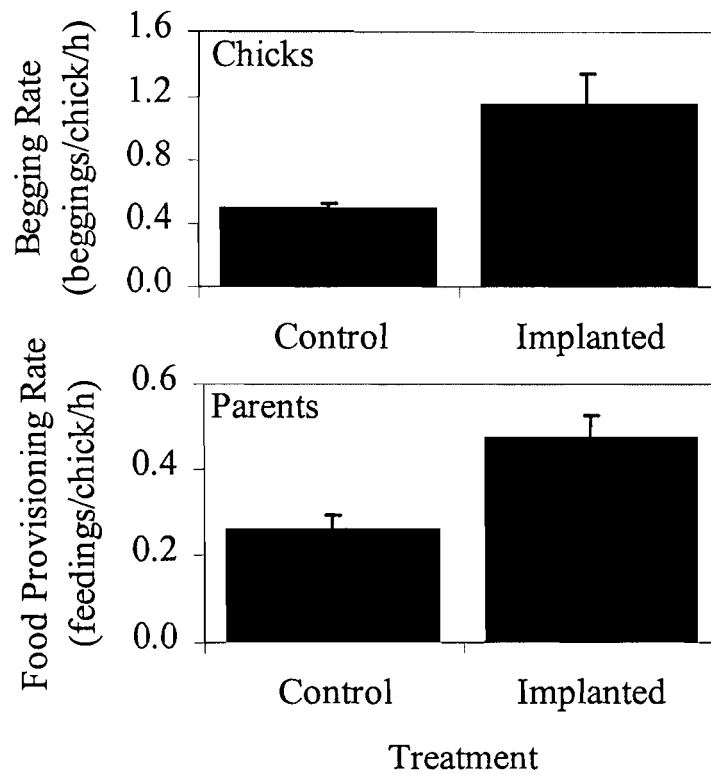


Figure 12. (CHICKS) Black-legged Kittiwake chicks increase their begging rate in response to experimentally increased plasma levels of corticosterone. (PARENTS) Black-legged Kittiwake parents of implanted chicks increase feeding of their young in response to the experimentally increased begging rate of chicks.

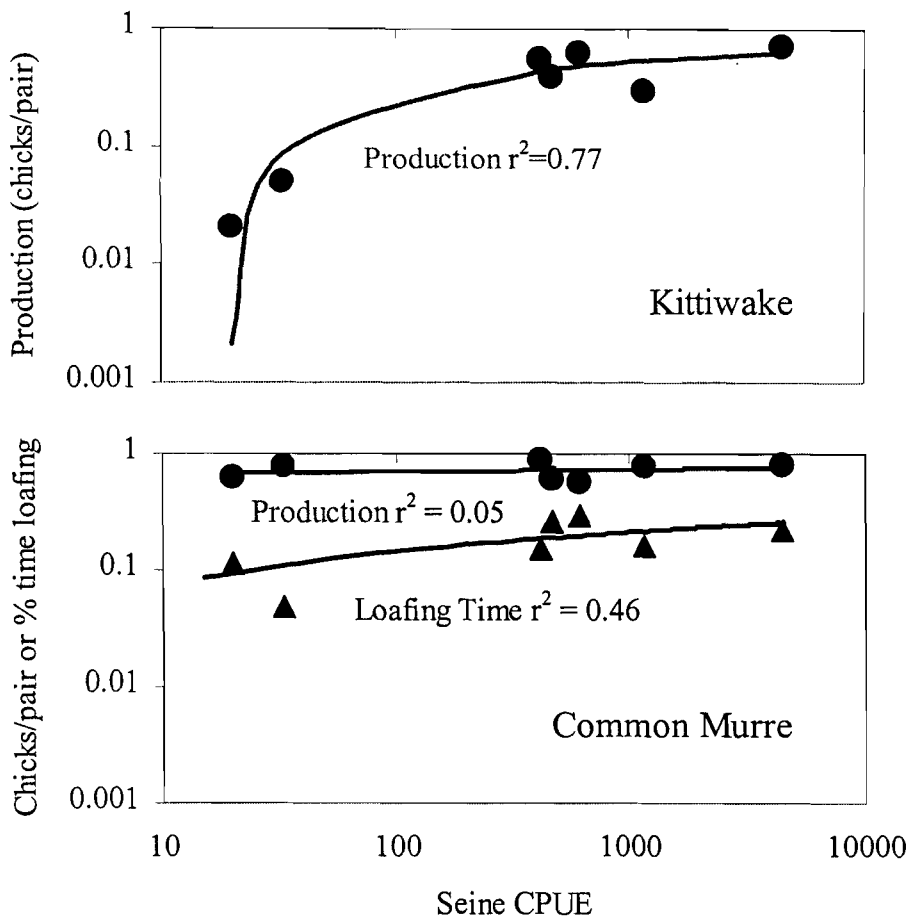


Figure 13. Biological and behavioral responses of Black-legged Kittiwakes and Common Murres to variation in prey abundance. Constructed using data from 1995 (Gull Island only) to 1997 (Gull, Chisik and Barren islands). Kittiwakes show a non-linear (sigmoidal, note log scale) response in productivity. Murres productivity is insensitive to fluctuations in prey density, but murres spent less time attending nest-sites (“loafing”) when prey densities were low.