APPENDIX M

APEX: 96163M

Exxon Valdez Oil Spill Restoration Project Report

Cook Inlet Seabird and Forage Fish Studies

Restoration Project (APEX) 96163M
Annual Report

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Cook Inlet Seabird and Forage Fish Studies

Restoration Project (APEX) 96163M
Annual Report

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 96163M 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 Science 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 and the University of Alaska, Fairbanks.

Abstract: In 1995 and 1996, 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. Offshore and southern waters of Cook Inlet were dominated by juvenile walleye pollock and capelin, important prey for murres and puffins. Nearshore waters of Cook Inlet were dominated by sandlance, which were consumed by seabirds (e.g., kittiwakes, guillemots, murres) in proportion to their local abundance. Halibut consumed large numbers of capelin in southern areas, and more sandlance in the north. Forage fish densities ranged from 10's fish/cubic m (pollock) to 100's and 1000's of fish/cubic m (sandlance). Acoustically-measured forage fish biomass was lowest around Chisik Island, moderate in Kachemak Bay, and highest around the Barren Islands. Correspondingly, seabird densities at sea and seabird breeding success 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. Capelin and sandlance had higher energy loads (fat content) than pollock or cod, and in areas where these fish were observed in high densities, seabirds consumed large quantities and had the highest breeding success. Experiments further revealed that kittiwake and puffin chick growth was better in chicks raised on oil-rich sandlance or capelin, than on relatively lean pollock.

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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The 1997 Annual Report for the Cook Inlet Seabird and Forage Fish Study (CISeaFFS) is comprised of several related papers (in following order):

1) *APEX Project 97163M: Cook Inlet Seabird and Forage Fish Studies (CISeaFFS).* Summary document that integrates all aspects of the project, from oceanography to seabird productivity, and reviews hypotheses under examination in CISeaFFS. 8 pp.

2) *Temporal and Geographic Variation of Fish Populations in Nearshore and Shelf Areas of Lower Cook Inlet, Alaska.* Manuscript under review for submission to Estuarine, Coastal and Shelf Science. 50 pp.

3) *Seabird Populations, Productivity, and Behavior at Gull and Chisik Islands, Cook Inlet, in 1996.* Report of seabird biology at study colonies for EVOS Trustees and Minerals Management Service. 30 pp.

4) *Time-budgets of Common Guillemots (Uria aalge) at declining and increasing colonies in Alaska.* Manuscript under review for submission to Ibis. 12 pp.

5) *Breeding Biology and Feeding Ecology of Pigeon Guillemots at Kachemak Bay, Alaska, in 1996.* Report of Pigeon Guillemot biology for CMI funded research (University of Alaska Fairbanks, Minerals Management Service) and EVOS Trustees.

APEX Project 97163M: Cook Inlet Seabird and Forage Fish Studies (CISeaFFS)

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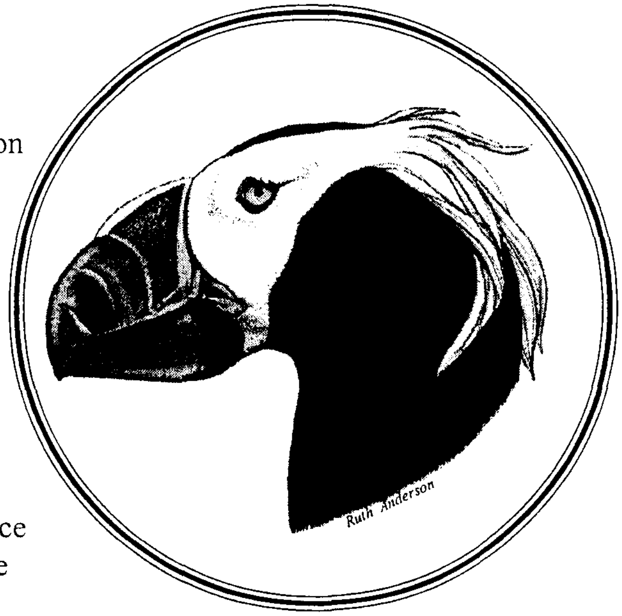

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It is difficult to assess the potential for recovery of seabirds from the Exxon Valdez oil spill (EVOS) and other human impacts (e.g., gill-nets, harvest, commercial fisheries, etc.) because long-term changes in the marine environment were apparently also affecting seabirds at the time of the spill, and during subsequent years. 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. These changes correlate with long-term cycles in seawater temperature. It is not known whether fish communities will return to their previous composition and population levels.

CISeaFFS ("Sisyphus") was initiated in 1995 as a long-term research project 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 multidisciplinary research project of the Alaska Science Center and the Alaska Maritime National Wildlife Refuge, which has management responsibility for most seabird colonies in Alaska.

METHODS

In 1995 and 1996, populations, productivity, diets and foraging behavior of seven seabird species (Common Murre, Black-legged Kittiwake, Pigeon Guillemot, Tufted Puffin, Horned Puffin, Pelagic Cormorant, Glaucous-winged Gull) were studied at three seabird colonies in lower Cook Inlet (Chisik, Gull and Barren islands). Oceanographic measurements (SST's, CTD's), seabird transects and hydroacoustic surveys for fish, mid-water and benthic trawls, and beach seines were conducted in core study areas around (<40 km) each colony (Figure 1, next page). In 1996, surveys extended throughout lower Cook Inlet, as far south as Shuyak Island. Also in 1996, coastal transects were added to the survey of core areas to increase sampling of the productive nearshore zone.

OCEANOGRAPHY

The Alaska Coastal Current flows west and north into Cook Inlet (Figure 2), and upwelling of cold, nutrient-rich water occurs around islands and on shallow coastal shelves (Figure 3). Satellite imagery shows this cold water extending well north into Cook Inlet and Kachemak Bay (Figure 3). Vertical CTD salinity and temperature profiles of the water column (Figure 4), and continuously recording temperature probes (Figure 5), reveal that water around the Barrens is completely mixed, cold, and highly saline. Water in Kachemak Bay has a shallow layer of warm, low-salinity water overlaying cold, saline water like that observed at the Barrens. Water near Chisik Island, on the west side of Cook Inlet, is much warmer and less saline, because south-flowing currents carry warm, fresh water from the head of Cook Inlet. The difference in oceanographic regimes between the east and west side of Cook Inlet has important implications for the forage fish and seabirds residing in each area.

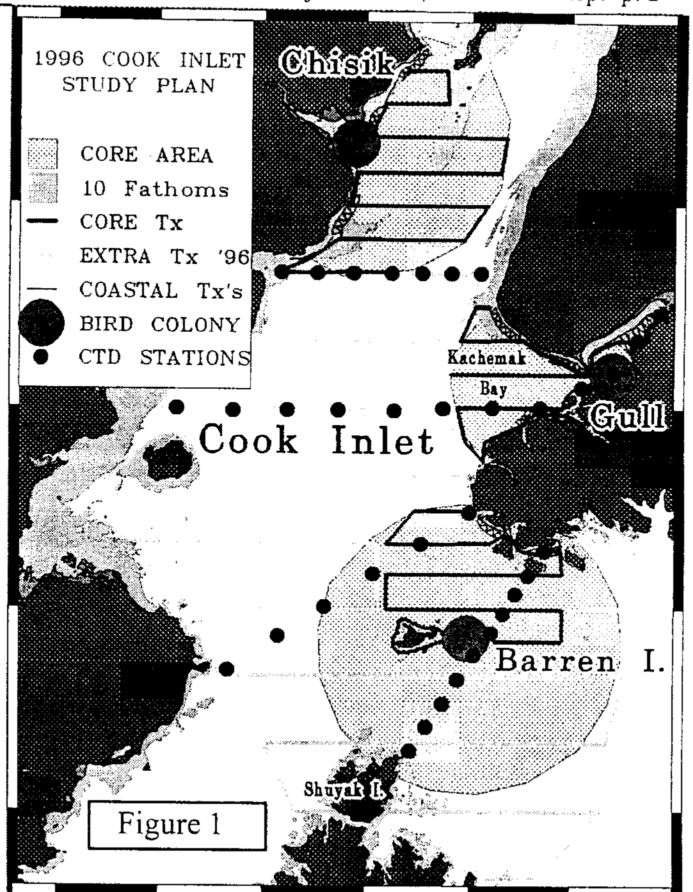


Figure 1

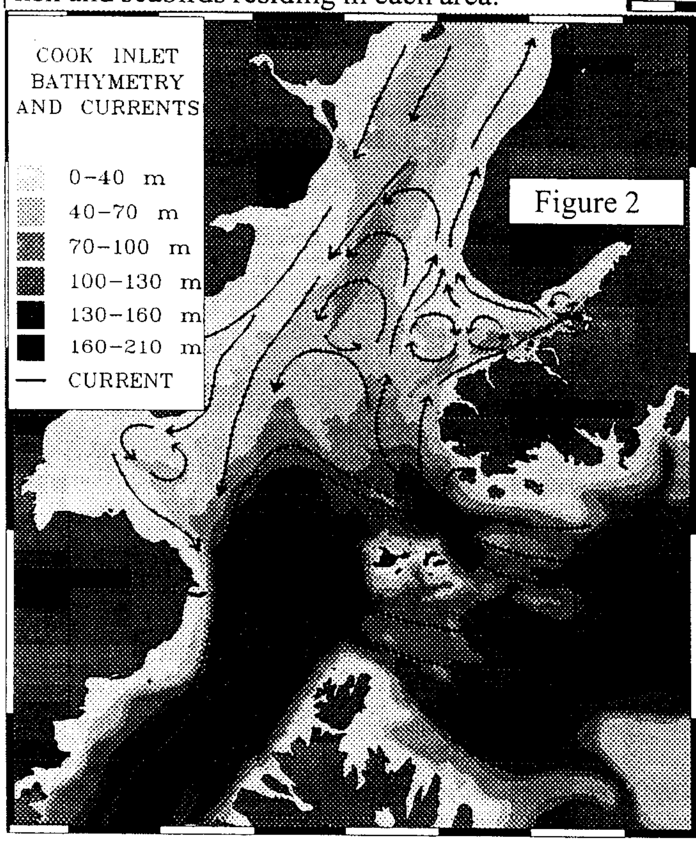


Figure 2

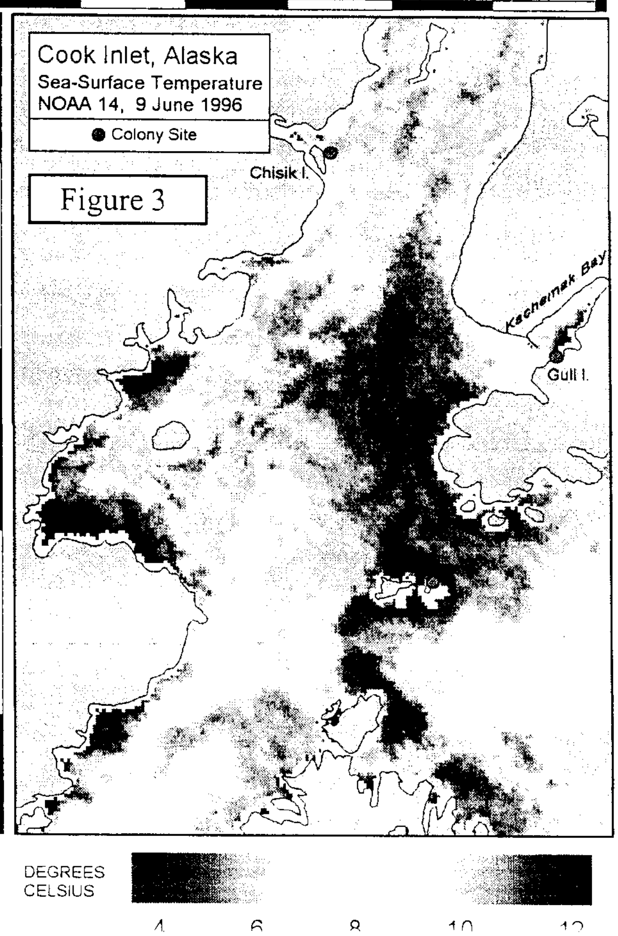


Figure 3

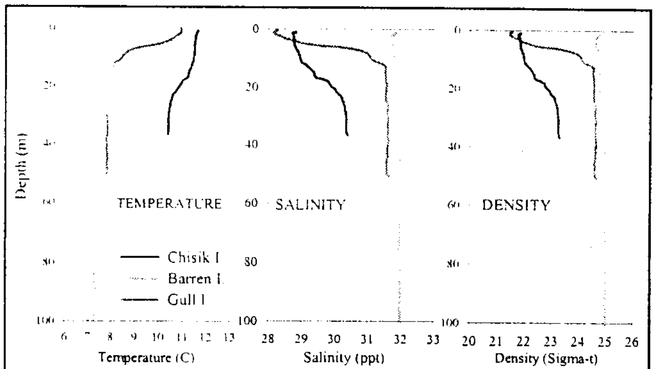


Figure 4. Temperature, salinity and density profiles of the water column at the three study colonies obtained from CTD casts in July, 1996

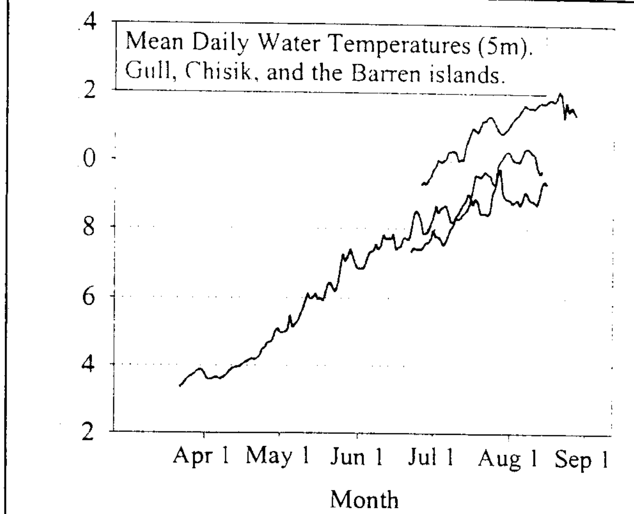
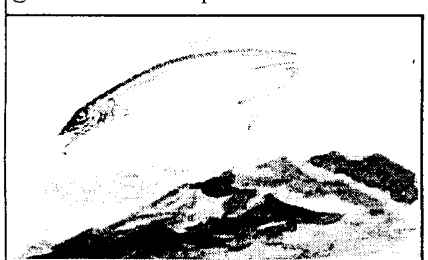


Figure 5. Mean daily water temperatures at 5 m depth obtained from continuously recording temperature probes at the three study colonies in Cook Inlet.

FISH

The abundance and species composition of fish in Cook Inlet were examined by conducting mid-water and benthic trawls (Figures 6&8), beach seines (Figures 7&8), and hydroacoustic surveys (Figures 9&10). Pelagic forage fish abundance increased by about an order of magnitude (Fig. 10), and diversity decreased (Fig. 8), as we sampled from North (Chisik) to South (Barrens). Benthic trawls revealed a similar pattern for bottom fishes. Pacific sandlance dominated in both coastal and offshore waters around Gull Island (Kachemak Bay), although capelin and pollock were also common offshore. Around the Barrens, juvenile pollock and capelin dominated offshore catches, while coastal beach seines caught sandlance almost exclusively. The abundance of fish in coastal waters varied seasonally (Figure 7), with peak seine catches in June-August for most species.



"The Mighty Sandlance", watercolor by William Spear (1994)

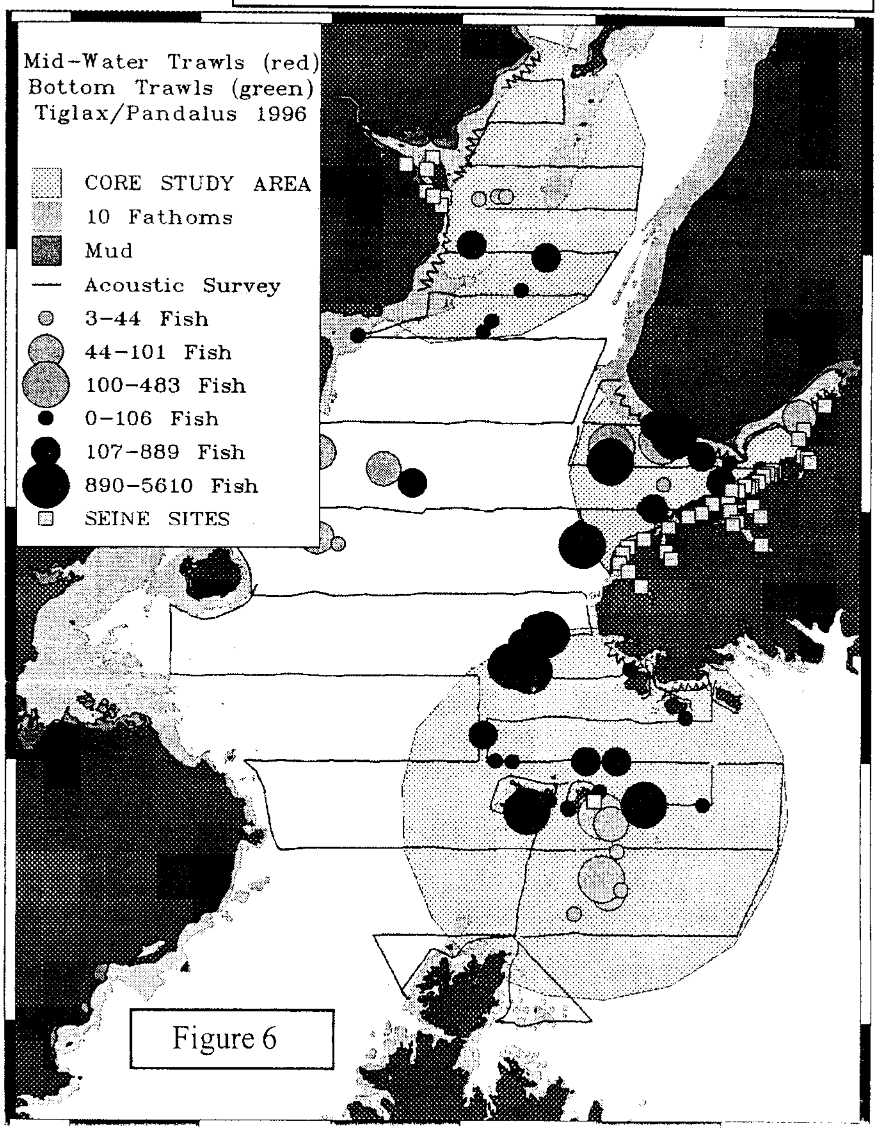


Figure 6

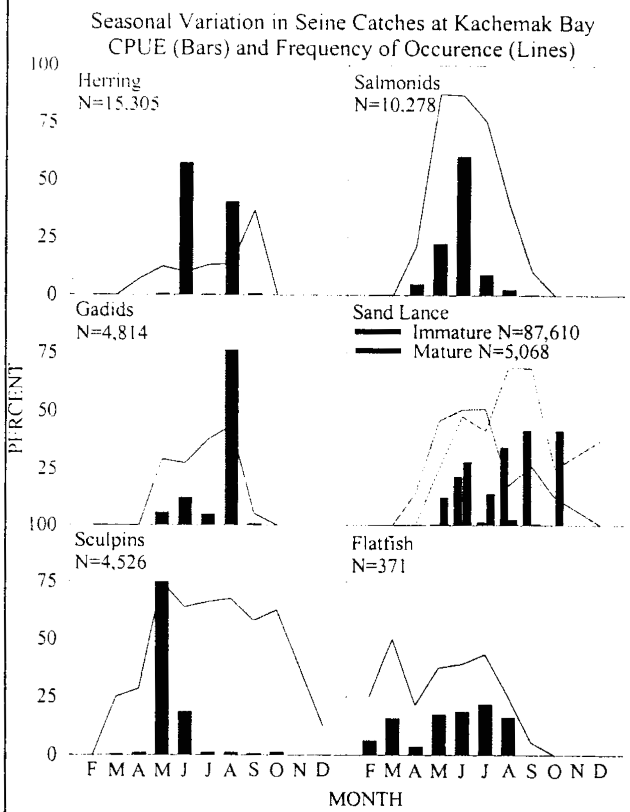


Figure 7. Catch per unit effort (CPUE) and frequency of occurrence of fish caught in beach seines in Kachemak Bay, 1996.

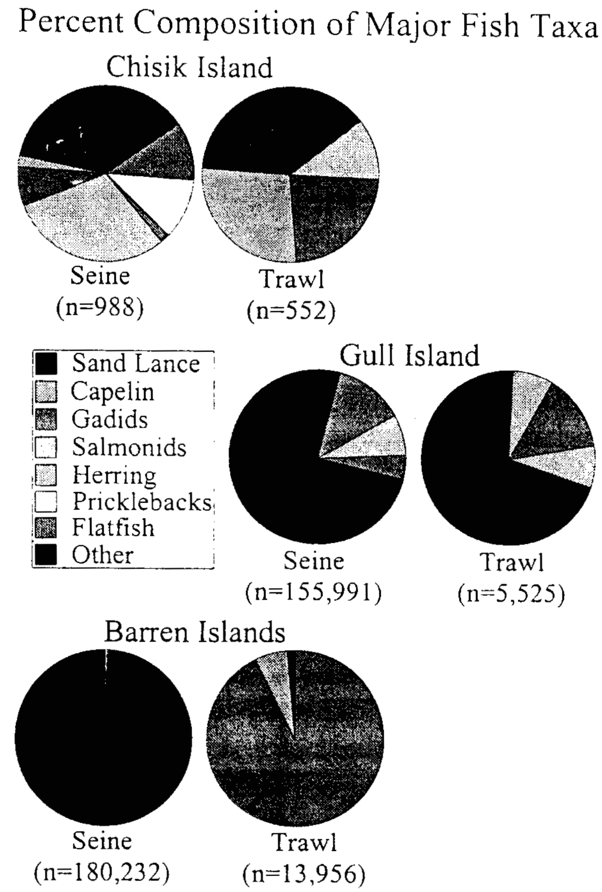


Figure 8. Species composition of fish catches in mid-water trawls and beach seines in lower Cook Inlet, summer 1996.

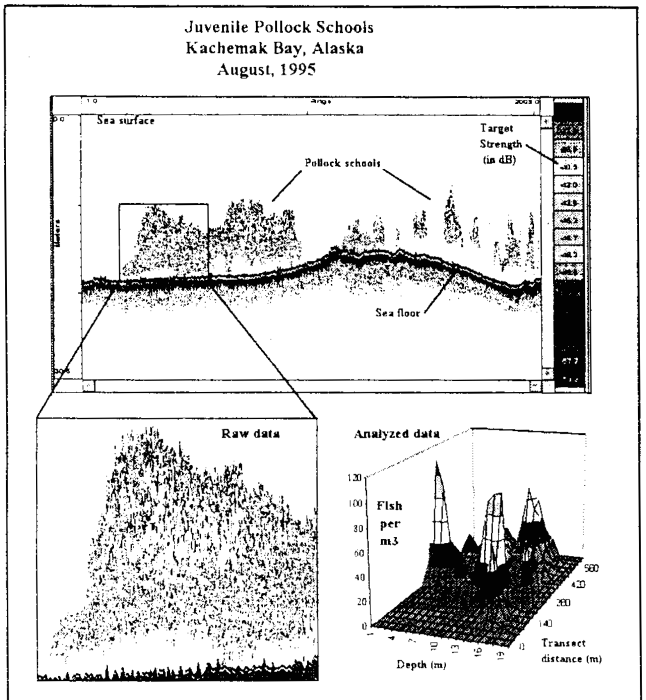


Figure 9. Example of fish schools recorded on a Biosonics DT4000 Digital Echosounder, and integration to obtain absolute fish densities.

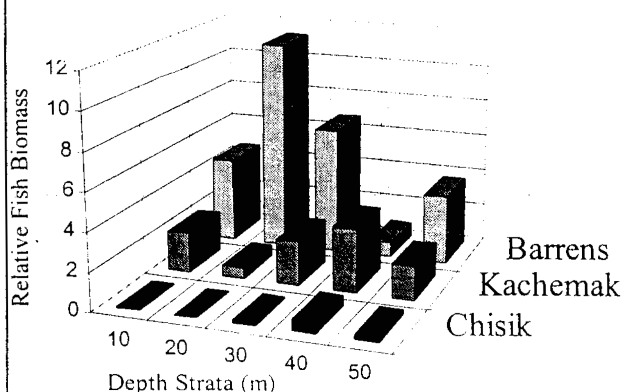
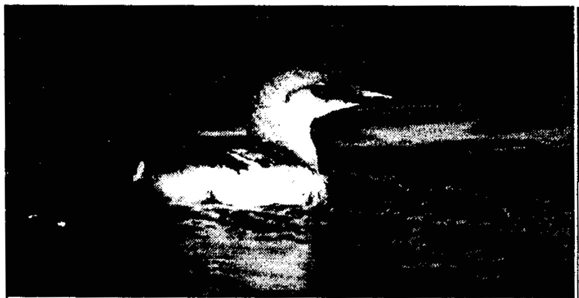


Figure 10. Relative abundance of fish in each of the three core colony study areas (Fig. 1) as determined by hydroacoustic surveys in summer, 1995. (Similar results in 1996).



SEABIRDS AT SEA

The abundance and distribution of fish-eating seabirds corresponded to patterns of oceanography and fish distribution in lower Cook Inlet. Seabirds were concentrated around the Barrens (Fig. 11), northeast along the Kenai coast, and in Kachemak Bay. Shallow coastal habitats were particularly rich, whereas birds were conspicuously scarce in the west half of lower Cook Inlet. A detailed look at Common Murre distribution (Figure 12) reveals that high-density murre foraging areas are close to Gull Island in Kachemak Bay, and further away from the Barrens in several directions. Chisik murres forage little in the vicinity of Chisik Island, and appear to fly southeast to good foraging areas in Kachemak Bay. Kittiwakes reveal a similar pattern (Figure 13), except many appear to forage within 40-50 km of Chisik, and birds from the Barrens forage a long distance north along the coast of the Kenai Peninsula.

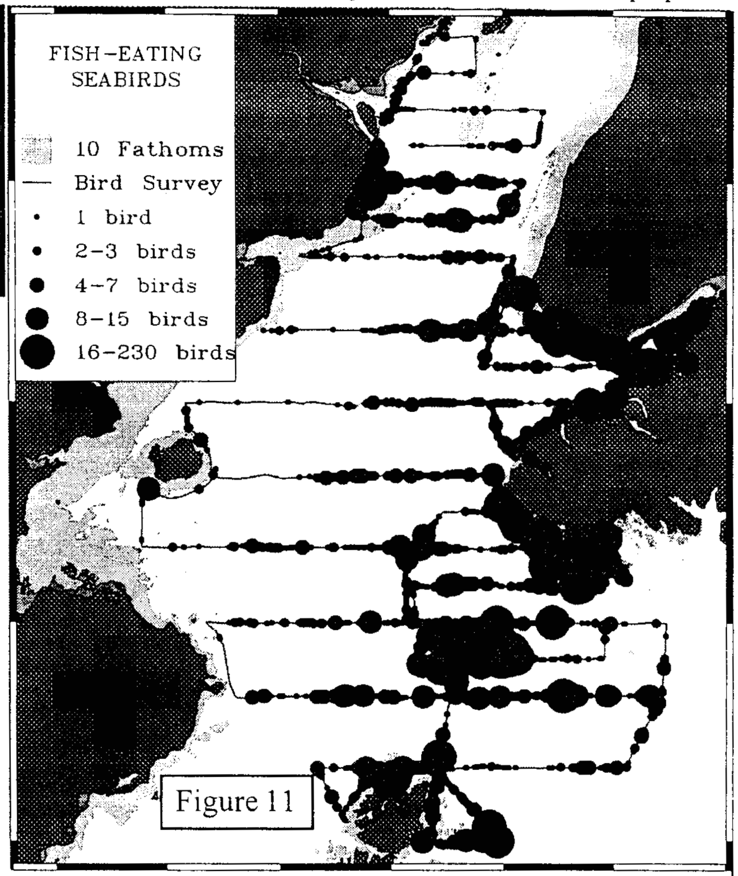


Figure 11

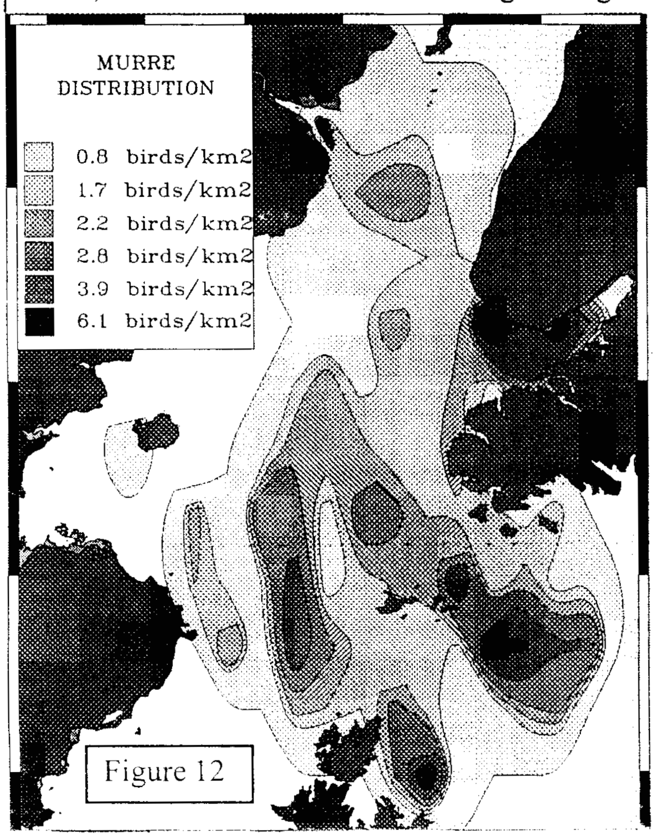


Figure 12

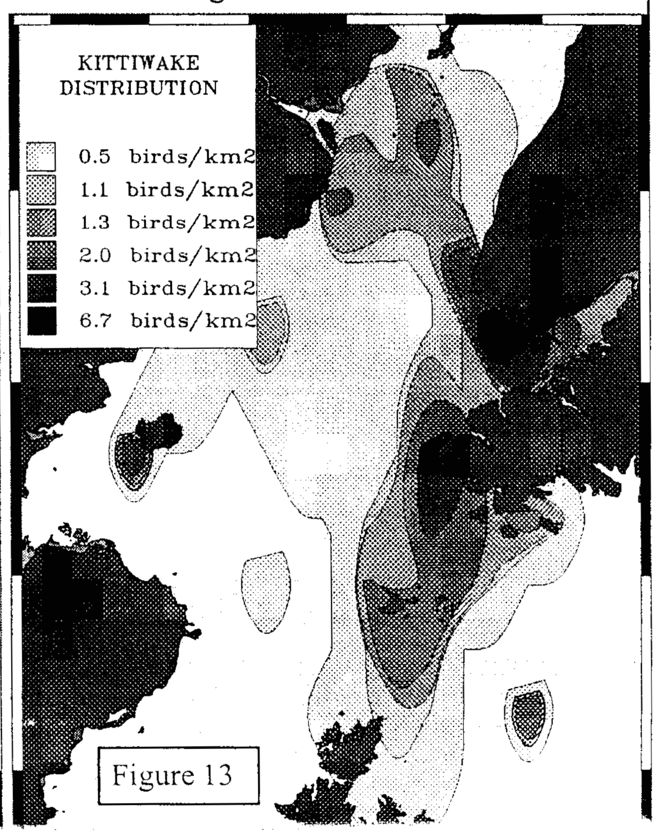
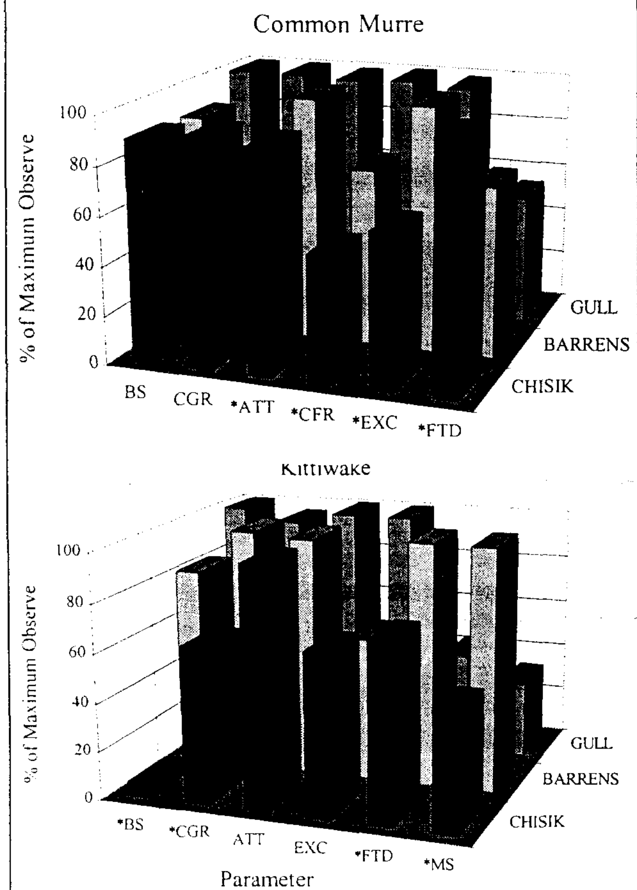


Figure 13

SEABIRDS AT COLONIES — THE BOTTOM LINE—

We consider here preliminary analyses of data on Common Murres and Black-legged Kittiwakes. Diets of chicks fed by adults in 1996 (Figure 14) reflect the patterns observed from fish and bird surveys at sea. Diet diversity decreases from North to South. Kittiwakes feed chicks more on sandlance in coastal areas (especially in the North), whereas murre chick diets include more offshore species such as capelin and pollock (especially in the South). Adult murres preferentially feed chicks energy-rich capelin. In 1996, adult diets comprised more than 70% pollock, while chicks were fed more than 90% capelin (Figure 14).

Figure 15. Variation in different parameters of breeding and behavior for murres and kittiwakes at each of 3 study colonies in 1996.



Parameters: BS- Breeding Success, CGR- Chick Growth Rate, ATT- Attendance by Adults, CFR- Chick Feeding rate, EXC- Exchange Rate of Brooding Adults, FTD- Foraging Time Duration, MS- Mean Meal Size. Asterisk (*) indicates significant difference in parameter values between colonies.

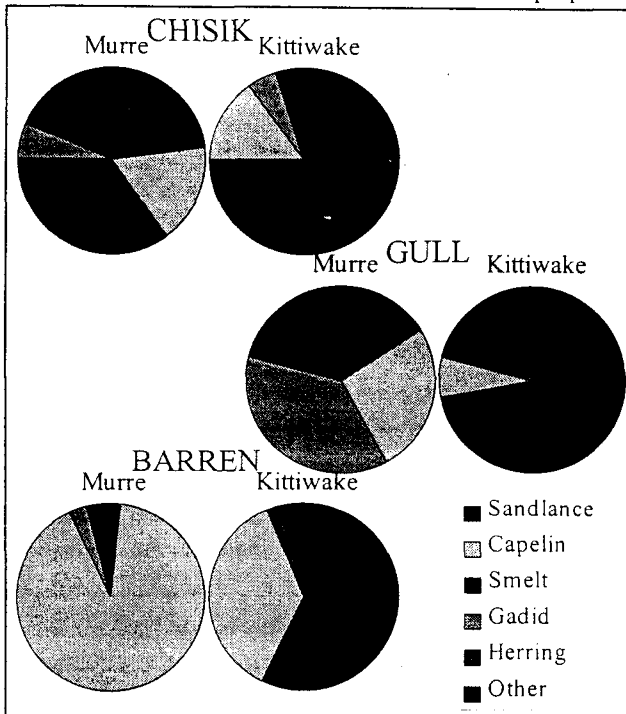


Figure 14. Diet composition of Common Murre and Black-legged Kittiwake chicks in lower Cook Inlet, summer, 1996.

The results of studies at colonies and at sea can be integrated by contrasting murre and kittiwake population parameters at the three study colonies. Data are expressed as percentages of highest observed parameter values (Figure 15). For example, murre breeding success was highest at Gull Island (100%=0.87 chicks/pair), and proportionally lower at Chisik (0.78 ch/pr) and the Barrens (0.77 ch/pr). There was no statistical difference in chick production between colonies, despite the apparent regional differences in fish availability. Murre chick growth rates also did not differ between Chisik and Gull islands (no data from Barrens). However, murres at Chisik spent more time foraging (mean trip = 243 min), fed chicks less frequently (only 2.58 meals/day), and had fewer brooding exchanges (usually after feeding chicks), than murres at the Barrens or Gull Island. As one indication of this extra effort, murres at Chisik spent less time in attendance ("loafing") at nest-sites compared to Gull Island (Figure 16). However, even Gull Island birds appeared stressed during late chick-rearing (29 August). Despite the extra effort required at Chisik, murres there managed to maintain high chick production.

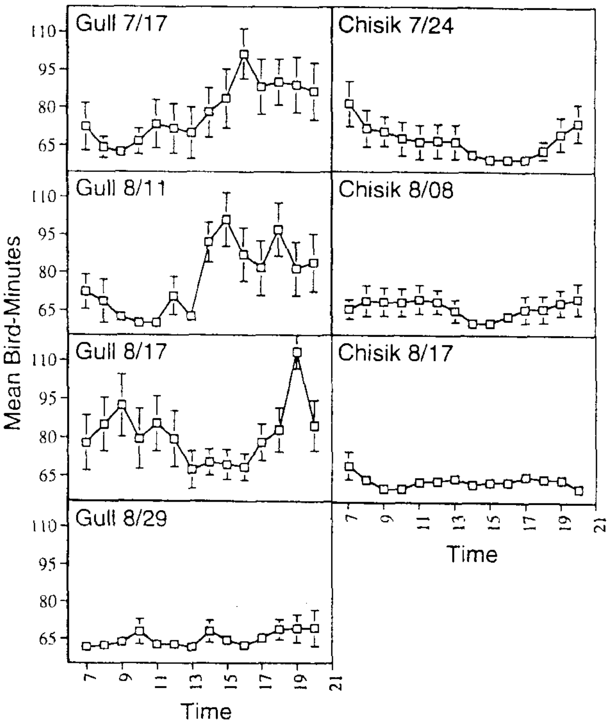


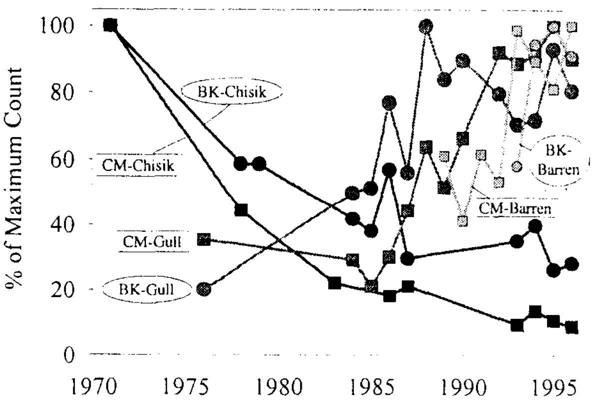
Figure 16. Diurnal attendance patterns of murres at Gull and Chisik Islands during incubation (July) and chick-rearing (August). Note >60 bird-minutes = "Loafing"

Kittiwakes exhibited a very different response (Figure 15). While productivity was high at Gull Island (0.87 ch/pr), kittiwakes almost failed to fledge chicks at Chisik. Similarly, chick growth rates were much lower at Chisik (11.1 g/day). Attendance at nest-sites did not vary between colonies, but this is because rarely was more than one bird present at a nest (unlike murres where the "off-duty" bird often spent hours "loafing" at the site). Chick meal deliveries are difficult to measure as kittiwakes regurgitate many times at "one feeding", but brooding exchange rates were low at both Chisik and the Barrens compared to Gull Island. Correspondingly, Barrens (mean=5.4 h) and Chisik (4.0 h) kittiwakes spent far more time away on foraging trips. Unlike murres, which can carry only one fish at a time, kittiwakes may carry many fish in their crop to regurgitate later to chicks. It appears that Gull Island kittiwakes make many short foraging trips, and deliver many small loads to chicks. Barrens kittiwakes make fewer and much longer foraging trips, but deliver large loads (mean=18.3 g). Chisik kittiwakes make long foraging trips, but deliver loads only slightly bigger than those at Gull Island. Apparently, the latter combination was inadequate to support chick production.

In summary, murres can compensate for shortage of food in adjacent waters by flying further, and using some of their "loafing time" to feed chicks. Kittiwakes may compensate by flying further, and carrying larger loads back to the colony— if prey are available within some threshold distance (ca. <45 km, which is less than for murres, ca. <70 km). Such was not the case at Chisik in 1996, and this problem may account for the steady decline in populations there over the past 25 years (Fig. 17). Kittiwakes have produced almost no chicks during this period. In contrast, murres at Chisik have had high breeding success during the past two years (only data available), and yet their population has been declining at a rate similar to kittiwakes. It may be that the stress of chick-rearing at Chisik increases over-winter mortality of adult murres. Alternatively, adult murres and kittiwakes may be emigrating from Chisik to Gull Island, where populations have increased substantially during the past 20 years.

Figure 17

Population Trends of Common Murres (CM) and Black-legged Kittiwakes (BK) at Chisik, Gull, and Barren Islands



HYPOTHESIS TESTING - PROGRESS

In our Detailed Project Description (1995/1996) we proposed to examine several hypotheses about how seabirds respond to changes in forage fish abundance and distribution in lower Cook Inlet:

1) Seabird recovery from the EVOS is limited by present-day forage fish densities. To date, our studies suggest that seabirds at 'oil-affected' colonies at Barren and Gull islands were not limited by food supplies in 1995-96, whereas they were at Chisik Island. However, the numerical response of populations occurs at decadal time scales, and many more years of study are required to assess the form and density threshold of response curves.

2) Seabird breeding failures and population declines are due to long-term changes in forage fish abundance or species composition. Assessment of this hypothesis requires comparison of long-term data on seabird population biology and forage fish trends. Data for lower Cook Inlet are patchy for seabirds, and still being analysed for forage fish (APEX Project 97163L). Preliminary evidence suggests that at least the converse of the hypothesis is true in Kachemak Bay: a major shift in forage fish abundance and composition occurred in Kachemak Bay during the early 1980's, leading to an increase in local seabird productivity and population size.

3) Seabird species respond to different threshold densities of prey abundance. Our data appear to confirm this hypothesis. Kittiwakes fail to thrive on prey densities at which murres and puffins are capable of rearing chicks. However, prey switching may modulate the form of responses and the threshold densities at which responses occur may depend on prey type.

3) Large seabirds have more 'free time' to adjust foraging effort as prey densities fluctuate. Our data appear to confirm this hypothesis. Murres (ca. 1000g) can adjust foraging effort to compensate for lower prey densities, whereas kittiwakes (ca. 500g) appear to have little or no 'spare time'

4) Prey density or distribution near the sea surface is influenced by depth of the thermocline (or pycnocline). We have not examined data yet to test this hypothesis. However, waters in lower Cook Inlet (LCI) are very well-mixed and forage fish are abundant at many depth levels, so this environmental factor may not be important in lower Cook Inlet.

5) Weather (wind, sea state) affects foraging success of seabirds, and annual variability in seabird breeding success is influenced by weather. Two years of data are insufficient to test this hypothesis.

6) Kittiwake foraging success (and hence breeding success) is limited by availability of prey at the sea surface (as opposed to overall prey abundance). We have not examined the data yet to explicitly test this hypothesis. However, evidence suggests that overall prey abundance has a strong influence on foraging success. Prey abundance and availability at the surface may be correlated.

7) Forage fish prey differ in quality (primarily energy content), and therefore seabird chick growth may be limited by diet composition. In collaboration with Dan Roby, and from previous studies, we know that different prey have markedly different nutritional value. Experiments conducted in Kachemak Bay in 1996 (APEX Project 97163N) clearly demonstrated that chick growth is markedly affected by prey type. The energy content of prey is a very important determinant of chick growth, but other factors may also influence subsequent chick survival (fat deposition, stress).

8) Seabirds work harder (adjust time spent foraging) when feeding on low quality prey. This hypothesis is supported by observations of longer feeding trips and fewer chick meal deliveries by murres at the Barren islands (where adults eat mostly pollock) compared to murres at Gull I. (where adults eat mostly sandlance). Data still need to be analysed by pro-rating foraging invest-

Temporal and Geographic Variation of Fish Populations in Nearshore and Shelf Areas of Lower Cook Inlet, Alaska.

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Keywords: fish; nearshore zone; continental shelf; species composition; temporal variation; seasonal variations; Cook Inlet; Alaska

Abstract

The nearshore and shelf fish communities of Lower Cook Inlet, Alaska were studied at 3 locations (Kachemak Bay, Chisik Island, and the Barren Islands). The Barren Island waters are largely oceanic, Kachemak Bay receives largely oceanic water but has a significant freshwater runoff component, and Chisik Island waters are predominantly estuarine in nature. Beach seines and mid-water trawls were the primary capture methods at all sites. Kachemak Bay was sampled over the course of two years (1995 &

1996), whereas Chisik Island and the Barren Islands were only sampled in the summer of 1996.

The study areas support a diverse nearshore fish community of at least 52 species. Of these species, 50 were caught in Kachemak Bay, 24 at Chisik Island, and 12 at the Barren Islands. Pacific sand lance was clearly the dominant nearshore species at the Barren Islands and Kachemak Bay comprising 99% and 71% of the total individuals respectively. The nearshore fish community at Chisik Island did not show any clear dominance by a single species, which was paralleled by an increased community diversity over the other two sites. Significant changes have occurred in the nearshore fish community of Kachemak Bay between 1976 and the present with increased diversity, particularly in regard to gadids which were almost absent in 1976. A strong seasonality of the nearshore community was noted with a paucity of species and individuals present in the winter. Several species were only present for a portion of the summer. Significant differences in the nearshore community were noted between high and low tides but not between consecutive sets or years (1995 and 1996).

Shelf waters were less diverse in their species assemblages than for nearshore areas. Of at least 26 species found, 14 were present at Kachemak Bay, 19 at Chisik Island, and 7 at the Barren Island. Similar trends in community structure to nearshore areas was noted with no clear dominance and high diversity at Chisik Island compared to a markedly dominated community at both Kachemak Bay and the Barren Islands. However, the Barren Island shelf areas showed a paradoxical situation over nearshore areas with walleye pollock the dominant species, as opposed to sand lance being dominant for both nearshore and shelf areas of Kachemak Bay.

Introduction

The main purpose of this study was to assess in terms of abundance, diversity, and species composition, the changes in the nearshore fish community over 20 years and between three geographically distinct locations within Lower Cook Inlet. In addition, concurrent offshore fish sampling allowed comparisons to be made between shelf and nearshore fish communities.

Blackburn (1980) surveyed the nearshore fish of Kachemak Bay during the summer of 1976, which until the present was the most comprehensive investigation for this area. The current study was designed to sample the nearshore habitat of Kachemak Bay as comprehensively as possible over the course of two summers at the same sites investigated by Blackburn to establish if temporal changes have taken place.

The importance of inshore coastal marine habitats as nursery areas for juveniles of many marine fish species is well documented, and it has been shown that many species are dependent on these areas during the juvenile phase of their life cycles (Poxton *et al.*, 1983; Orsi & Landingham, 1985; Bennett, 1989; Blaber *et al.*, 1995; Santos & Nash, 1995; Dalley & Anderson, 1997). Many studies have also described seasonal variation in shallow water fish assemblages (e.g., Horn, 1980; Allen, 1982; Nash & Gibson, 1982; Nash, 1988; Bennett, 1989). However, there is a paucity of information available concerning seasonal variation of nearshore fish assemblages in Alaska, due largely to the difficult working conditions and logistics of winter fieldwork.

This study is a component of the Exxon Valdez Oil Spill (EVOS) Trustee Council funded project in the northern Gulf of Alaska, which is currently researching forage fish/vertebrate predator interactions. Profound changes in seabird populations have been linked to shifts in the abundance and composition of forage fish stocks in the Gulf of Alaska over the past twenty years (Piatt & Anderson, 1996). Coincident with cyclical fluctuations in sea-water temperatures, the abundance of several forage species such as capelin (*Mallotus villosus*) declined precipitously in the late 1970s while populations of large predatory fish such as walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus pacifica*) increased dramatically. Correspondingly, seabird diets shifted from mostly capelin in the 1970s to mostly Pacific sand lance and juvenile pollock in the late 1980s. Furthermore, a variety of seabirds and marine mammals have exhibited signs of food stress through the 1980s and early 1990s (Piatt & Anderson 1996). Three main study areas were identified in the Lower Cook Inlet centered around seabird colonies; Gull Island in Kachemak Bay, Chisik Island on the west side of Cook Inlet, and the Barren Islands in the mouth of Cook Inlet. Gull Island is an increasing colony, Chisik is failing (Slater *et al.*, 1994), and the Barren Islands are regarded as stable (Roseneau *et al.*, 1995). Investigation of fish communities in nearshore and shelf areas around these colonies provide information to relate differing forage fish abundance and composition to seabird diets and productivity.

Materials and methods

Study sites

Lower Cook Inlet (Figure 1) is located in the southcentral region of Alaska. The area supports several important seabird colonies, numerous marine mammals, a large overwintering and summer bald eagle (*Haliaeetus leucocephalus*) population, major staging areas for migrating shorebirds, as well as commercially and recreationally important fisheries including salmon (*Oncorhynchus Spp.*) and halibut (*Hippoglossus stenolepis*).

Kachemak Bay is situated at the southern tip of the Kenai Peninsula in Alaska. The bay is 38km wide at its entrance, defined as a line from Anchor Point on the north to Point Pogibshi on the south, and is approximately 62km long. The upper 6km are mud flats which are exposed most of the time. Depths in the bay are relatively shallow, ranging from about 35 to 90m, with deeper areas (100 to 165m) between Gull and Yukon islands on the south side of the bay. Water entering the bay is largely oceanic, originating from the Gulf of Alaska via the Kennedy entrance at the southern end of the Kenai Peninsula.

Chisik Island is located on the western side of Cook Inlet (Figure 1). The island is 10.5km long and about 3.6km wide at its northern end but narrows to less than 0.4km at its southernmost point. It lies in the mouth of the glacially fed Tuxedni Bay. Water passing the island is estuarine, having passed up the east side of Cook Inlet before circulating around and down the west side past Chisik Island. Although a navigable channel is present on the west side of the island (Snug harbor) the nearshore habitat around the island is dominated by shallow glacial silt and mud flats exposed at low tides, and rocky substrates with few sandy beaches present.

The Barren islands are located at the entrance to Cook Inlet (Figure 1) and mark the transition between deep oceanic Gulf of Alaska waters and the estuarine Cook Inlet. The Alaska Coastal Current enters Cook Inlet past the Barren Islands leading to intense upwelling of cold, nutrient-rich waters onto the shallow shelf areas of southeast Cook Inlet (Piatt, 1994). The islands are renowned for storm conditions and tidal rips as water moves in and out of the Cook Inlet (second highest tidal range in North America).

Field sampling

In Kachemak Bay, sampling occurred between 16 June and 26 July, 1995, and from February 8 until December 10, 1996. Weather and sea conditions prevented samples being collected in January and November of 1996. Sampling at Chisik Island occurred between July 3 and August 17, 1996, and at the Barren islands between June 26 and September 8, 1996.

Beach seining was the primary method of capture for nearshore fish in this study. This method of fishing provides a very effective, non-selective method for sampling shallow, inshore waters with sandy, or smooth bottom environments (Cailliet *et al.*, 1986). Out of a total of 305 sets made in 1995/96 between spring (May) and fall (September) only 4 sets caught no fish.

Beach seining during the summer of 1995/96 utilized a 44m long variable mesh beach seine. The net had 4m deep, 3 mm knotless nylon stretch mesh (sm) for the middle 15.3m and tapered to 2.3m deep with 13 mm knotted nylon sm in the wings. Thirty meters of rope was attached to each end of the seine for use in deployment. The net was set parallel to shore at a distance of 25 meters as described by Cailliet *et al.* (1986). Samples were collected approximately every two weeks from May to September and once per month through the winter. The beach seine used in the Barren Islands was smaller in size; 36.7m long by 4.9m deep, tapering to 1.0m deep at the wings. This net was constructed with a 4mm sm bag for the middle 9.1m, 13mm sm for the 3.0m inner wings, and 32mm sm for the outer 10.8m wings.

Beach seines in the 1976 season were made with a net 47.3m long by 3.7m deep, tapered to 1.0m deep in the wings. The 10.7m wide cod end was constructed of 7mm sm knotless nylon. The tapered wings were variable mesh with a 6.1m length of 13 mm sm followed by a 12.2m tapered outerwing of 38 mm sm. The net was deployed closer to shore (10m as opposed to 25m in 1995/96) which probably resulted in the increased catch per unit effort (CPUE) from 305 fish per set in 1976 to 511 fish per set in 1995/96.

Beach seining was carried out at 38 sites within Kachemak Bay. These sites were chosen as they were also visited by Blackburn (1980). Some sites visited by Blackburn were not sampled, either due to unsuitable substrates now being present (such as mussel beds) or from new beach-front housing development. Beach seining was carried out at eight sand substrate sites on the west side of the Chisik Island. Beach seining at the Barren Islands was carried out at one site (East Amatuli Cove) which provided the only logistically feasible location.

Beach seining was conducted within a one hour window either side of high or low tide to allow comparisons between the tidal states. To reduce habitat and tidal range variability, high tide/low tide comparisons were made during periods of maximum tidal range at a limited number of sites (6), which were sampled at the same time and frequency each month. Allen *et al.* (1992) state that a single seine haul provides a good representation of species richness and rank for the dominant species. To increase the representation of low-dominance species and to decrease the chance of missing schooling species that are moving along shorelines, each seining event consisted of two consecutive sets made adjacent to each other. Seining was not conducted in swells of over 0.5m which prevented the net being retrieved without the lead line repeatedly leaving the bottom (rolling) allowing fish to escape.

Once onto the beach, fish were immediately sorted by species and subsampled (by volume) if necessary. Fish needed for further analysis were placed into labeled plastic bags and subsequently either frozen or preserved in 10% formalin. All other fish were released alive. Lengths (fork-length in mm) and weights (0.01g) of collected fish were recorded. Species were identified using the keys of Hart (1973), Eschmeyer (1983), and Kessler (1985).

Comparisons with the nearshore beach seining samples were made with fish data collected by other methods. Cast netting (2.4m diameter, 13mm monofilament sm) was used to sample fish schools found close offshore being preyed on by feeding mellées of seabirds (usually black-legged kittiwakes *(Rissa tridactyla)*). Minnow traps and diver observations were used over neighboring rocky substrates to assess other fish species present that were not represented in beach seines. Mid-water trawls were used to sample the shelf environment using the Alaska Department of Fish and Game research vessel *Pandalus*. On transects of the study areas, forage fish abundance was recorded with a DT4000 digital 120kHz echosounder. Significant fish aggregations identified by these hydroacoustics were fished using a 9m-wide mouth modified herring trawl lined with a 3mm cod-end with collecting bucket. Mid-water trawling was monitored using a Furuno-net sounding system. Tow duration ranged from 20-60 minutes depending on fish concentrations. Recovered fish were identified, measured, and samples frozen for later analysis.

Water temperatures at the three study areas were collected using Onset Computer Corporation Optic StowAway temperature loggers (Version 2.02). These loggers were calibrated and programmed to read water temperature every 10 minutes. Weighted loggers were placed at 5m water depth below chart datum at 60 Foot Rock (Kachemak Bay), Snug Harbor (Chisik Island), and East Amatuli Cove (Barren Islands), moored either with line or 3mm stainless steel cable attached to a stainless steel expansion bolt drilled into rock. Information for the logger in Kachemak Bay was downloaded approximately every six months. Temperature loggers at Chisik Island and the Barren Islands were left in the water only for the duration of the field season. Sea surface temperature and salinity data (measured using the practical salinity scale) for shelf areas were recorded during CTD casts digitally on a Seabird SBE21 thermosalinograph.

Analyses

Four diversity indices were calculated. The Shannon-Wiener index (H') (Pielou, 1977) which increases as both the number of species (richness) and the equitability of species abundance (evenness) increase. For the species 'richness component' of diversity, Margalef's index (D) was calculated (Margalef,1969). For the equitability of species abundance, Pielou's evenness function (J') was used (Pielou,1977). Similarity between species lists from different sampling periods was tested using the Jaccard similarity coefficient for presence and absence data (Boesch, 1977). All diversity calculations are based on numbers of individuals and the use of natural logs ($\log_e$). Species assemblages were statistically compared using the Mann-Whitney rank sum test. All species were used for these calculations that occurred in at least one of the two communities being compared.

Results

Physical Environment

The only physical variable measured in the nearshore was temperature. Temperatures are depicted in Figure 2. The different effective depth of the loggers at spring and neap tides (due to being fixed to the substrate) explains the periodicity noted in the graphs. Kachemak Bay temperatures peaked at 10.4°C in early August and dropped to a minimum of (??) in ?? Cold oceanic water entering the Cook Inlet from the Gulf of Alaska, warms as it moves around the Cook Inlet past Kachemak Bay and subsequently past Chisik Island (Figure 1) which is observed in the nearshore temperature profiles (Figure 2).

Analysis of CTD results showed Cook Inlet waters to be well mixed except for Kachemak Bay where a notable summer thermocline exists at approximately 5m water depth due to freshwater glacial runoff into the bay (Figure 3). Shelf temperatures were similar in the Barren Islands and Kachemak Bay, but were notably warmer at Chisik Island. Salinities of shelf waters were highest in the Barren Islands (31-32), followed by Kachemak Bay (29-31), and then Chisik Island (29-30).

Temporal Comparison of the nearshore fish in Kachemak Bay between 1976 and 1995/96

Beach seines from the 1995/1996 period were limited to May 16 to September 27 (305 beach seines) to coincide with the 1976 sampling season (Blackburn, 1980). This data set was also used to compare between areas.

A total of 155,991 fish of 50 species were identified in Kachemak Bay during the May to September seasons of 1995 and 1996 (Table 1). Of these species 35 were caught primarily in their juvenile form. No species were caught in the winter that were not represented in the summer. Of the fish collected, Pacific sand lance was the most numerous comprising 71% of the total individuals. Along with Pacific sand lance, three other species, Pacific herring, Pink salmon, and Pacific cod comprised over 92 % of the total individuals. Great sculpins and Pacific sand lance were the most frequently caught fish during 1995/1996 occurring in over 50 percent of all catches. Dolly Varden were the third most commonly occurring species occurring in over 46 percent of catches.

Biomass results were collected in 1995 only. Of the species collected, Salmonids dominated the biomass comprising nearly 73% of the total. Of the remaining biomass Pacific sand lance and Pacific herring comprised nearly 60 percent. However, except for Dolly Varden, the results for salmonids are highly biased from one beach seine in Port Graham on 23 July when over 296 Kg of pink and chum salmon were caught (52% of biomass for all 60 beach seines conducted in 1995). Dolly Varden were consistently the dominant biomass in the nearshore environment throughout the summer until their departure into freshwater streams and rivers.

A total of 39,927 fish of at least 28 species (greenling and sculpins were not always identified to species) were collected during the 1976 field season in 131 sets (Table 1). For comparisons with 1995/96 data, all sculpin and greenling species were combined.

Of the fish collected, Pacific sand lance, as in 1995/96 was the most numerous comprising 81% of the total individuals. Pacific sand lance and Pacific herring alone made up over 93 % of the total individuals in 1976 compared to the four species in 1995/96. Four of the five dominant species by number caught in 1976 were the same as in 1995 (Pacific sand lance, Pacific herring, Dolly Varden, and pink salmon). Pacific sand lance and Pacific herring were the number one and two most numerous fish in both years of study. During 1976, only 4 (0.01%) of fish were gadids (3 saffron cod and 1 pacific cod). This figure increased to 7012 out of 155,991 (4%) in 1995/96 with Pacific cod the fourth most numerous fish caught for the time period. All four species of gadid exhibited a marked increase in frequency of capture (Table 1) indicating a dramatic increase in gadid populations between the time periods. Dolly Varden was the most important fish in relation to biomass in 1976. Rock sole as in 1995/96 was the most common flatfish caught in seines. As for gadids, rock sole appear to have also increased in number (both in relation to frequency of capture and numbers caught) since the 1970s.

Species diversity indices are summarized in Table 2 for the two time periods. The Shannon-Wiener index (H') was greater in the 1995/96 season compared to 1976 and reflects the large number of gadids only present during the 1990s (accounting for two thirds of the difference in H'). Species richness (D) was also higher in the 1995/96 season compared to 1976 as a result of four species comprising 92% of individuals in 1995/96 compared to 2 species comprising 93% in 1976. The low equitabilities (J') in both time periods reflect the high level of dominance in both of these assemblages by Pacific sand lance.

Jaccard's similarity coefficient indicated only a moderate (59%) similarity between the two time periods. Increased effort during the 1990s may partly explain this with 10 species caught only in one or two seines out of a total 305 which were not caught in 1976. These species may have been too rare in the nearshore to have been sampled by the 1976 sampling effort.

A significant difference in the species assemblages of 1976 and 1995/96 was noted for CPUE, percent composition, and frequency of capture (Mann-Whitney rank sum test; P=0.007, 0.018, 0.033 respectively).

Seasonal investigation of the Kachemak Bay nearshore fish community

Results from all 283 beach seines (130,325 fish of 46 species) made only in 1996 were used for the investigation of seasonal trends to alleviate inter-annual variation.

Winter beach seines showed the nearshore waters to be almost devoid of fish with no schools caught or observed between December and March. Juvenile rock sole and great sculpins were the most abundant fish in the nearshore during February and March. Numbers of juvenile great sculpins increased rapidly in the spring with an influx of small juveniles (<20mm). The occupance of these juveniles dropped by the end of June leaving a relatively steady inshore population of 2nd. year sculpins throughout the rest of the summer (Figure 4). Flatfish were caught at a similar rate throughout the spring and summer but were not found after October (Figure 4). In April Dolly Varden moved into the nearshore environment where they remained through July before following salmon into their freshwater natal systems to overwinter (as described by Isakson *et al.*, 1971, Orsi & Landingham, 1985).

During May, diversity within the nearshore rapidly increased with 20 species identified (Figure 5). Although the nearshore environment is dominated throughout the summer by Pacific sand lance, a diverse community is present with 31 species collected in June and July, and 34 in August. Fish move offshore in September with CPUE (Figure 6) dropping rapidly by October paralleled by a decline in species present from 34 in August to 3 in December (Figure 5).

Only one capelin was caught in 1976, 1995, and 1996 Kachemak Bay beach seines until October 1996 when 1586 1st. year capelin (and 1 2nd year) capelin were collected in three seines. Many other capelin in several large schools were visually observed at the same time. Capelin were also caught in 3 out of 8 seines during December.

Seasonal results for selected taxa are summarized in Figure 4. All species were present to a greater proportion during the summer months indicating an inshore migration to take place as the water warms in spring and an offshore migration at the end of summer. Pacific sand lance as noted by Blackburn (1980) move out of the nearshore in July with fewer numbers being caught at this time. Pacific herring also displayed this trend. However, only five herring catches of over 100 individuals in June and four in August at Halibut Cove contributed almost 99 percent of the total herring numbers for the year. The low frequency of capture of herring schools and resultant possibility of missing schools at a very limited range of sites (only the three Halibut Cove sites) may account for the low herring catch in July.

Catch per Unit Effort (CPUE) drops dramatically in mid-July for the nearshore community (Figure 6) as was also noted in 1976 (Blackburn, 1980). This is largely driven by the offshore Pacific sand lance migration but is compounded by two other species, pink salmon and Pacific cod. Large catches of juvenile pink salmon increase CPUE for June as they migrate along shorelines (Orsi & Landingham,

1985) but tail off rapidly in July as they move offshore (Blackburn, 1980). Large catches of gadids (particularly Pacific cod and walleye pollock) that do not appear in large numbers until August (Figure 4) increase the August CPUE. Adult Pacific sand lance appear to remain offshore longer, with August sand lance numbers dominated by 1st. year individuals; it is not until October that adult Pacific sand lance return to inshore waters to spawn (Blackburn, 1980; Dick & Warner, 1982).

Seasonal community indices are summarized in Figure 5. The Shannon-Wiener diversity index (H') and the Margalef index show diversity and species richness to steadily climb through the season, peaking in July before dropping rapidly through August to September and then increasing (although with vastly fewer individuals and species) into the winter. Evenness (J') drops throughout the season as Pacific sand lance dominate the nearshore summer community rising again in the fall with decreased number of species and individuals.

Comparisons between adjacent sets, tides, and years

Table 3 summarizes results of sets made immediately after the first during 1996 for selected species based on their abundant or common status (Table 1). The impact of disturbance from the first of a double set on an area may scare fish away or attract fish to a disturbed prey source. Results need to be analyzed for both frequency of occurrence as well as for CPUE. For densely schooling fishes, differing school size can markedly impact CPUE as seen for Pacific sand lance which were caught at a similar frequency at the 1st. and 2nd. set of low or high tide, but displayed markedly different CPUE results. This result may also be a function of disturbance disrupting school structure, so a less dense school is present in the nearshore for the second set. Although numbers of individuals caught on first and second sets varied, little difference was noted for frequency of capture, and no significant differences were observed for total catch, CPUE, or frequency of capture for consecutive sets at high or low tide (Mann-Whitney rank sum test; P>0.05).

Figure 7 displays results of sets made at adjacent high and low tides at the same sites. On high tides, 27 species were collected compared to 41 on low tides. Gadids were collected at almost twice the frequency at low tide as compared to high tide as well as in greater numbers. Juvenile Pacific sand lance displayed the most notable difference between high and low tide catches being caught both more frequently at high (47%) than low (30%), as well as in far greater numbers; cpue being approximately 7 times greater at high tide. Adult sand lance did not show this level of disparity between tides, being collected at a similar frequency and in similar numbers at either tidal state. Sculpins (predominately great sculpin) were collected more commonly and in greater numbers at low tide. The low tide result is strongly influenced by juvenile fish (<20mm) which were collected in large numbers at low tides during May and June. Flatfish (predominately rock sole) were collected in low numbers at high and low tide. However, they commonly occurred (over 50% of sets) in the low tide sets as compared to occasionally (13%) in high tide sets.

Species diversity index was higher at low tide compared to high tide (1.55 and 1.00 respectively). Species richness at high and low tides was similar (2.42 and 2.53 respectively). The equitability indices for high and low tides (0.30 and 0.42) indicated a higher degree of dominance for the high tide community resulting from the high proportion of Pacific sand lance in high tide sets.

Jaccard's similarity coefficient indicated a 62 percent similarity between the species assemblages of the two tidal states. A significant difference in the high and low tide species assemblages was noted for percent composition (Mann-Whitney rank sum test; P=0.031).

During June and July 1995, 27,944 fish of 42 species were caught in 60 beach seines. During June and July of 1996, 50,859 fish of 37 species were caught in 283 beach seines. Table 4 displays results of the comparison between sets made in June and July of 1995 and 1996. Forty four species were collected over the course of the two years in June and July of which 30 were caught in both years. Species diversity index (H') was similar for both 1995 and 1996 (1.21 and 1.22 respectively) as was species richness (D) (3.61 and 3.43 respectively) and equitability (J') (0.34 in both years).

Jaccard's similarity coefficient indicated a 68 percent similarity between the species assemblages of the two time periods. The species not represented in either year were generally rare species occurring in only a few seines. No significant difference in the species assemblages between 1995 and 1996 was noted for percent composition (Mann-Whitney rank sum test; P=0.815). The significant similarity between the 1995 and 1996 surveys as well as the close community indices supports the validity of beach seines for nearshore comparisons and the significance of the disparity between the 1976 and 1995/96 species assemblages.

Impact of substrate type in Kachemak Bay

Seining was restricted to the habitat types of sand and gravel. Areas of cobble were generally accompanied by boulders and bedrock causing snagging, and areas of substrates finer than sand were generally low angled mudflats of too shallow a depth to seine. This resulted in little variation in substrate type. However, one sheltered site at the south end of Halibut Cove was markedly different from the other sites in having a large mud component to the substrate. This site accounted for 78 percent of the total herring (juvenile) catch for the entire 1996 sampling period. The site is historically an important herring area in Kachemak Bay (Bucher and Hammarstrom, 1996).

Beach seines sample nearshore sandy substrates and were not used on neighboring rocky beaches or areas with mussel beds and other potentially net-snagging terrain. In conjunction with beach seining, fish traps and diver observations were used to assess presence of other species in areas close to those beach seined. The northern ronquil (*Ronquilus jordani*) was commonly seen by divers or found in fish traps over rocky substrates. This represented the only species observed in the nearshore, not caught in beach seines and is directly related to its habitat preference.

Cast netting was used in areas close offshore at sites of feeding mellées. Net avoidance is readily observable with cast netting which requires fish to be at the surface both to aim the cast as well as to allow the net to catch them. Of eight successful casts, five contained Pacific sand lance, and three capelin. Average numbers of capelin were much higher (2900 per cast) than for sand lance (774 per cast) which may reflect the greater ability of sand lance to avoid this type of capture. The occupance of large numbers of capelin close to shore (within 1km) shows them to be an important summer nearshore fish although not found in direct proximity to the littoral habitat sampled by beach seines.

The nearshore fish community of Chisik Island and the Barren Islands

A total of 988 fish of 24 species were caught in 30 seines in the nearshore waters of Chisik Island during the field season of 1996 (July 3 to August 17). The fish are listed in Table 5 and the corresponding common and scientific names given. Of the fish collected, Dolly Varden was the most numerous comprising 30% of the total individuals and frequently caught occurring in 63% of seines. Pacific sand lance did not dominate the community as seen in Kachemak Bay and the Barren Islands comprising 24% of the total individuals and occurring in 33% of seines. Pacific snake pricklebacks comprised 12% of the total individuals and Pacific cod 8%. The large amounts of mud in this system probably account for the low numbers of Pacific sand lance which require clean sand and gravel substrates in which to rest during periods of inactivity (Dick & Warner, 1982). Sculpins as for Kachemak Bay and the Barren Islands were frequently caught occurring in 53 percent of seines. Starry flounder although not the most numerically abundant flatfish (rock sole) was the second most frequently caught species occurring in 47% of seines exclusively as juveniles.

A total of 180,232 fish of at least 12 species (482 unidentified sculpins, 1 unidentified flatfish and 1 unidentified greenling) were caught in 40 seines in the nearshore waters of the Barren Islands during the field season of 1996 (June 26 to September 8). The Barren Island beach seine catches were dominated by Pacific sand lance (Table 5, Figure 8) which comprised over 99 percent of the catch (predominately juveniles) and occurred in 90 percent of all seines. Pacific cod occurred in over 50 percent of seines ranking 2nd., followed by sculpins occurring in over 40 percent of seines and butter sole (the dominant flatfish) occurring in 18 percent of seines. Pacific cod and pink salmon were the 2nd. and 3rd. numerically dominant species (503 and 449 individuals respectively).

CPUE results showed the Barren Islands to be the most productive nearshore waters of the three study areas followed by Kachemak and Chisik Island. The productivity (represented by CPUE) was vastly less at Chisik Island with only six percent and less than one percent of the CPUE found at this location. Chisik Island and Kachemak Bay displayed greater diversity and species richness than the Barren islands

(Table 2). The colder oceanic domain present in the Barren Islands appeared to reduce species diversity as compared to the warmer increasingly estuarine domains of Kachemak Bay and Chisik Island. Equity (J') was much greater at Chisik Island showing this community to be much less dominated by a particular species.

Comparison of nearshore and shelf communities

Mid-water trawls were made during July of 1996 at each of the study areas. Results are detailed in Table 6 and are summarized in Figure 8. Nine species were collected in mid-water trawls that were not present in any of the beach seine collections (Table 6). Mid-water trawls were much less diverse in the number of species present than for beach seines (Table 6). Kachemak Bay displayed similar proportions of the most abundant taxa between trawls and beach seines with Pacific sand lance dominating catches.. Mid-water trawls made at Chisik Island as for beach seines displayed no clear dominance with low numbers of all the most common species. The shelf environment of the Barren Islands was dominated by walleye pollock contrasting the dominance by sand lance in the nearshore where only a single walleye pollock individual was caught.

CPUE at Chisik Island was 27% and 11% of that found respectively at Kachemak Bay or the Barren Islands (Table 7) paralleling CPUE result for beach seines (Table2). Community diversity indices displayed similar trends to those found for nearshore beach seines (Table 2). Shannon-Wiener (H') diversity index and species richness (D) were highest for Chisik Island followed by Kachemak Bay and a large drop in diversity at the Barren Islands. Equity (J') was highest at Chisik Island followed by Kachemak Bay and a high level of dominance found in the Barren Islands.

The most notable difference between the different study zones was the large component of walleye pollock in shelf areas compared to sand lance in the nearshore areas. Overall for all shelf trawls walleye pollock occurred in 88% of sets compared to 3% of beach seines. Walleye pollock does not appear to use the nearshore environment as a nursery area as observed for related species such as the Pacific cod.

Discussion

Limitations of Study

The scope of the study, was affected by limitations of the equipment used. Sampling the nearshore environment with a beach seine is limited to sandy to cobble substrates. Mussel beds and rocky substrates prevent recovery of the net without snagging occurring, which allows fish to escape. Periods of high current or inshore swells of over 0.5m generally prevented effective retrieval of the net, thus fish preferring surf zone habitat may also be under represented. The surf zone is important or preferentially used by some species due to the low number of predators and food rich waters (Bennett, 1989). Fish that stay preferentially in these areas are therefore under represented by this study.

Allen *et al.* (1992) stated that beach seine catches of burrowing fish would be reduced due to their ability to escape under the net. Dick & Warner (1982) and Gordon & Leavings (1984) also raised doubt as to the adequacy of the beach seine as a sampling tool for sand lance with large schools observed avoiding the beach seine. Therefore Pacific sand lance, the dominant species within the nearshore areas of Kachemak Bay and the Barren Islands may occur to a greater degree than was observed by this study. Juvenile (both 0 and 1 group) cod have been shown to spend the day in deeper waters, moving into the nearshore at night (Keats, 1990; Methven & Bajdik, 1994). Therefore cod (as well as the other gadids) may be under-represented by our catches (made during daylight hours).

Nearshore fish community

The number of species collected in Kachemak Bay was high in comparison to other temperate nearshore investigations using beach seines as a sampling method. In Alaska, Hancock (1975) caught 17 species at Clam Lagoon, Adak, Isakson *et al.* (1971) found 40 species in the nearshore waters of Amchitka, and Orsi & Landingham found 42 species at southeast Alaska sites. Thorman (1986*a*) found 18 species in the Bothnian sea (Sweden), Allen & Horn (1975), Horn (1979), and Allen (1982) found 23, 21, and 32 species respectively in nearshore Californian locations. Nash (1988) found 33 and 23 species respectively at Ellingstad and Hvervenbukta in southern Norway.

Several investigators of northeast Pacific bay, estuarine, and inshore fish populations (e.g., Allen & Horn, 1975; Hancock, 1975; Horn, 1980; Allen, 1982; Gordon & Leavings, 1984; Orsi & Landingham, 1985) have observed five or fewer species usually comprise 75% or more of the total fishes sampled even though total number of species may be much larger. Our results dramatically highlighted this result with 4 species comprising over 92% of total numbers in 1995/96, and 2 species comprising over 93% in 1976 at Kachemak Bay. In the Barren Islands, 99% of total numbers was from sand lance alone. Chisik Island showed a different pattern with five species making up 79% of total numbers. These fish as stated by Allen (1982) were generally low in the trophic structure as would be expected by ecological patterns of relative abundance.

Great variation in diversity was noted in Kachemak Bay on a seasonal basis due to the paucity of species in the winter months. High latitude temperate fish assemblages, particularly those of shallow water habitats are subject to large seasonal variations in temperature and day length. These physical factors impart a strong natural seasonality to community structure (Nash, 1988) with fish leaving shallow waters in the winter at their lower thermal tolerance seeking warmer water offshore, as well as for some species to leave this area in the summer months as their upper thermal tolerance is reached. Results for Kachemak Bay paralleled many studies including Allen and Horn (1975), Allen (1982), and Bennett (1989) which have observed a general pattern of increased numbers of species and numbers of individuals during the late spring through fall period in nearshore waters. In the Gulf of Mexico fish were almost absent from the surf-zone during the winter months (Ross *et al.*, 1987), and Bennett (1989) only found about half the number of species to be present in winter on the southwestern Cape coast of South Africa. Livingston (1976), Horn (1980), Allen (1982), Thorman (1986*b*), and Methven & Bajdik (1994) in addition, also observed a summer depression in abundance between peaks in spring and fall. This was clearly observed in the CPUE for beach seines in Kachemak Bay although was not paralleled by a reduction in species number as seen by Thorman (1986*b*).

Allen (1982) states that the composition of fish assemblages in shallow areas depends to a great extent on water temperature and salinity. Temperature and salinity accounted for 83% of the variation in abundance of individual species collected in upper Newport Bay, California (Allen, 1982). Seasonal declines in catch during July at Kachemak Bay are probably related to temperature and salinity of nearshore waters, as well as to biological responses to predation, feeding, or spawning. Thorman (1986*a*) suggested that fish in exposed areas may avoid the shallowest regions remaining in slightly deeper less disturbed waters. This may be a factor, as well as temperature in the low numbers of individuals and species present in the nearshore during winter when there is generally increased wave action. The storm-prone nearshore areas of the Barren Islands displayed lower species number supporting Thorman (1986*a*) as well as Horn (1980) who stated unstressed fish assemblages tend to be higher in diversity.

Thorman (1986*b*) noted the average number of fish species is positively correlated with minimum salinity and total abundance is positively correlated with increased temperature. The increased diversity of Chisik Island over the Barren Islands or Kachemak Bay coincides with this observation. We expect that with a similar effort at Chisik to Kachemak Bay a similar or greater number of species would have been collected. However, our results contrast Thorman (1986*b*) in that the Barren Islands with the coldest waters had the highest abundance of fish. Thorman (1986*b*) states temperature to be the primary factor regulating abundance and recruitment of juveniles. Pacific sand lance, may be positively rather than negatively influenced by the cooler waters of the Barren Islands.

Chisik Island and Kachemak Bay, both heavily influenced by freshwater influence and characterized by substrates ranging from rock to mud exhibit the greatest range of habitat diversity of the three sites. These sites also exhibited the greatest number of species in accordance with Blaber *et al.* (1995) who suggested numbers of species present in inshore zones was positively correlated to increasing habitat diversity. Nearshore sampling in the Barren Islands was limited to one site reducing the diversity of sites being sampled. However, this site is one of the few sheltered sites in the islands with other beaches exposed to high wave action. These exposed, high energy beaches would not be expected to hold a high diversity species assemblage (Horn, 1980; Thorman, 1986*a*).

Salmonids as for other Alaskan nearshore studies were an important component of the nearshore community. Salmonids were the third ranked most important species by percent composition in

Kachemak Bay. Pink Salmon were second ranked by percent composition occurring in 23 percent of seines in a study of Clam Lagoon, Adak (Hancock, 1975). Orsi & Landingham (1985) found salmonids to be the dominant nearshore species in southeastern Alaska. Between March and June of 1981 and 1982 pink salmon fry dominated their catches comprising over 83 percent of the catch in both years.

Large catches of capelin by cast net, their occurrence in mid-water trawls, and in seabird (Reference) and halibut (Roseneau & Byrd, 1996) diets show them to be numerous in Cook Inlet waters, although not generally found in the nearshore zone. Capelin is of prime interest in this area due to its importance as a forage fish. Apart from three seines in October, 1996 in Kachemak Bay there has been little evidence of capelin occurring in the nearshore areas of Cook Inlet. Seasonal usage of the nearshore by capelin may impact catches, with this species occupying inshore waters outside the range of beach seines but inside our mid-water trawl survey area during the summer months. This may be a result of competition with sand lance in the nearshore environment. Capelin were documented sharply declining in the 1970s (Piatt & Anderson, 1996) and have been documented as returning to Cook Inlet waters during the 1990s (Roseneau *et al.*, 1996) and may become more prevalent in the nearshore in subsequent years as their numbers increase.

The apparent increase in gadids during the 1995/96 sampling period over 1976 was the most dramatic temporal difference between the species assemblages of Kachemak Bay. Gadids were not caught in significant numbers in the whole of Lower Cook Inlet during the 1976 survey, ranking ninth and comprising 0.2% (85 individuals in 262 seines) of the total catch (Blackburn, 1980). The increase in gadids between the 1970s and 1990s corresponds with a concurrent increasing trend in frequency of capture of gadids from the 1970s to present in offshore trawls (Bechtol, 1997). Houghton (1987) in a study of inshore fish habitats north of the Alaska peninsula (Bering sea coast) found walleye pollock, unlike for Kachemak Bay or Amchitka (Isakson *et al.*, 1971) to only occur offshore, whereas Pacific cod were also found inshore. Kachemak Bay's oceanic influence may explain the presence of pollock in the nearshore areas. Methven and Bajdik (1994) noted seasonal abundance of cod to peak in April to June and mid-August to November. Our results showed a small peak in gadid abundance in June with the proportion of gadids being caught in August supporting these results. The seasonality of fish such as Pacific cod needs to be taken into account in nearshore studies. Houghton (1987) studied consecutive years and found Pacific cod to be a numerically dominant species in 1984, but was not present in 1985. This was related to the shorter field season in 1985 which finished before the inshore migration of juvenile cod.

Pacific sand lance were the dominant inshore species north of the Alaska peninsula comprising 63% of the total catch (Houghton 1987) as was found in Kachemak Bay and the Barren Islands. Utilizing other fishing methods they found sand lance to be most abundant close to shore within the 6m isobath and were distributed widely and irregularly. Larger sand lance appeared to occur offshore which coincides with the apparent offshore movement of adult sand lance in midsummer before spawning inshore during early winter. Ganssle (1973) states that adults of the northern anchovy (*Engraulis mordax*) are less available in inshore waters during periods of warming and that young-of-the-year fish seem to tolerate higher temperatures than adults. This appeared to parallel the result noted for Pacific sand lance where adult sand lance were not caught throughout the period of maximum sea temperatures although first year fish were still present, although in much reduced numbers. This phenomenon of reduced adult sand lance numbers in mid-summer has also been noted via interpretation of seabird diets for Atlantic sand lance (Monaghan *et al.*, 1996). This period is a time of maximum predation by chick-rearing seabirds and mature sand lance may also avoid the nearshore and surface areas to avoid this predation.

Sculpins, as for Kachemak Bay were the most commonly caught species in studies of Clam Lagoon (Hancock, 1975) and Amchitka in the western Aleutians (Isakson *et al.*, 1971). However, unlike Clam Lagoon, they were not the numerically most important species in Kachemak Bay. Sculpins ranked second at Chisik Island and third at the Barren Islands for frequency of occurrence in beach seines.

Flatfish as for gadids displayed increased numbers and frequency of capture over results for the 1970s. This was in accordance with trends noted for the Gulf of Alaska by Piatt & Anderson (1996) with a general increase of the flatfish catch over the past twenty years.

Implications to Seabirds

Piatt & Anderson (1996) suggested forage fish abundance is directly related to seabird productivity. Large numbers of high quality, schooling, nearshore forage fish at the Barren Islands and Kachemak Bay provide a large easily accessible food base for seabirds. At Chisik Island, no large agregations of forage fish were observed in the nearshore or offshore areas. This forces Chisik Island seabirds to forage further afield with a resultant drop in nesting success. Pritchard ( ), Sirean & Irons, ( ) and Kuletz ( ) have all linked sand lance abundance to seabird productivity in areas of Prince William Sound, Alaska and Kachemak Bay. Sand lance abundance parallels the productivity for black-legged kittiwakes (a species using sand lance as it's primary food) noted at the three study areas. Sand lance due to their nearshore densely aggregated distribution and high energy value may be the principle component in 'sand lance selective' seabird productivity in the current system.

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Table 1. Totals and frequency of occurrence by species for the 1976 (May 21-September 29) and 1995/96 (May 16-September 27) sampling periods.

			1976[1] (131 Sets)		1995/96 (305 sets)	
STATUS	COMMON NAME	LATIN NAME	Total Fish	% Occurrence	Total Fish	% Occurrence
Abundant >50% of sets in at least one of the time periods	Dolly Varden	*Salvelinus malma*	790	51.1	1635	46.6
	Pacific Sand Lance	*Ammodytes hexapterus*	32490	40.5	110800	50.8
	Great Sculpin	*Myoxocephalus polyacanthocephalus*	120	32.8	484	56.7
Common 10-50% of sets in at least one of the time periods	Pink Salmon	*Oncorhynchus gorbuscha*	804	24.4	8589	39.0
	Rock Sole	*Lepidopsetta bilineata*	43	15.3	379	30.2
	Pacific Herring	*Clupea harengus pallasi*	4666	14.5	19808	17.4
	Pacific Cod	*Gadus macrocephalus*	1	0.8	4419	27.2
	Whitespotted Greenling	*Hexagrammos stelleri*	33	10.7	208	17.0
	Tubenose Poacher	*Pallasina barbata aix*	9	5.3	128	15.7
	Threespine Stickleback	*Gasterosteus aculeatus*	35	13.0	42	6.2
	King Salmon	*Oncorhynchus tshawytscha*	288	12.2	77	5.6
	Surf Smelt	*Hypomesus pretiosus pretiosus*	178	11.5	48	4.9
	Silverspotted Sculpin	*Blepsias cirrhosus*	1	0.8	156	13.8
Occasional 1-10% of sets in at least one of the time periods	Pacific Snake Prickleback	*Lumpenus sagitta*	54	6.9	177	5.6
	Chum Salmon	*Oncorhynchus keta*	8	3.1	786	7.5
	Saffron Cod	*Eleginus gracilis*	3	1.5	523	8.9
	Pacific Staghorn Sculpin	*Leptocottus armatus*	12	6.1	13	3.3
	Red Salmon	*Oncorhynchus nerka*	1	0.8	774	8.5
	Pacific Tomcod	*Microgadus proximus*	0	0.0	660	9.2
	Crescent Gunnel	*Pholis laeta*	5	2.3	59	4.9
	Starry Flounder	*Platichthys stellatus*	7	3.8	45	2.6
	Pacific Sandfish	*Trichodon trichodon*	0	0.0	45	6.2
	Kelp Greenling	*Hexagrammos decagrammus*	0	0.0	46	4.6
	Buffalo Sculpin	*Enophrys bison*	2	0.8	25	3.6
	Slender Eelblenny	*Lumpenus fabricii*	0	0.0	268	4.3
	Masked Greenling	*Hexagrammos octogrammus*	20	3.8	3	0.3
	Rock Greenling	*Hexagrammos lagocephalus*	0	0.0	47	3.6
	Lobefin Snailfish	*Polypera greeni*	0	0.0	16	3.3
	Lingcod	*Ophiodon elongatus*	2	1.5	5	1.3
	Butter Sole	*Isopsetta isolepis*	2	1.5	4	1.3
	Walleye Pollock	*Theragra chalcogramma*	0	0.0	1410	2.6
	Coho Salmon	*Oncorhynchus kisutch*	66	1.5	4	0.7
	Warty Sculpin	*Myoxocephalus verrucosus*	0	0.0	13	2.0
	Sablefish	*Anoplopoma fimbria*	0	0.0	52	1.6
	Longnose Prickleback	*Lumpenus longirostris*	8	1.5	0	0.0
	Northern Rockfish	*Sebastes polyspinis*	1	0.8	2	0.7
	Daubed Shanny	*Lumpenus maculatus*	0	0.0	7	1.3
	Flathead Sole	*Hippoglossoides elassodon*	0	0.0	6	1.3
	Sawback Poacher	*Sarritor frenatus*	1	0.8	1	0.3
Rare <1% of sets in at least one of the time periods	Soft Sculpin	*Gilbertidia sigalutes*	0	0.0	5	1.0
	Petrale Sole	*Eopsetta jordani*	0	0.0	12	1.0
	Prowfish	*Zaprora silenus*	0	0.0	2	0.7
	Padded Sculpin	*Artedius fenestralis*	0	0.0	3	0.7
	Pacific Halibut	*Hippoglossus stenolepis*	0	0.0	4	0.7
	Lemon Sole	*Parophrys vetulus*	0	0.0	2	0.7
	Capelin	*Mallotus villosus*	0	0.0	1	0.3
	Arctic Shanny	*Stichaeus punctatus*	0	0.0	1	0.3
	Yellow Irish Lord	*Hemilepidotus jordani*	0	0.0	1	0.3
	Ribbed Sculpin	*Triglops pingeli*	0	0.0	1	0.3
	Smooth Alligatorfish	*Anoplagonus inermis*	0	0.0	1	0.3
	Smooth Lumpsucker	*Aptocyclus ventricosus*	0	0.0	1	0.3

[1] 1976 data also includes: 28% sets with unidentified sculpins and 25% sets with unidentified greenlings.

Table 2. Summary of nearshore community parameters for Kachemak Bay (1976 & 1995/96), Chisik Island, and the Barren Islands.

Location	Year	CPUE	H'	J'	D
Kachemak Bay	1976	305	0.74	0.23	2.27
Kachemak Bay	1995/96	511	1.05	0.29	3.26
Chisik Island	1996	33	2.13	0.67	3.34
Barren Islands	1996	4506	0.06	0.03	0.91

Table 3. CPUE and (Frequency of Occurrence) on consecutive sets for high and low tidal states at Kachemak Bay for selected species.

Species	High Tide (142 Sets)		Low Tide (96 Sets)	
	Set 1	Set 2	Set 1	Set 2
Pacific Herring	1.7 (10)	0.7 (11)	0.2 (4)	35.3 (10)
Pink Salmon	37.3 (28)	21.4 (23)	3.0 (48)	17.8 (35)
Dolly Varden	3.0 (39)	8.5 (37)	5.7 (40)	2.8 (44)
Pacific Cod	3.4 (11)	4.7 (17)	18.5 (29)	13.5 (25)
1st. Year Sand Lance	892.9 (54)	156.6 (61)	67.5 (35)	11.7 (29)
Mature Sand Lance	5.2 (27)	9.5 (28)	48.4 (40)	4.6 (42)
Whitespotted Greenling	0.1 (6)	0.1 (6)	0.4 (23)	1.6 (25)
Silverspotted Sculpin	0.0 (0)	0.1 (3)	1.6 (25)	0.5 (27)
Great Sculpin	0.3 (44)	1.4 (56)	1.8 (58)	0.9 (50)
Tubenose Poacher	0.07 (7)	0.1 (8)	0.3 (17)	0.3 (10)
Rock Sole	0.1 (6)	0.3 (16)	3.0 (63)	2.4 (50)

Table 4. Comparison of nearshore fish catch at Kachemak Bay between 1995 and 1996 for species occuring in over 10 percent of seines.

	1995			1996		
Species	Frequency of Capture	% of Total Catch	CPUE	Frequency of Capture	% of Total Catch	CPUE
Sand Lance	75.0	66.6	310.2	67.2	60.0	250.1
Dolly Varden	68.3	1.8	8.5	55.7	1.8	7.5
Great Sculpin	68.3	0.7	3.2	49.2	0.2	1.0
Pink Salmon	51.7	3.0	14.0	52.5	13.8	57.4
Rock Sole	33.3	0.2	1.0	36.9	0.4	1.5
Pacific Cod	41.7	7.4	34.4	18.9	0.5	2.2
Herring	30.0	16.1	75.1	11.5	16.5	68.8
Whitespotted Greenling	20.0	0.2	0.9	21.3	0.1	0.5
Tubenose Poacher	31.7	0.3	1.3	11.5	>0.1	0.2
Silverspotted Sculpin	20.0	0.2	0.8	17.2	0.1	0.5

Table 5. Numbers of individuals caught in beach seines at Chisik Island and the Barren Islands.

		Chisik Island 30 Sets	Barren Islands 40 Sets
Pacific Herring	*Clupea harengus pallasi*	18	0
Pink Salmon	*Oncorhynchus gorbuscha*	21	449
Coho Salmon	*Oncorhynchus kisutch*	1	0
Red Salmon	*Oncorhynchus nerka*	1	0
Dolly Varden	*Salvelinus malma*	297	5
Surf Smelt	*Hypomesus pretiosus pretiosus*	0	22
Capelin	*Mallotus villosus*	13	135
Eulachon	*Thaleichthys pacificus*	3	0
Longfin Smelt	*Spirinchus thaleichthys*	5	0
Pacific Cod	*Gadus macrocephalus*	74	503
Pacific Tomcod	*Microgadus proximus*	2	0
Walleye Pollock	*Theragra chalcogramma*	0	1
Threespine Stickleback	*Gasterosteus aculeatus*	10	0
Pacific Sandfish	*Trichodon trichodon*	0	0
Pacific Snake Prickleback	*Lumpenus sagitta*	119	0
Crescent Gunnel	*Pholis laeta*	11	0
Prowfish	*Zaprora silenus*	0	0
Pacific Sand Lance	*Ammodytes hexapterus*	233	178601
Rock Greenling	*Hexagrammos lagocephalus*	1	1
Kelp Greenling	*Hexagrammos decagrammus*	0	5
Whitespotted Greenling	*Hexagrammos stelleri*	22	0
Lingcod	*Ophiodon elongatus*	0	13
Silverspotted Sculpin	*Blepsias cirrhosus*	2	0
Padded Sculpin	*Artedius fenestralis*	2	0
Pacific Staghorn Sculpin	*Leptocottus armatus*	2	0
Great Sculpin	*Myoxocephalus polyacanthocephalus*	32	0
Unidentified Sculpins		0	482
Sawback Poacher	*Sarritor frenatus*	5	0
Pacific Halibut	*Hippoglossus stenolepis*	1	0
Butter Sole	*Isopsetta isolepis*	0	13
Rock Sole	*Lepidopsetta bilineata*	62	0
Starry Flounder	*Platichthys stellatus*	51	0
Total Fish		988	180,232
Total Species		24	12

Table 6. Numbers of fish caugh in mid-water trawls at Kachemak Bay, Chisik Island, and the Barren Islands.

Common Name	Latin Name	Kachemak Bay 16 Sets	Chisik Island 6 Sets	Barren Islands 17 Sets
Walleye Pollock	*Theragra chalcogramma*	456	123	12,912
Pacific Sand Lance	*Ammodytes hexapterus*	3857	132	195
Capelin	*Mallotus villosus*	441	141	840
Pink Salmon	*Oncorhynchus gorbuscha*	413	44	0
Pacific Cod	*Gadus macrocephalus*	317	4	1
Pacific Sandfish	*Trichodon trichodon*	0	59	0
King Salmon	*Oncorhynchus tshawytscha*	0	19	0
Tadpole Sculpin	*Psychrolutes paradoxus*	16	0	0
Snailfish Spp.	*Cyclopteridae*	1	4	0
Eulachon	*Thaleichthys pacificus*	0	10	0
Prowfish	*Zaprora silenus*	9	0	1
Rock Sole	*Lepidopsetta bilineata*	2	1	6
Flatfish Spp.	*Pleuronectidae*	6	0	0
Armorhead Sculpin	*Gymnocanthus galeatus*	0	5	0
Sculpin Spp.	*Myoxocephalus Spp.*	2	0	1
Sculpin Spp.	*Gymnocanthus Spp.*	2	0	0
Dover Sole	*Microstomus pacificus*	0	2	0
Poacher Spp.	*Bathyagonus Spp.*	2	0	0
Smooth Alligatorfish	*Anoplagonus inermis*	0	2	0
Pacific Herring	*Clupea harengus pallasi*	0	1	0
Spinyhead Sculpin	*Dasycottus setiger*	0	1	0
Northern Sculpin	*Icelinus borealis*	0	1	0
Ribbed Sculpin	*Triglops pingeli*	0	1	0
Arrowtooth Flounder	*Atheresthes stomias*	0	1	0
Starry Flounder	*Platichthys stellatus*	1	0	0
Pacific Lamprey	*Lampetra tridentatus*	0	1	0
Total Fish		5525	552	13,956
Total Species		14	19	7

Table 7. Summary of shelf community parameters for Kachemak Bay, Chisik Island, and the Barren Islands.

	CPUE	H'	J'	D
Kachemak Bay	345	1.07	0.40	1.51
Chisik Island	92	1.89	0.64	2.85
Barren Islands	821	0.31	0.16	0.63

Figure 1. Map of lower Cook Inlet showing the three study areas and oceanography.

Figure 2. Seasonal variation in 1996 water temperatures at 5 m depth at Kachemak Bay (1), Chisik Island (2) and the Barren Islands (3).

Figure 3. Depth variations in physical parameters for shelf areas at Kachemak Bay (—), Chisik Island (····) and the Barren Islands (----).

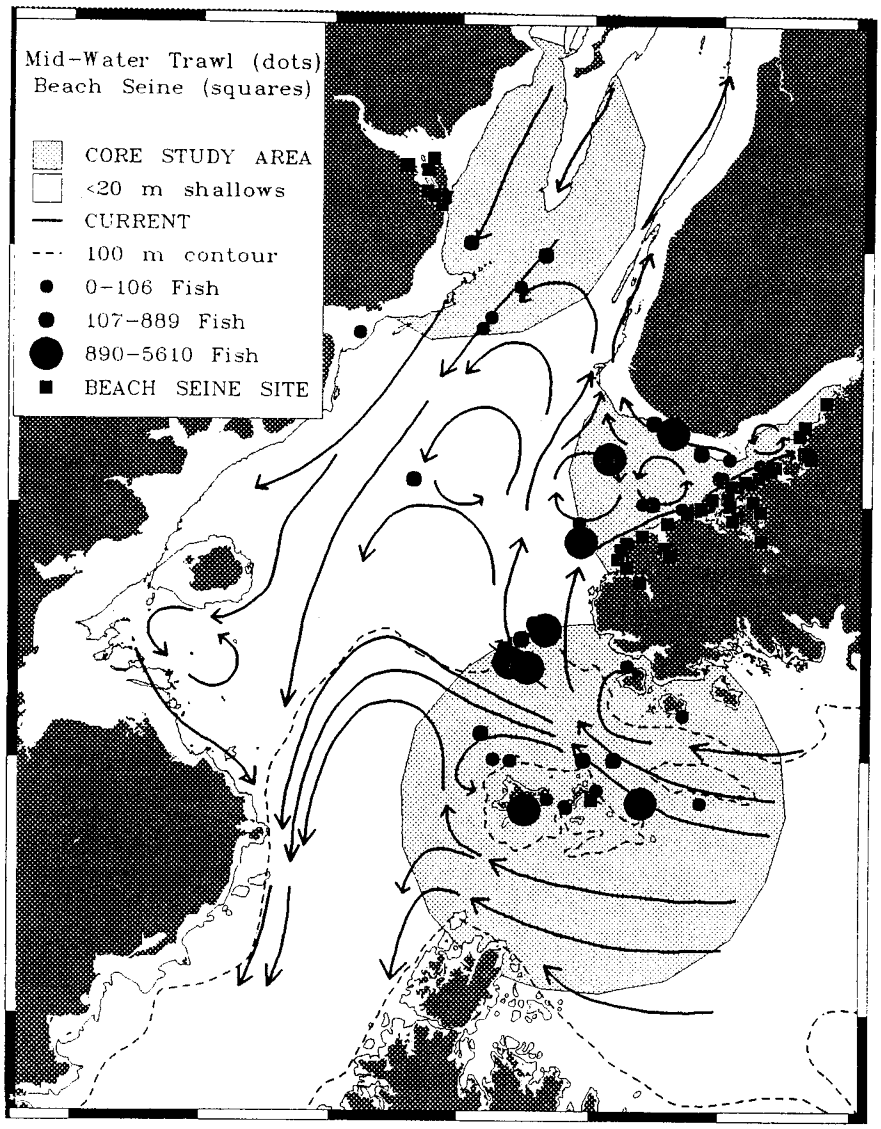
Figure 4. Seasonal variations in nearshore abundance for selected species at Kachemak Bay. CPUE by month (bar graph) and frequency of occurrence (line graph).

Figure 5. Seasonal fluctuations of community parameters [number of species, species diversity (H'), evenness (J'), and species richness (D)] for the nearshore fish community of Kachemak Bay.

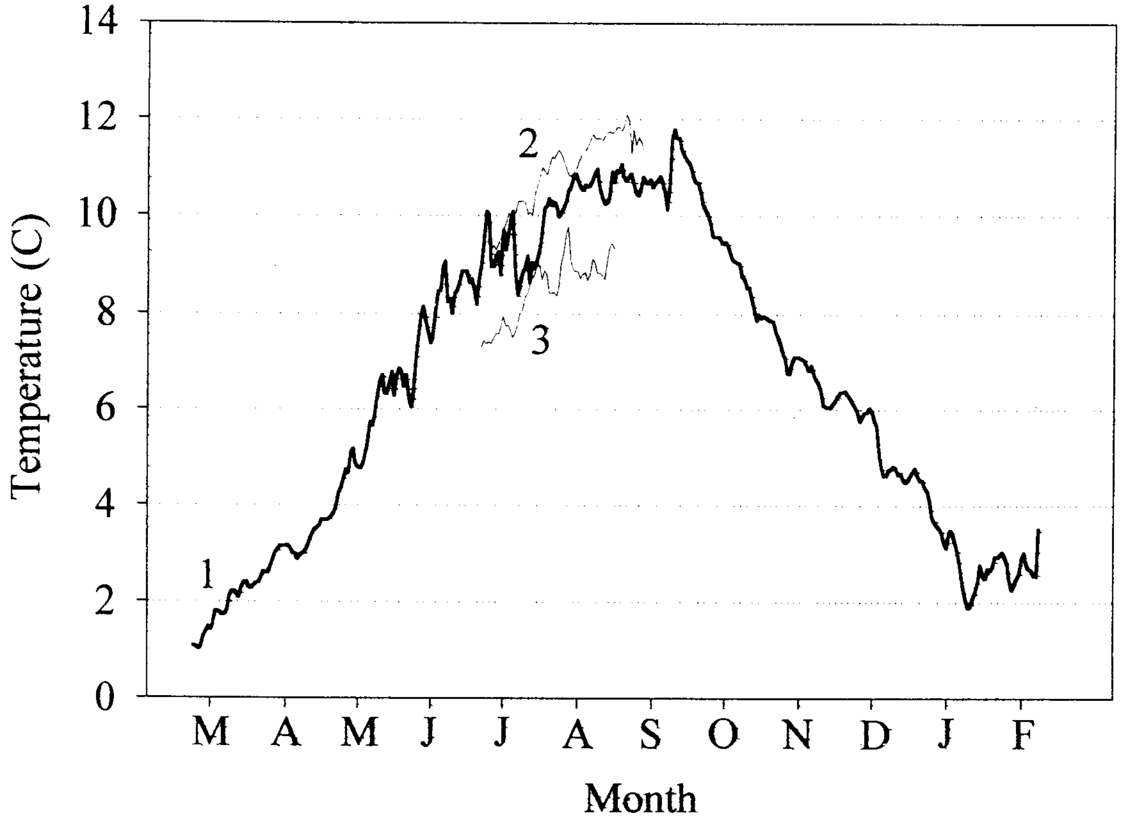
Figure 6. Seasonal variation in nearshore CPUE during 1976 (••••) and 1996 (—) at Kachemak Bay.

Figure 7. CPUE of major taxa caught in the nearshore on adjacent high (■ N=93) and low tides (□ N=90) during 1996 (February-October). Numbers are percent frequency of occurrence.

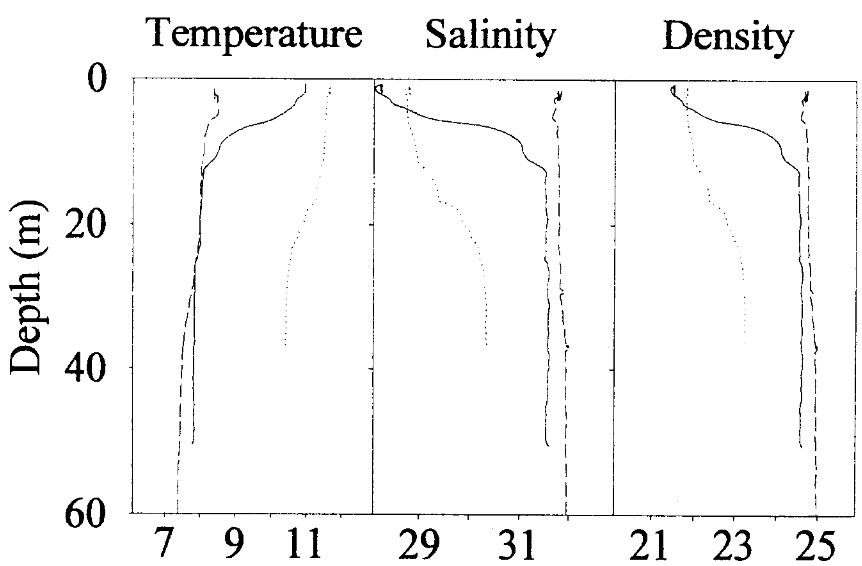
Figure 8. Percent composition of major taxa in the nearshore (■) and shelf (□) areas of Kachemak Bay, Chisik Island, and the Barren Islands.

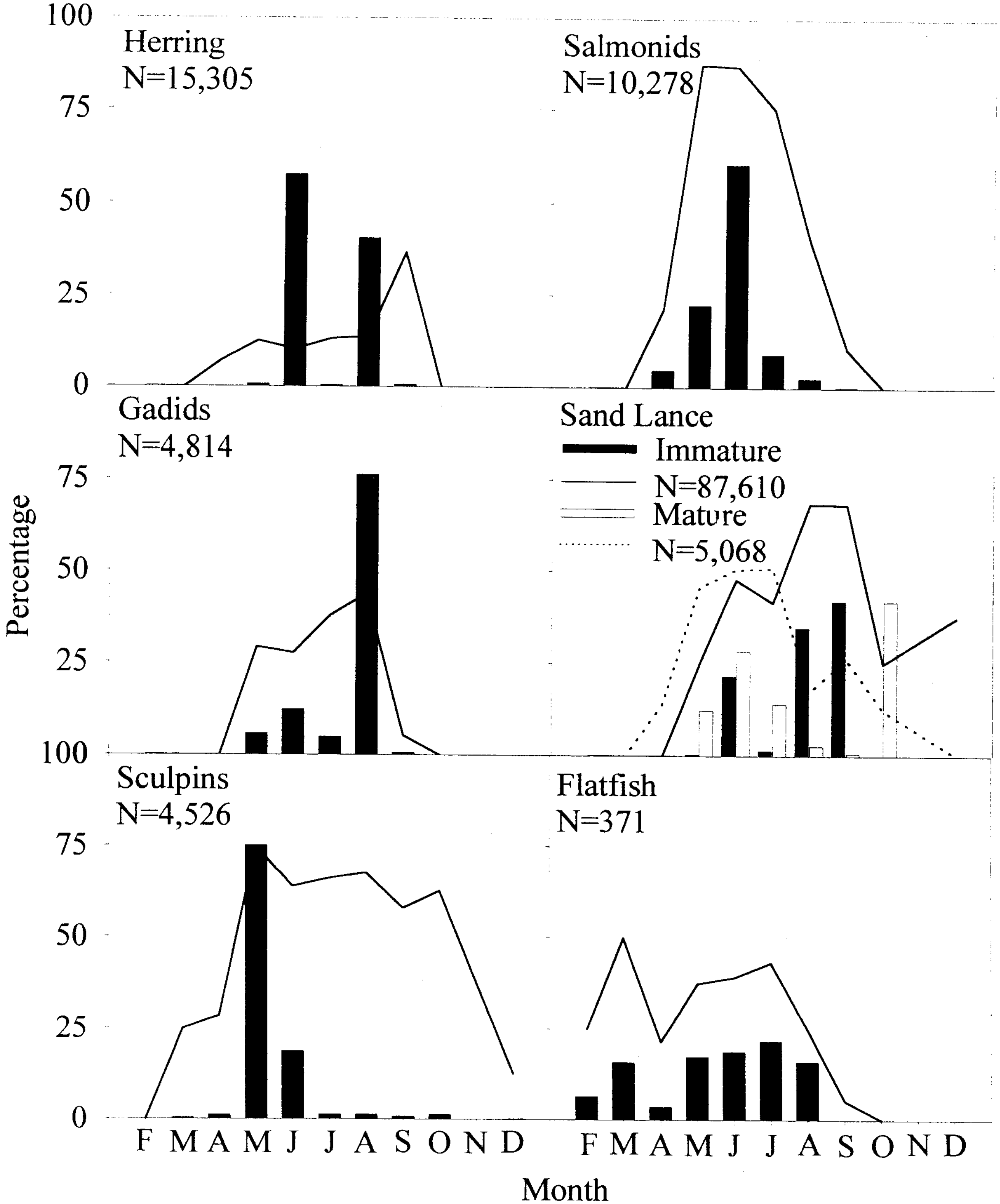


Mid-Water Trawl (dots)
Beach Seine (squares)
CORE STUDY AREA
<20 m shallows
CURRENT
100 m contour
0-106 Fish
107-889 Fish
890-5610 Fish
BEACH SEINE SITE

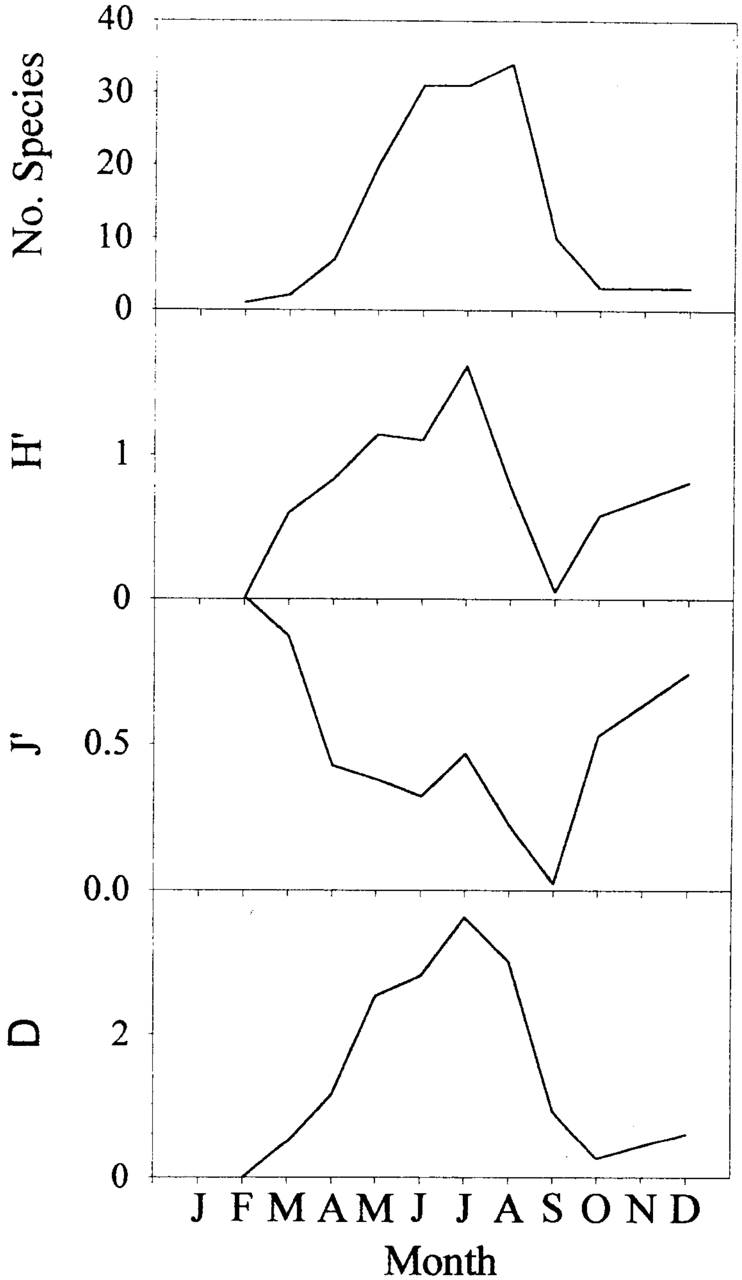


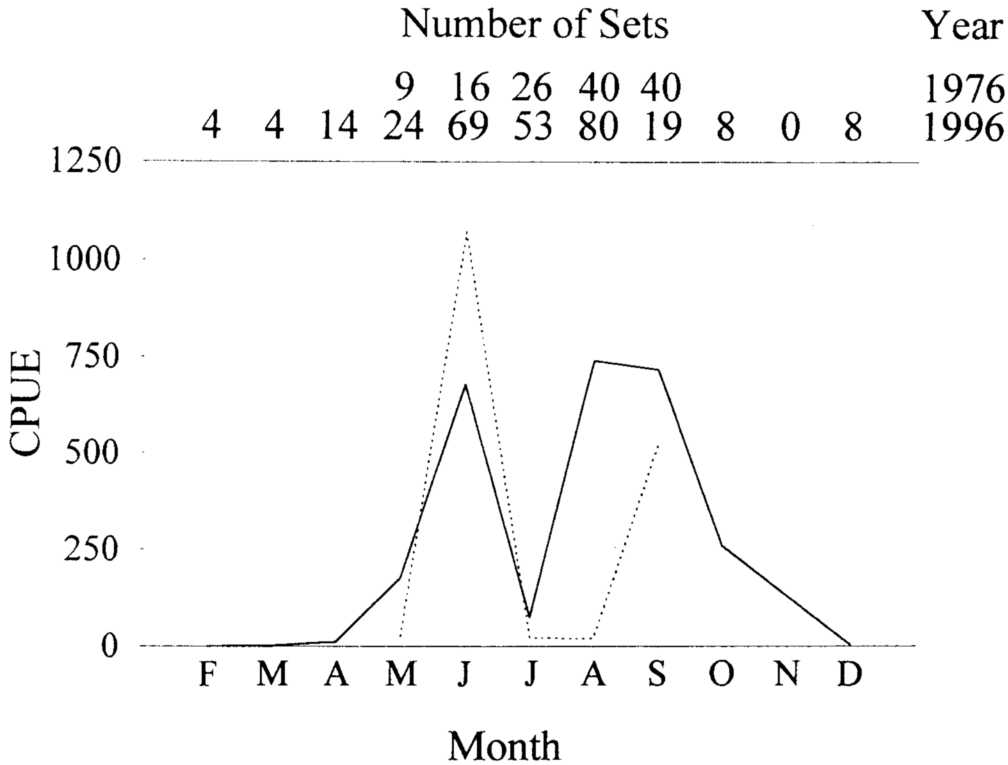
14
12
10
8
6
4
2
0
Temperature (C)
1
2
3
M A M J J A S O N D J F
Month

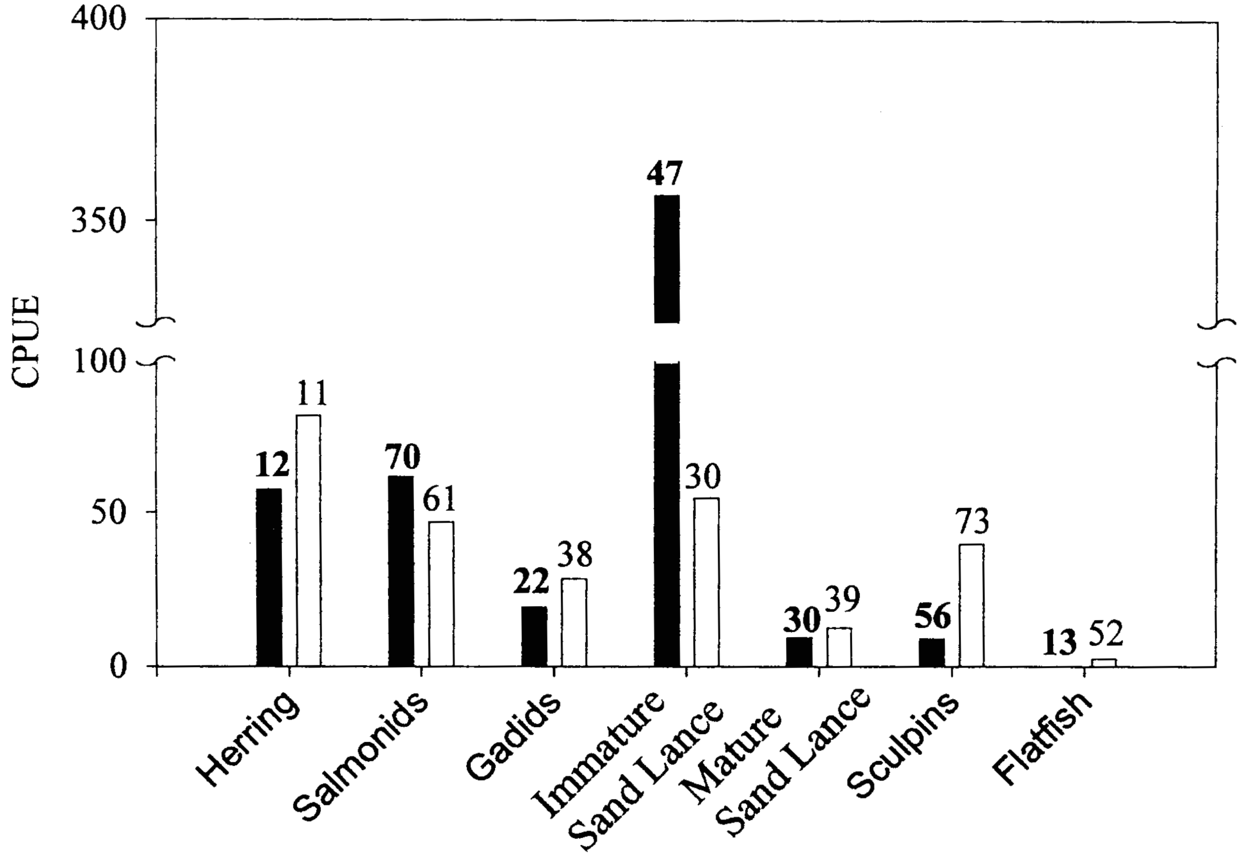

Temperature
Salinity
Density
Depth (m)
0
20
40
60
7
9
11
29
31
21
23
25



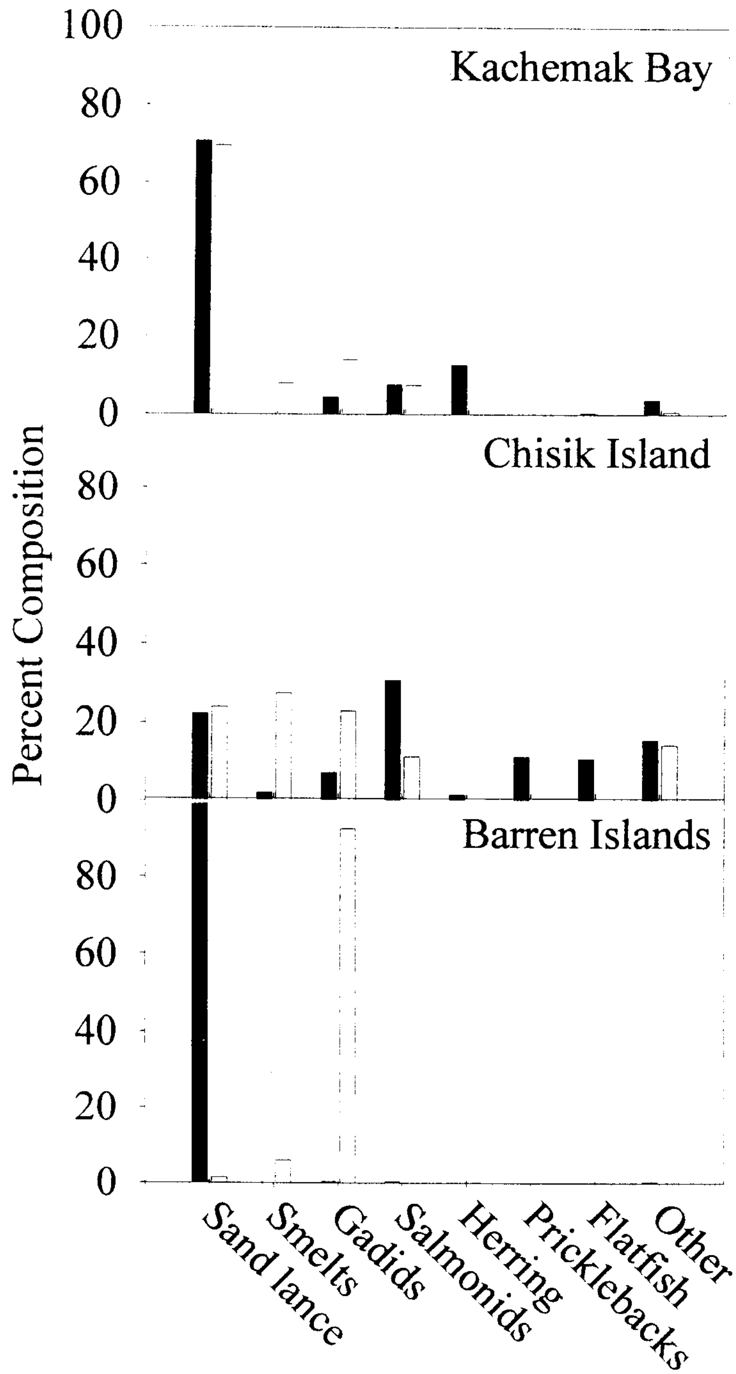
100
75
50
25
0
Herring
N=15,305
Salmonids
N=10,278
Gadids
N=4,814
Sand Lance
Immature
N=87,610
Mature
N=5,068
Sculpins
N=4,526
Flatfish
N=371
Percentage
F M A M J J A S O N D
Month


No. Species
40
30
20
10
0
H'
1
0
J'
0.5
0.0
D
2
0
J F M A M J J A S O N D
Month


Number of Sets
Year
9 16 26 40 40
1976
4 4 14 24 69 53 80 19 8 0 8
1996
1250
1000
750
500
250
0
CPUE
F M A M J J A S O N D
Month



400
350
100
50
0
CPUE
12
11
70
61
22
38
47
30
30
39
56
73
13
52
Herring
Salmonids
Gadids
Immature Sand Lance
Mature Sand Lance
Sculpins
Flatfish



Percent Composition
Kachemak Bay
Chisik Island
Barren Islands
100
80
60
40
20
0
Sand lance
Smelts
Gadids
Salmonids
Herring
Pricklebacks
Flatfish
Other

Seabird Populations, Productivity and Behavior at Gull and Chisik Islands, Cook Inlet, in 1996

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DRAFTof PRELIMINARY
RESULTS: November 1996

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. 1990), 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 1992). 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/km^2) 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 murres, black-legged kittiwakes, pigeon guillemots, pelagic cormorants, glaucous-winged gulls, tufted puffins and horned puffins. Preliminary analyses indicate that the types and quantities of forage fish available to seabirds at each colony differed significantly, and this influenced breeding success of seabirds at each colony.

In 1996, this research program was refined and expanded where appropriate. For example, we increased hydroacoustic sampling of nearshore habitats, tried some new fishing techniques (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). The basic components of this study have not changed, however, and we will measure the same fundamental parameters of forage fish and seabird biology for the duration of the 10-year study (1995-2005).

This report details some of the results obtained at Gull and Chisik Islands, including population trends, breeding success, and time-activity budgets for several of the key species breeding at these islands. Results presented here will eventually be combined with those from the Barren Islands (data presently being analysed by the Alaska Maritime National Wildlife Refuge).

METHODS

Study Areas

Chisik: Chisik and Duck Islands (collectively referred to as Chisik) are located on the western side of lower Cook Inlet at about 60° 09' N, 152° 34' W (fig 1). Both are part of the Alaska Maritime National Wildlife Refuge. Chisik Island encompasses about 2606 ha, has a peak elevation of 815 m, and is located about 0.8 km from the mainland. Duck Island is 0.4 km east of Chisik, covers about 2.4 ha and reaches a maximum elevation of 49 m. Common murres (*Uria aalge*), black-legged kittiwakes (Rissa *tridactyla*), horned puffins (Fratercula *corniculata*), and in smaller numbers pelagic cormorants (Phalacrocorax *pelagicus*), double-crested cormorants (*P. auritus*), tufted puffins (F. *cirrhata*) glaucous-winged gulls (Larus *glaucescens*) and parakeet auklets (Cyclorrhynchus *psittacula*) nest on cliffs and talus slope of the islands. The gulls also nest throughout the vegetated interior portions of the island. The majority of the study was conducted at Duck Island, and personnel stayed at the Duck Island Camp. Two - three people occupied the camp from 22 June - 7 September. They commuted to study areas on Chisik by a 13' outboard- powered inflatable boat. All study sites on Duck were accessed by foot.

Gull: Gull Island is located in Kachemak Bay on the eastern side of lower Cook Inlet (fig 1). The island is situated 5 km southeast of the tip of Homer Spit at 59° 35' 10" N, 151° 19' 45" W and is owned by the Seldovia Native Corporation. This small island is composed of four rocky portions which connect at extremely low tides. The island is largely composed of steep rocky cliffs with a small vegetated area across the top. Murres, kittiwakes, pelagic cormorants, tufted puffins and in smaller numbers red-faced cormorants and horned puffins nest on the cliff faces and upper edges of the island. Gulls nest in all areas, but dominate the vegetated areas. The study was conducted on all accessible portions of the island, both by foot and from an outboard-powered, 4.8 m rigid-hulled inflatable boat. Due to limited accessibility and space, personnel commuted daily to the island by boat from a remote field camp 7 June - 4 September. Some monitoring was also conducted at 60-foot Rock, a small rocky island about 6 km south of the Homer Spit, which is part of the Alaska Maritime National Wildlife Refuge.

Productivity

Murres

Murre productivity data were collected at 7 study plots established in 1995 and 1996 on Chisik and Gull. These plots, each containing 7- 21 nest sites (defined as sites with eggs), were checked with 8 X 42 or 10 X 42 binoculars or 15 X 60 spotting scope every 2 - 4 days, weather depending. Each plot was checked from a specific observation point or blind; viewing distances varied between 3 - 200 m. Nest sites were mapped by hand and plots photographed. On each visit, nest sites were checked for adults, eggs, chicks, or adults in incubation or brooding postures. Plot checks were initiated when murres began to lay eggs (Chisik: 28 June, Gull: 30 June) and sites were followed until nest fates could be determined. Chicks last seen at age 15 days or older were considered to have fledged (Hatch and Hatch 1990). Mean productivity (chicks fledged per egg), hatching success (chicks hatched per egg), and standard errors were calculated by using plots as sample units. Differences were tested using t-tests.

On Gull Island an index of murre productivity was also calculated by counting the number of chicks per adult on a single visit to large subcolonies (69 - 103 chicks) just prior to peak fledging period.

Kittiwakes

Kittiwake productivity data were collected at 9 study plots on Chisik and 10 study plots on Gull established in 1995 and 1996. The majority of these plots, each containing 6 - 35 nests (defined as nest structures which contain eggs at some point during the breeding season), were checked with 8 X 42 or 10 X 42 binoculars and 15 X 60 spotting scope every 3-10 days during early incubation and every 3 - 5 days when chicks began to hatch. Four plots on Chisik were checked by using an extendable mirror pole held just above each nest to reflect the contents to the observer holding the pole below. Methods for mapping plots and collecting data were similar to those used for murres. Plot checks were initiated during the incubation period when personnel arrived at the colonies, and nests were followed until their fates could be determined. Chicks last seen at age 34 days or older were considered to have fledged (Hatch and Hatch 1990). Mean productivity (chicks fledged per nest), hatching success (chicks hatched per nest), clutch size, and standard errors were calculated using plots as sample units. Differences were tested using t-tests.

An index of productivity (chicks per active nest) was also calculated for kittiwakes on Chisik and Gull. Counts were taken through binoculars by two observers in a boat 5 - 30 m off shore. All nests on Gull and a large sample of nests on Chisik were counted 26 - 29 June at the period of mid-incubation. Active nests were defined as those which appeared to contain eggs, mainly inferred from adult incubation posture. The same areas were surveyed similarly for visible chicks 4 - 6 August, prior to peak fledging. Counts were averaged between observers.

Cormorants

Six double-crested cormorant nests on Chisik Island were monitored from Duck Island through a spotting scope 29 July - 12 August. Due to the great distance, observations were limited to counts of adults, nests, and chicks large enough to see over the nest rims. One additional nest on Duck was monitored similarly. Maximum productivity was calculated as the greatest number of chicks seen per active nest (defined as nests with adults seen in incubating posture for at least three consecutive checks).

On Gull, the contents of eighteen pelagic cormorant nests were checked with 8 X 42 or 10 X 42 binoculars three times during the incubation cycle and every 4 - 6 days during the chick-rearing period. Methods for collecting and analyzing data were similar to those used for kittiwakes on Gull, except means and standard errors are calculated using individual nests as sample units. Chicks last seen at age 41 days or older were considered to have fledged (Hatch and Hatch 1990).

Two pelagic cormorant nests on Chisik were checked by boat through binoculars nine times from 7 July through 2 September. Productivity was inferred by the observation of a chick in one nest during four consecutive checks.

An index of productivity (chicks per active nest) was calculated for all pelagic cormorant nests on Gull Island. Methods used were similar to those used for the kittiwake index count. Nests were counted 5 July, at mid-incubation, and all visible chicks were counted 23 August, just prior to the fledging period.

Puffins

Horned puffin productivity data were collected from fifty-five nests in four plots at Duck Island. All accessible nest sites were checked 4 - 5 July, during the period of mid-incubation. Those with both adults and eggs that could be directly observed were followed. Additional sites were added as found at later dates. Nests were checked for adults, eggs, chicks, or evidence of occupancy (fresh digging, guano, trampled vegetation) every 4 - 5 days or until nest fate could be determined. Chicks last seen at age 36 days or older were considered to have fledged. Mean productivity (chicks per egg), hatching success (chicks hatched per egg), and standard errors were calculated as for murres.

Gulls

On Gull Island, data on gull hatching success were collected from five plots that were established in 1995. Each plots contained 18 - 33 individually marked nests. Plots were checked every five days during incubation for nest contents and every 2 - 3 days when chicks were expected to hatch. Hatching success was determined as possible for each egg. Because chicks were not individually marked, only chicks which could be assigned to a nest by occupation or proximity were recorded as successfully hatched. Eggs with unknown fates due to chicks leaving the nest bowl were not included in hatching success calculation. Limited gull productivity data were collected at Chisik. During the late incubation/early chick-rearing period areas on Duck Island known to contain nesting gulls were searched for nests. Contents of all nests found 24 June were recorded, and nest containing eggs were revisited 29 June to determine egg fate. Due to the unknown number of eggs laid, an index of hatching success (chicks seen per nest) was calculated. The same index was calculated with Gull Island nests for comparative purposes. Differences were tested using t-tests.

Phenology

Median hatch date was chosen as the primary measure of nesting chronology. When the events were not observed, laying and fledging dates were determined using previously established ranges in incubation and chick departure days (Hatch and Hatch 1990). When nest status changed from egg to chick between nest checks, the mid- date between checks was used to establish hatch date. When an even number of days passed between observed status change, the later date was used. When greater than nine days between status change elapsed, hatching dates were not calculated. Hatching dates for cormorants on Chisik were not estimated because nest contents were never observed.

Populations

On Chisik Island, murres were counted 6 - 9 times on two previously established and three newly established population plots. Counts were taken between early incubation and early hatching periods by two observers with binoculars from a boat or a land-based observation point. Counts were taken between 1000 and 1600 hours, weather permitting, and averaged between observers. Mean plot populations were calculated using replicate counts as sample units. On Gull Island, murres were counted 8 - 10 times on twelve previously established population plots. A single count was also taken at ten new population plots established and photographed this year. Counts were made and data analyzed using similar methods to those used at Chisik.

On Chisik and Gull, kittiwakes, cormorants, and gulls were counted 6 - 10 times on 8 and 12 plots respectively. All counts were made by observers in a boat. Gulls were also counted 6 times on two gull population plots (one counted from land, one from a boat) established on Duck Island this year. Counts were made and data analyzed using similar methods to those used for murres.

Horned and tufted puffins on and around Duck Island were counted twice during the late incubation/early hatching period. Counts were taken between 2100 - 2135, the period of highest estimated activity, by two observers circumnavigating the island by foot. All birds in the air and on the water within 200 m of the shore were counted. Counts were averaged for mean population indices.

Time-Activity Budgets

Murres

On Chisik Island, continuous diurnal observations of incubating and brooding murres were conducted by observers alternating shifts in a blind 8 - 30 m away. Observations of arrivals, departures, incubation and brooding shift exchanges, feeding, and prey type and size, if possible, were made through 8 X 42 or 10 X 42 binoculars. Activity was recorded to the nearest minute. Three watches were conducted between 0500 - 2259 on 11 sites with incubating murres . Seven watches were conducted between 0600 - 2159 on 7 - 10 sites during the chick-provisioning period. Total numbers of arrivals, departures, and nest exchanges were recorded for each site each day. Total numbers of chick feedings and minutes of adult attendance were recorded for each site each hour and totaled for each watch. Hourly adult attendance was recorded in bird-minutes, derived from the total number of minutes each adult spent at the nest site in an hour (e.g. a site continuously occupied by 1- 2 adults would have a range of 60 - 120 bird-minutes of attendance). Nest exchanges that occurred between two adults within one minute were not recorded as additional nest attendance. Foraging trip lengths, the number of minutes elapsed between each observed adult departure and subsequent arrival, were calculated and analyzed for all sites in each watch. Diurnal patterns of adult attendance and numbers of chick feedings were analyzed for each site for each watch.

On Gull Island, a time-lapse video camera was used to record the same murre activities observed on Chisik. The camera was set to include 10 viewable murre sites within the picture frame, and the connected video recorder taped four still frames per second from 0600 - 2159. Personnel pre-programmed the camera to record and retrieved the videotape when taping was completed. The tapes were later viewed on a color monitor by 2 - 4 observers. All visible activities at the nest sites were recorded to the nearest full minute. Data were summarized and analyzed as described for the murre activity watches at Chisik.

Mean adult attendance, chick feeding rates, adult trip lengths, and number of next exchanges were compared between colonies. Differences in time-activity budgets were tested with analysis of variance (ANOVA), Kruskal-Wallis ANOVA, Mann-Whitney Rank Sum Tests, and t-tests. Correlations with time were tested by Pearson Product Moment Correlation (PPMC).

Kittiwakes

On Chisik Island, kittiwake nests were observed from 0500 - 2259 once during incubation, once during late incubation/early chick provisioning (nests analyzed separately), and three times during the chick provisioning period. Six to ten nests were observed in each watch. On Gull

Island, activity data at kittiwake nests were recorded from 0600 - 2159 twice during incubation and three times during the chick provisioning period. Eight to twelve nests were observed in each watch. Data were collected and analyzed using similar methods as described for murres on each island. Only the first bout of chick feeding from an adult that had previously been away from the nest for more than 30 minutes was recorded. As chick feeding was often difficult to discern on the videotapes, all apparent attempts were recorded at Gull Island but not included in the analyses. Differences in time-activity budgets were tested with ANOVA and t-tests.

Cormorants

On Gull Island, activity data at two pelagic cormorant nests were recorded from 0600 - 2159 four times during the incubation period and twice during the chick provisioning period. Data were collected using the same methods as described for murres on Gull and have not yet been analyzed.

Chick Growth Rates

Murres

On Chisik and Gull Islands, a sample of 15 - 30 unmarked murre chicks of unknown age were weighed and measured three times. Personnel visited the colonies at dawn or after sunset during the early, mid, and late chick-rearing periods and attempted to measure a representative sample of chicks of varying ages. Weight in grams, flattened wing chord to the nearest millimeter, and culmen to the nearest 0.1 millimeter were recorded for each chick. Personnel time in the colony was limited to 30 minutes. Mean mass as a function of wing length was plotted for all data. The linear phase of mass increase was determined to be between wing lengths of 30 - 40 mm by plotting mean mass as a function of wing length. For all measurements within the linear phase, mass was divided by wing length to derive an index of body condition. These values were averaged for each island and differences compared using t-tests.

Kittiwakes

On Chisik and Gull Islands, individually marked and/or known kittiwake chicks were weighed and measured every five days. Chicks with unknown hatch dates were aged using data from known-age kittiwake chicks in Shoup Bay, AK. Growth rate data were collected on 11 kittiwake chicks at Chisik and 34 chicks on Gull. Weight to the nearest gram, flattened wing chord to the nearest millimeter, and culmen and head-plus-bill length to the nearest 0.1 millimeter were recorded on each visit. Chicks at Gull Island were banded with stainless steel USFWS bands when they weighed over 250 g to distinguish twins and identify any chick movement between nests. Chicks were followed until their fates were determined. The linear growth phase was determined to be between 6 - 22 days by plotting mean mass at each age and choosing the period with the most linear increase. Least squares regression were calculated for each chick within the linear phase and values averaged for each island. Differences between islands were compared by t-tests.

Puffins

Nineteen horned puffin chicks at Duck were weighed and measured every 4 - 5 days until their fates were determined. Weight in grams, flattened wing chord to the nearest millimeter, and culmen to the nearest 0.1 millimeter were recorded on each visit. The linear growth phase was determined to be between 8 - 32 days by plotting mean mass at each age and choosing the period with the most linear increase. Least squares regression were calculated for each chick within the linear phase and values averaged for the island.

Chick Diets

Murres

On Chisik and Gull Islands, murre chick diet composition was determined from sample collections and provisioning observations. Murre chicks meals were collected opportunistically when personnel were in the colonies to measure chicks. All fish seen on the colony substrate were collected, identified, and preserved. Additionally, adults carrying fish were observed with binoculars from blinds or observation points. Personnel recorded every meal delivery into the colony and identified the prey type to lowest practical taxonomic level and estimated prey size in relation to murre bill length when possible. Unidentified prey were included to avoid biases towards easily identifiable species. Percent composition was calculated for all items collected on each island. Differences between islands were tested using Z tests with Yates correction.

Kittiwakes

Kittiwake chick regurgitants were collected opportunistically while handling chicks or induced through gentle throat massage. Special effort was taken to collect samples throughout the chick provisioning period. All samples were placed in individual bags, numbered, and preserved shortly after collection. Data have not yet been analyzed.

Puffins

Samples of horned puffin chick meals were collected on Duck Island throughout the chick provisioning period. Two methods were used. In one method, wire mesh screens were placed over nest crevice entrances to block returning adults and cause them to drop any prey items. The other method involved spreading a fine mesh gill net over an area with several puffin nest entrances in hopes of temporarily entangling returning adults and causing them to drop their prey. Both screens and nets were in place for 1.5 - 2 hours, then collected along with any samples. In additions, opportunistic sightings of dropped prey were collected. All samples were bagged, numbered, labeled with collection method, and preserved. Diet composition was calculated by individual fish and by bill load for all items collected.

Statistical Analyses

All statistical analyses were performed using SigmaStat (v. 2.0, Jandel Scientific Software). All means are reported pus or minus one standard error.

RESULTS

Productivity

Murres

Murre productivity was high at both Chisik (0.78 ± 0.04, n = 7) and Gull (0.87 ± 0.05, n = 7). There was no significant difference between the two values (t-test, df = 12, p = 0.185). Hatching success was similarly high at both colonies (Chisik: 0.82 ± 0.04, n = 7; Gull: 0.92 ± 0.03, n = 7). There was no significant difference between the colonies (t-test, df = 12, p = 0.069). The hatching success value at Gull may be a maximum value, since early egg loss may have been unaccounted for as nest observations were initiated as active sites were found.

Productivity appeared low at Gull based on index estimates. The mean number of chicks per adult in a single visit to two additional plots was 0.22 (n = 169 chicks).

Kittiwakes

Kittiwakes exhibited near reproductive failure at Chisik (0.05 ± 0.03 chicks fledged per nest, n = 9), but produced many fledglings at Gull (0.87 ± 0.10, n = 10) (t-test, df = 17, p = <0.001). At Chisik, great loss occurred during the chick stage. There was no significant difference in hatching success in the same plots at each island (Chisik: 0.71 ± 0.04; Gull: 0.71 ± 0.04; t-test, df = 17, p = 1.0). Mean clutch sizes were significantly higher at Chisik (1.85 ± 0.02) than at Gull (1.69 ± 0.05) (t-test, df = 17, p = 0.011)

The index productivity estimate at Chisik (0.05 chicks per nest, n = 2489) reflected productivity in the closely monitored plots. On Gull, the index productivity estimate (0.56, n = 5152) was somewhat lower than that seen in the plots.

Cormorants

An estimate of pelagic cormorant productivity at Chisik was limited to one nest which appeared to fledge a single chick. A second nest which disappeared early in the season likely did not contain any eggs. Pelagic cormorant productivity at closely monitored nests at Gull was high (1.83 ± 0.31, n = 18) and not significantly different from estimated productivity for all cormorants on the island (1.59 ± 0.14, n = 87)(t-test, df = 103, p = 0.48). Hatching success was also high in the closely monitored nests (0.77 ± 0.08, n = 20). Clutch size in these nests varied (3.1 ± 0.25, n = 20).

Estimated red-faced cormorant productivity at Gull was high (2.75 ± 1.11, n = 4).

Double crested cormorants appeared productive at Chisik. A maximum production value of 1.71 was estimated from the greatest number of large chicks discerned in eight nests.

Puffins

Horned puffin productivity at Chisik was fairly high (0.66 ± 0.07, n = 4), only somewhat lower than hatching success in the same plots (0.86 ± 0.07). Based on observed adult activity and the sighting of a large chick, the two horned puffin nests at Gull most likely fledged chicks.

Gulls

Based on an estimate of chicks per nest, gull hatching success per nest at Chisik (1.81 ± 0.16, n = 32) was significantly higher than a similar estimate at Gull (1.19 ± 0.10, n = 124)(t-test, df = 154, p = 0.004). However, hatching success per egg in closely monitored plots at Gull was lower (0.68 ± 0.03, n = 5). Mean clutch size in all nests was 2.37 ± 0.08 (n = 124).

Phenology

Murres

The median hatch date at Chisik was 10 August (range: 28 July - 20 August) and at Gull was 13 August (range: 3 August - 3 September). Murres at Chisik hatched significantly earlier than those at Gull (Mann-Whitney Rank Sum Test, p = <0.001).

Kittiwakes

The median hatch date at Chisik was 2 July (range: 27 June - 25 July) and at Gull was 8 July (range: 28 June - 29 July). Kittiwakes at Chisik hatched significantly earlier than those at Gull (Mann-Whitney Rank Sum Test, $p = <0.001$).

Cormorants

The median hatch date for pelagic cormorants at Gull was 10 July (range: 8 July - 5 August). Hatching was not be observed at Chisik.

Puffins

The median hatch date at Duck was 23 July (range: 15 July - 5 August). Hatching was not observed at Gull.

Gulls

Although early hatching was not observed at Chisik, hatching appeared to be much earlier at Chisik than at Gull. The median hatch date at Gull was 2 July (range: 28 June - 18 July). In contrast, all eggs on Chisik had hatched by 29 June.

Populations

Murres

The mean number of murres on plots at Chisik was 162 ($n = 9$). This value continues a declining trend from previous years (fig 2). The mean number of murres in newly established plots was 76 ($n = 6$). Expanding our monitoring effort in newly established plots will further document this trend. The mean number of murres on plots at Gull was 327 ($n = 10$). This value has decreased slightly in the past year, but continues a generally increasing trend in numbers in the past ten years (fig 3).

Kittiwakes

Mean numbers of kittiwakes (741, $n = 6$) and nests (714, $n = 3$) in plots at Chisik have increased slightly in the past year, continuing an unclear trend in population fluctuations (fig 4). Overall numbers of adults and nests have declined from counts in 1986. Mean numbers of kittiwakes (1175, $n = 10$) and nests (816, $n = 6$) on plots at Gull decreased slightly, yet overall numbers continue to remain stable (fig 5).

Cormorants

Mean numbers of pelagic cormorants (31, n = 10) and nests (20, n = 6) in plots at Gull declined in the past year. However, excluding a substantial drop in 1992, numbers of cormorants and nests have remained generally stable in the past ten years (fig 6).

Puffins

The mean number of horned puffins counted on Duck Island was 864 ± 67.38 (n = 2). The mean number of tufted puffins counted was 9 ± 2.13 (n = 2).

Time-Activity Budgets

Murres

For all watches combined, murres at Gull spent on average 68.9 ± 0.81 minutes per hour at the nest sites (n = 92), while murres at Chisik spent 62.9 ± 0.49 minutes per hour at the nest site (n = 163) (fig 7). Breeding murres at Gull spent significantly more time at their nest sites than those at Chisik (t-test, df = 14, p = 0.036). Patterns of attendance over the season were similar between islands. Both islands showed highest average attendance in watches during early incubation. Attendance declined at both colonies as the season progressed. Mean hourly attendance on the final watch at Chisik (52.7 ± 1.77) dropped below sixty minutes due to repeated desertion of chicks by some adults.

Daily patterns generally show higher mean attendance in the latter half of the day. Highest hourly values for all watches at Gull occurred between 1500 and 2159. During incubation, Chisik murre attendance showed the same general pattern as on Gull, but during the chick-rearing stage, highest hourly attendance occurred between 0700 - 1259.

Both chick feeding rates and adult trip durations showed strikingly different patterns between islands. For the entire provisioning period, the mean feeding rate at Gull was 5.03 ± 0.82 deliveries per chick per hour (n = 3) and at Chisik was 2.58 ± 0.29 (n = 3)(fig 8). Murre chicks at Gull were fed significantly more often than those at Chisik (Mann-Whitney Rank Sum Test, p = 0.009). Daily mean feeding rates at Gull differed significantly (Kruskal-Wallis ANOVA on ranks, p = 0.028) and increased as the season progressed (PPMC, r = 0.439, p < 0.050). The daily mean feeding rate at Chisik on one day (20 August) was significantly higher than that on two other days (12 and 19 August)(ANOVA, P <0.05), but there were no other significant differences between days. Daily mean feeding rates were not correlated with date (PPMC, r = 0.119, p = 0.399). Rates remained relatively level over the season.

Over the same period, mean adult trip duration at Gull was 129.37 ± 9.45 minutes (n = 127) and at Chisik was 242.9 ± 20.56 (n = 107)(fig 9). Murres at Gull spent significantly less time away from their nest sites that those at Chisik (Kruskal-Wallis ANOVA by ranks, P = <0.001). Daily mean trip durations at Gull differed significantly between watches (Kruskal-Wallis ANOVA on ranks, p = 0.001) and decreased as the season progressed (Pearson Correlation, p < 0.001). At Chisik there was no significant difference between daily mean trip durations (Kruskal-Wallis, p = 0.234), nor any correlation between feeding rates and date (Pearson Correlation, p = 0.959).

There was no significant difference between the mean number of exchanges of incubation duty between adults at the nest sites at Chisik (0.94 ± 0.14, n = 33) and Gull (1.17 ± 0.14, n = 35)(t-test, df = 66, p = 0.250). However, the number of exchanges during the brooding period at Gull (3.27 ± 0.73, n = 30) was significantly higher than that at Chisik (2.07 ± 0.15, n = 61)(t-test, df = 89, p = 0.032).

Kittiwakes

Adult kittiwakes at both islands spent little time at the nests when not incubating or brooding. Average hourly nest attendance at Chisik was 58.84 ± 0.46 minutes per hour (n = 88) and at Gull was 59.85 ± 0.40 (n = 68). A t-test detected no significant difference between the values (df = 154, p = 0.111). Daily mean values generally remained constant over the season, but dropped below sixty during the mid and late chick-rearing period at Chisik (59.2 ± 0.6; 54.1 ± 1.91) and late chick-rearing period at Gull (56.6 ± 4.04), when chicks were periodically left unattended.

The mean number of adult exchanges at the nests during the mid - late chick-rearing period at Chisik was 2.75 ± 0.52 (n = 12) and Gull was 4.11 ± 0.55 (n = 18) An ANOVA detected no significant difference between the values (p = 0.099).

During the mid-late chick-rearing period, the average time spent away from the nest site by the off-duty kittiwakes at Chisik was 215.17 ± 29.77 minutes per trip (n = 29), whereas at Gull the average duration was 137.6 ± 8.49 minutes (n = 90). Kittiwakes at Chisik were away for significantly longer periods of time than those at Gull (ANOVA, p = 0.030).

Cormorants

Data have not yet been analyzed.

Chick Growth Rates

Murres

During the linear growth phase, chick body condition at Chisik was 3.93 ±0.12 grams per mm wing length (n = 44), while those at Gull were 4.25 ± 0.19 grams per mm wing length (n = 25). A t-test detected no significant difference between values at each island (df = 67, p = 0.139).

Kittiwakes

During the linear growth phase, the average growth rate of all chicks at Chisik was 11.07 ± 1.87 grams per day (n = 11), while the average rate at Gull was 16.64 ± 0.61 grams per day (n = 34). Growth rates were significantly higher at Gull than at Chisik (t-test, df = 43, p = <0.001).

Puffins

During the linear growth phase, the average Horned Puffin chick growth rate was 9.43 ± 0.79 grams per day (n = 14).

Chick Diets

Murres

Murre chick diets at Chisik and Gull Islands comprised mainly capelin, sandlance, gadids, salmonids, and to a lesser degree, pricklebacks, genus *Lumpenus* (n = 368). Smelt and sandfish were prevalent in chick diets at Chisik only, comprising 33% and 7% of identifiable prey items respectively. There was no significant difference between islands in the proportion of capelin, sandlance, gadids and salmonids in total identified prey. Proportion of *Lumpenus* in diets at Chisik (1%) and Gull (3%) differed significantly (z-test with Yate's correction, p = 0.002).

Kittiwakes

Collections have not yet been analyzed.

Puffins

Sandlance dominated horned puffin chick meals at Chisik. Ninety-three percent of fish delivered to chicks were sandlance. The remainder were mainly capelin (4%) and salmonids (2%). Seventy-six percent of bill loads were completely sandlance. Fourteen percent contained more than one type of prey. The remainder contained only capelin (4%), salmonids (3%), and others (3%).

DISCUSSION

Discussion of results is focused on differences between colonies in the 1996 breeding season. Some comparisons in population trends are made with data from past monitoring efforts. This year, the scope of this project expanded to include more behavioral, diet, and productivity monitoring. With greater effort in coming years, detailed inter-annual analyses will become possible.

Murres

Common murres lay a single egg in dense colonies and have been shown to dive as deep as 200m and range as far as 100 km while provisioning chicks (Piatt 1987). Murres have been shown to adjust their foraging behavior in response to a changes in food supply (Burger and Piatt 1990, Monaghan et al. 1994). High productivity at both Chisik and Gull Islands suggest murres were able to utilize available resources successfully this year.

However, differences in adult behavior parameters between colonies suggest that murres at Chisik were working harder than those at Gull to achieve the same results. Murres at Gull made shorter foraging trips and non-brooding adults spent more time at the nest site, suggesting that murres at Gull may have been foraging closer to the colony than those at Chisik. These differences in behavior seemed to compensate for any differences in food supply, allowing high reproductive success.

Although resources were within threshold limits at Chisik for birds to fledge young, behavior adjustments suggest that food supply may have been be sub-optimal. The population decline suggests that while these resources supported production this year, they have not been great enough to sustain population growth.

Kittiwakes

Black-legged kittiwakes are a highly colonial species that typically lay one or two eggs in each nest (Hatch et al. 1993). They are surface feeders and forage close to the nesting colony. Variability in prey densities within their limited foraging range has been shown to have direct effects on nest success at the colonies (Uttley et al. 1994). Kittiwakes frequently experience complete colony reproductive failure, yet can fledge more than one chick per nest when conditions are favorable (Hatch et al. 1993).

High clutch sizes and hatching success rates at both Chisik and Gull suggest conditions were initially favorable to kittiwakes for reproduction. However, nest desertion and high chick loss at

Chisik shortly after hatching suggest adults were not able to provision chicks successfully. The near complete reproductive failure illustrates the extent of the chick loss. At Gull, kittiwakes continued to do well throughout the fledging period, suggesting that the forage base within the adults' range was favorable. The difference between colonies in time spent away by the provisioning adult reflected difference in foraging effort. The longer trips at Chisik may have surpassed a threshold limit for successful provisioning.

Fluctuations in kittiwake populations at Chisik may be influenced by fluctuations in reproductive success. Whereas at Gull, the stable population size may reflect a more consistent food supply, and hence, more consistent reproductive success.

CONCLUSION

At Chisik Island, foraging strategy seemed to be a crucial factor in reproductive success. Murres and horned puffins, species which have extended foraging ranges, bred successfully this year, while kittiwakes, a species with a restricted foraging range, did not. However, at Gull, both the far-ranging species and near-ranging species did well. This pattern suggests far-ranging species were better able to respond to changes in food supply.

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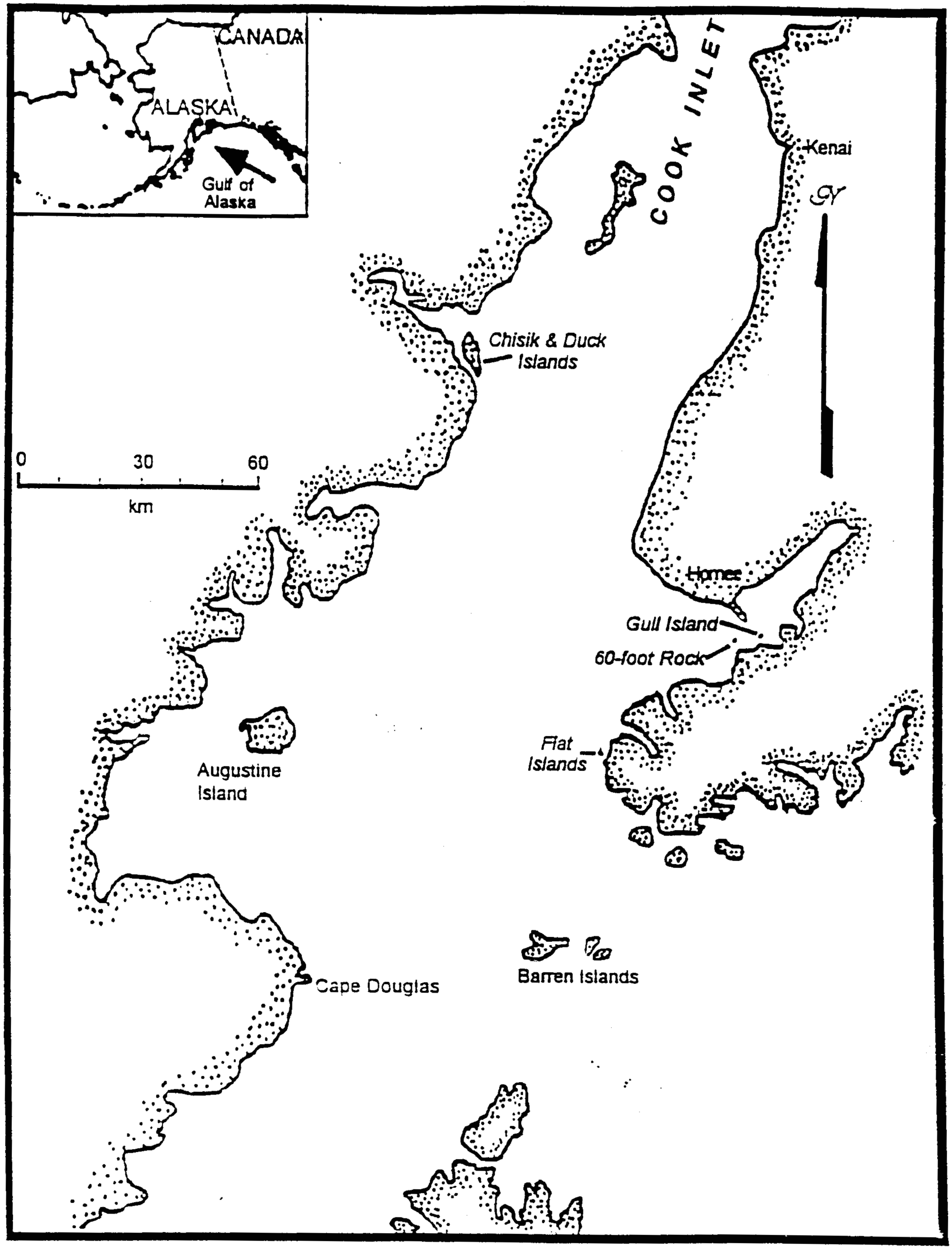

Figure 1. Study locations in lower Cook Inlet, Alaska.

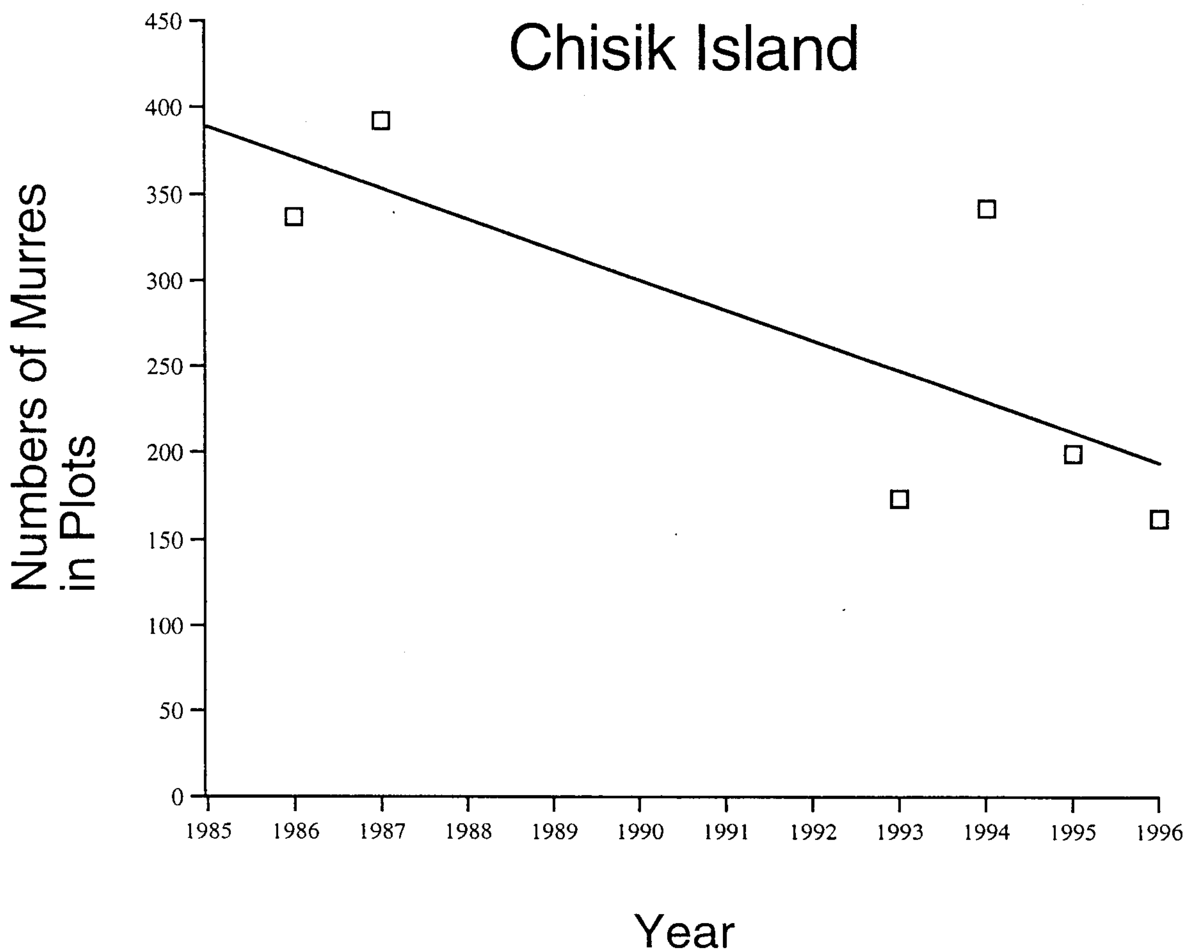

Fig 2. Numbers of common murres in plots 1 - 7 at Chisik Island.

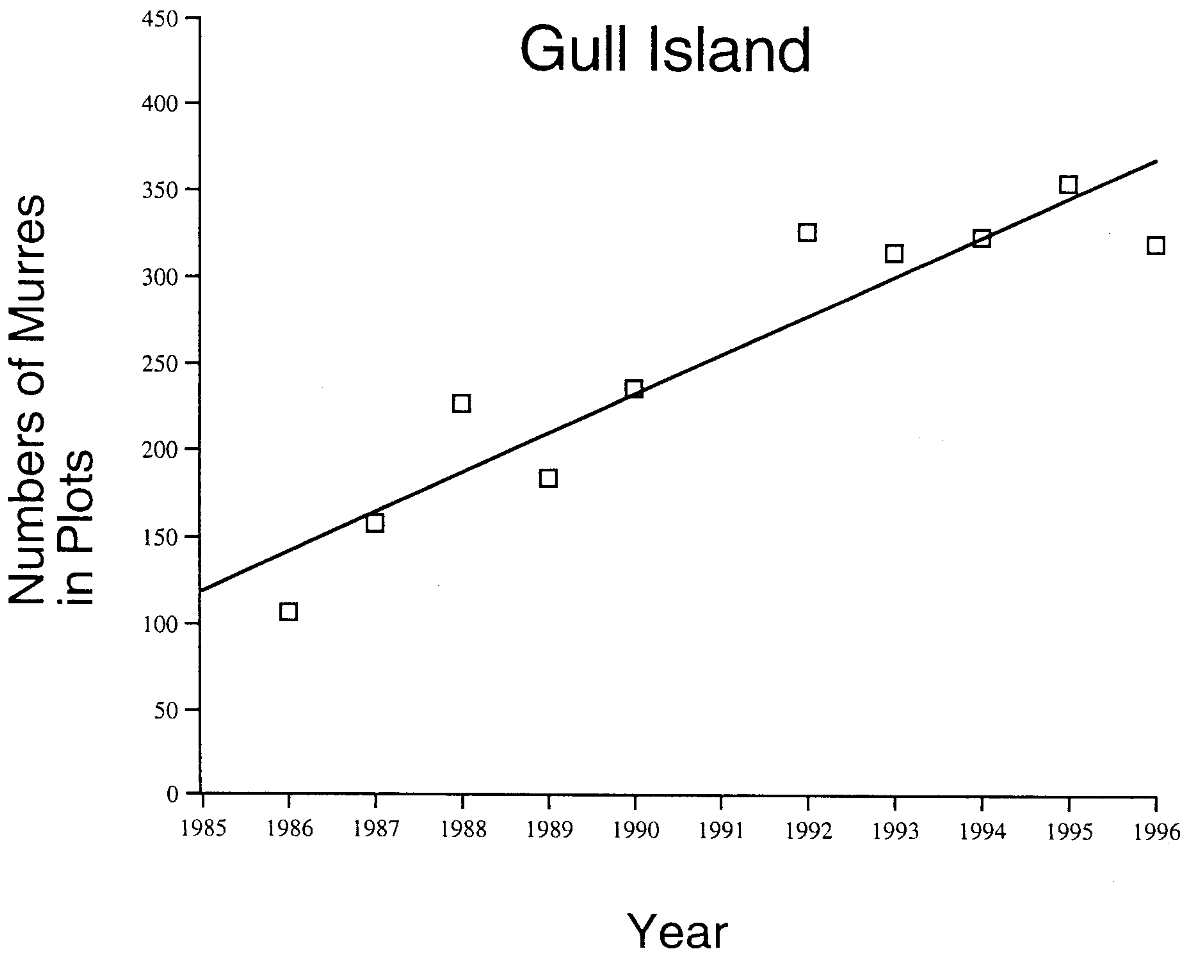

Fig 3. Numbers of common murres in plots 1 - 8 at Gull Island.

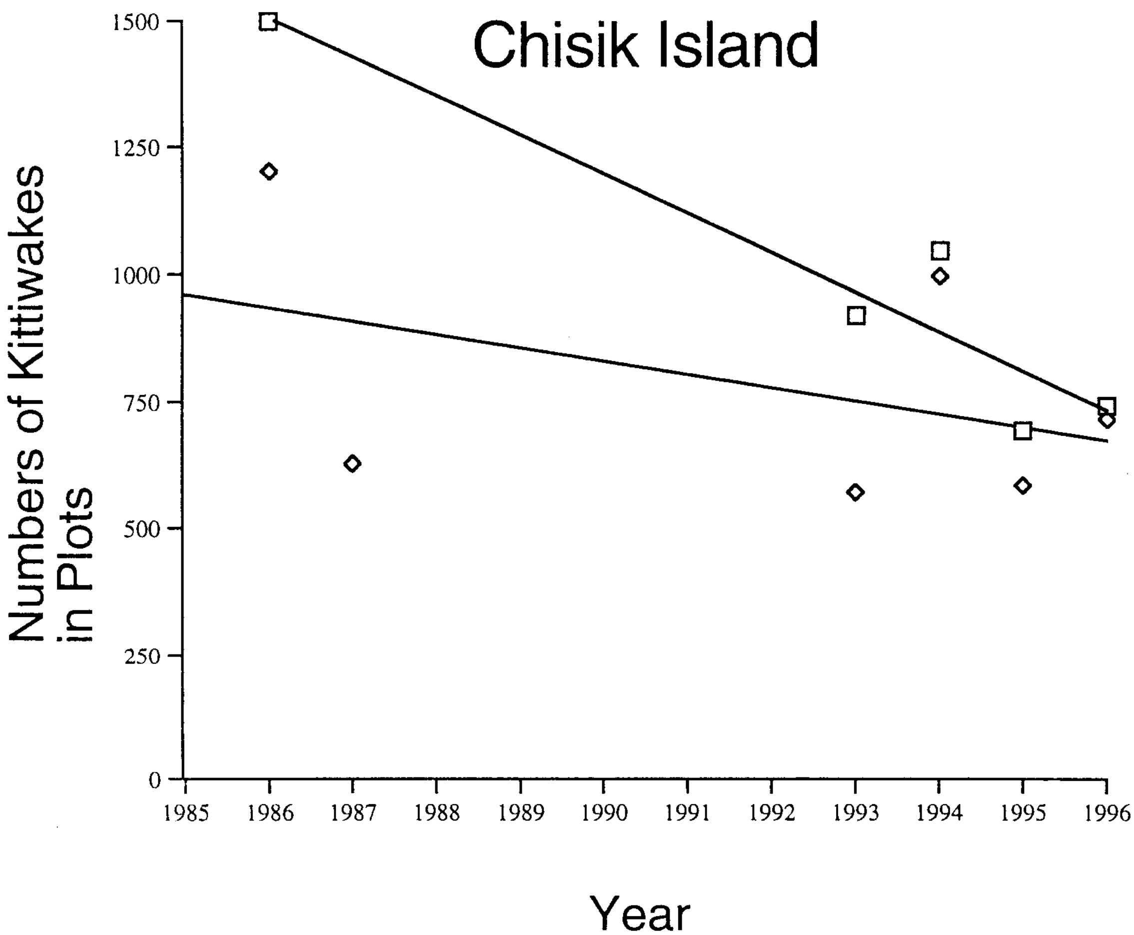

Fig 4. Numbers of black-legged kittiwakes (□) and nests (◇) on plots 1 - 7 at Chisik Island.

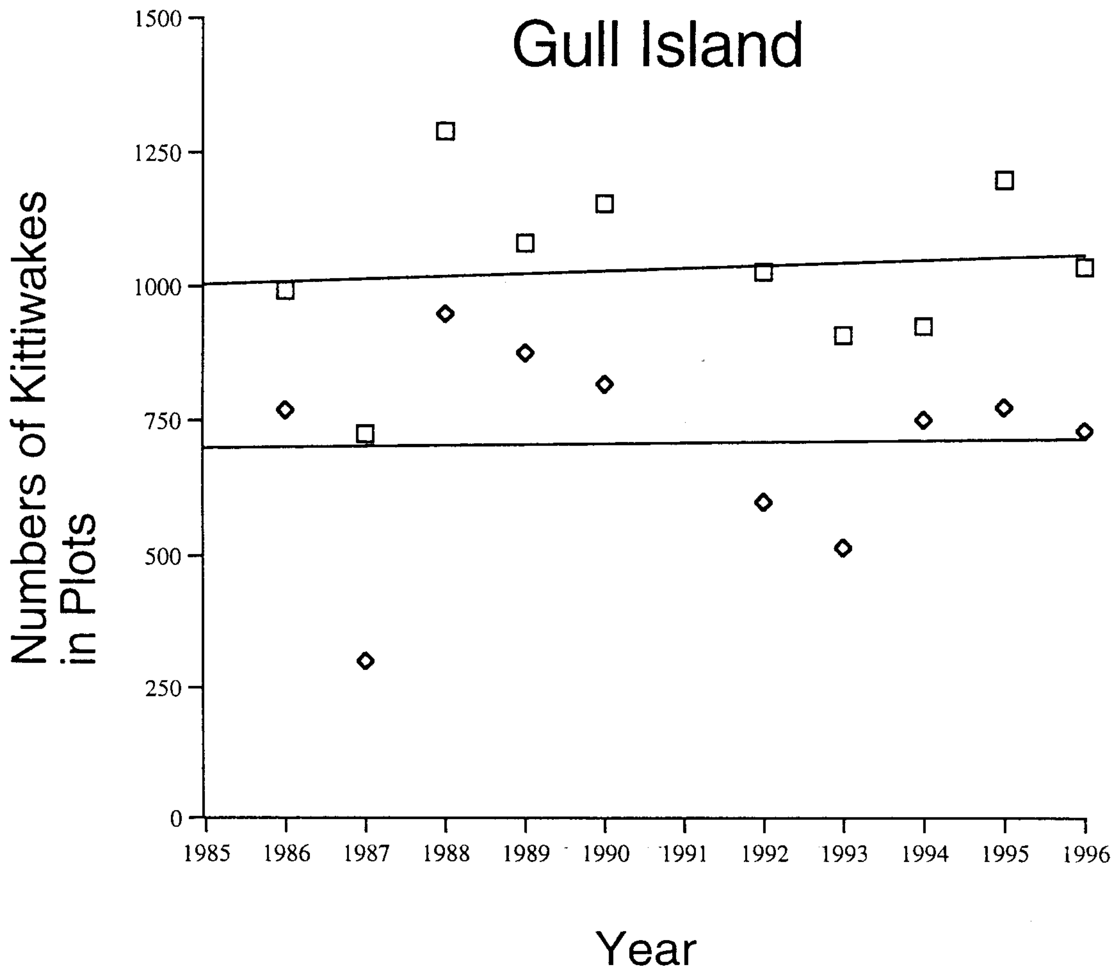

Fig 5. Numbers of black-legged kittiwakes (□) and nests (◊) in plots 1 - 8 at Gull Island.

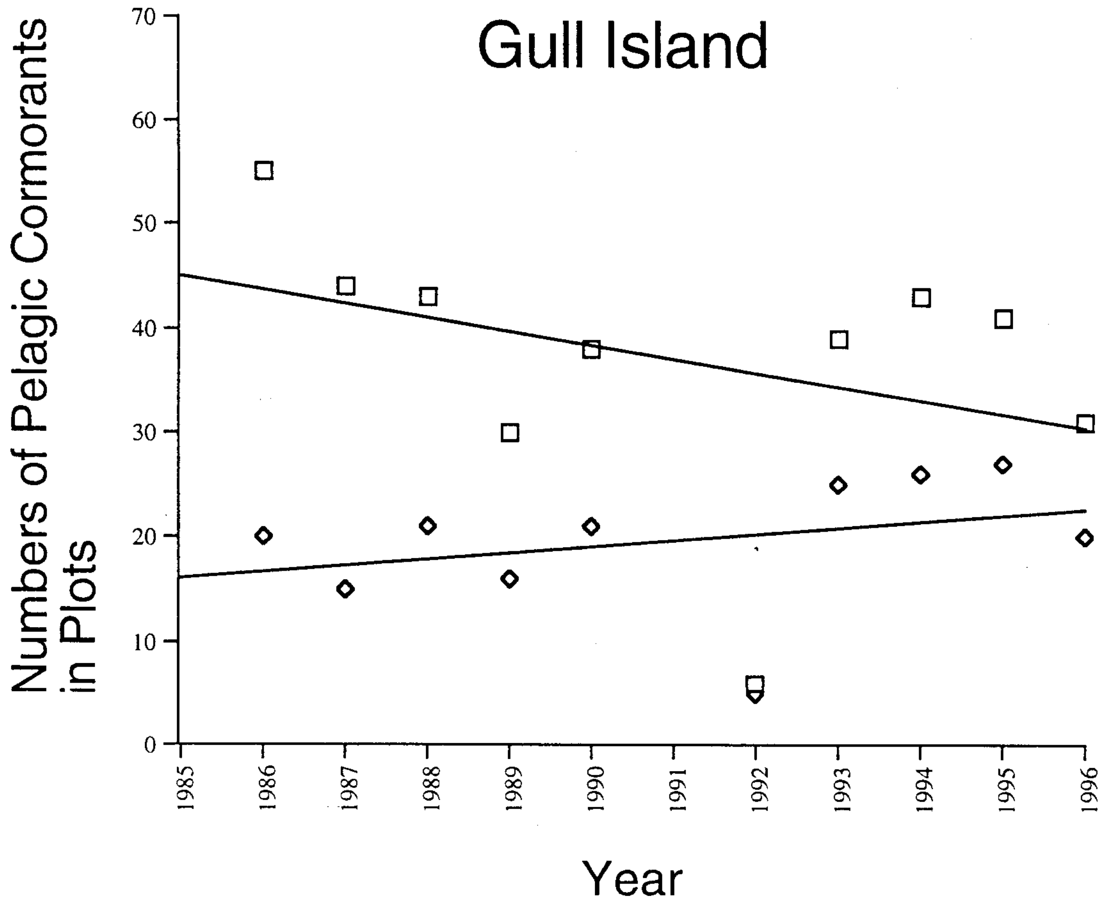

Fig 6. Numbers of pelagic cormorants (□) and nests (◊) in plots 1 - 8 at Gull Island.

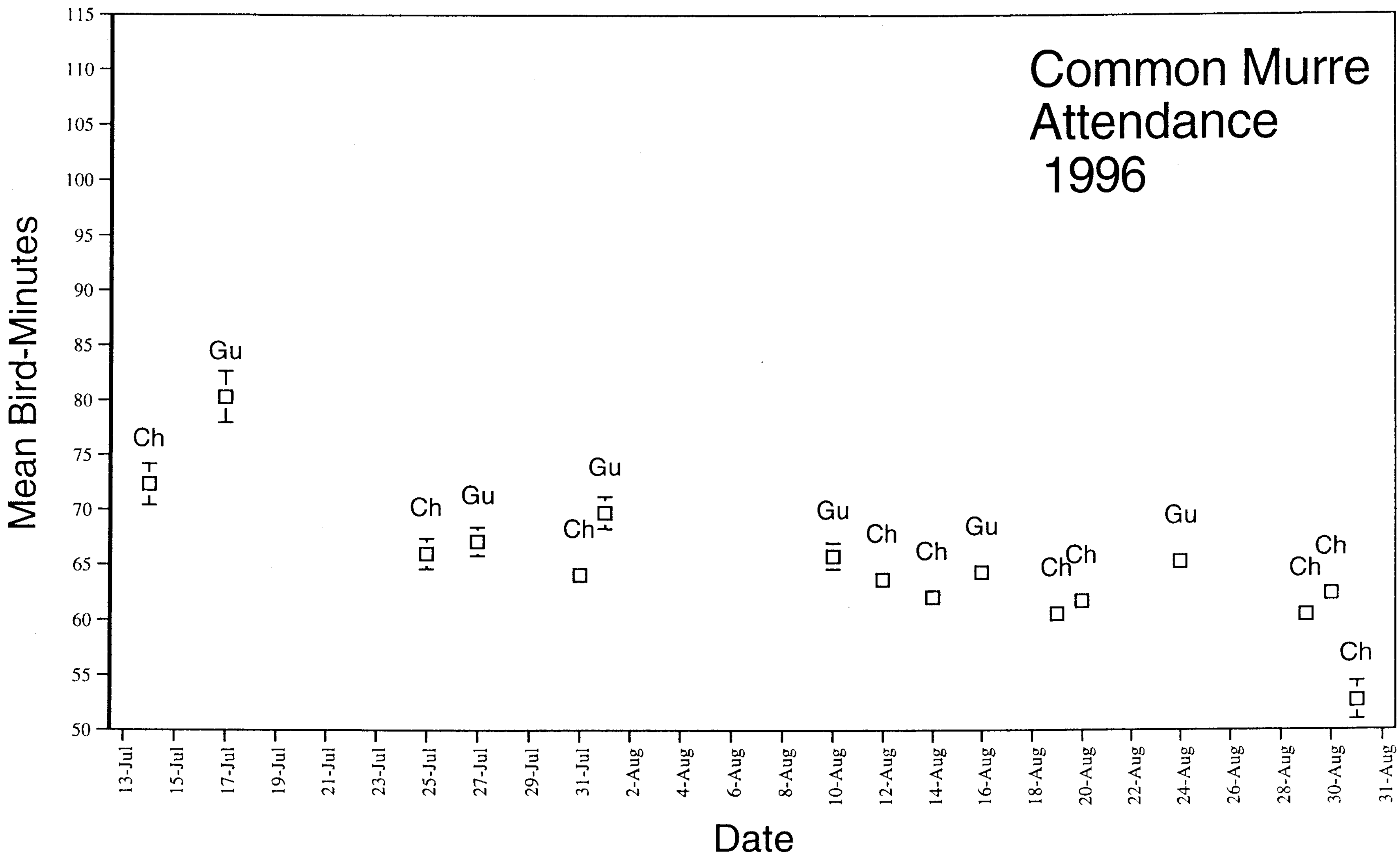

Fig 7. Mean hourly attendance (± s.e.) per all-day watch at common murre nest sites on Chisik and Gull Islands.

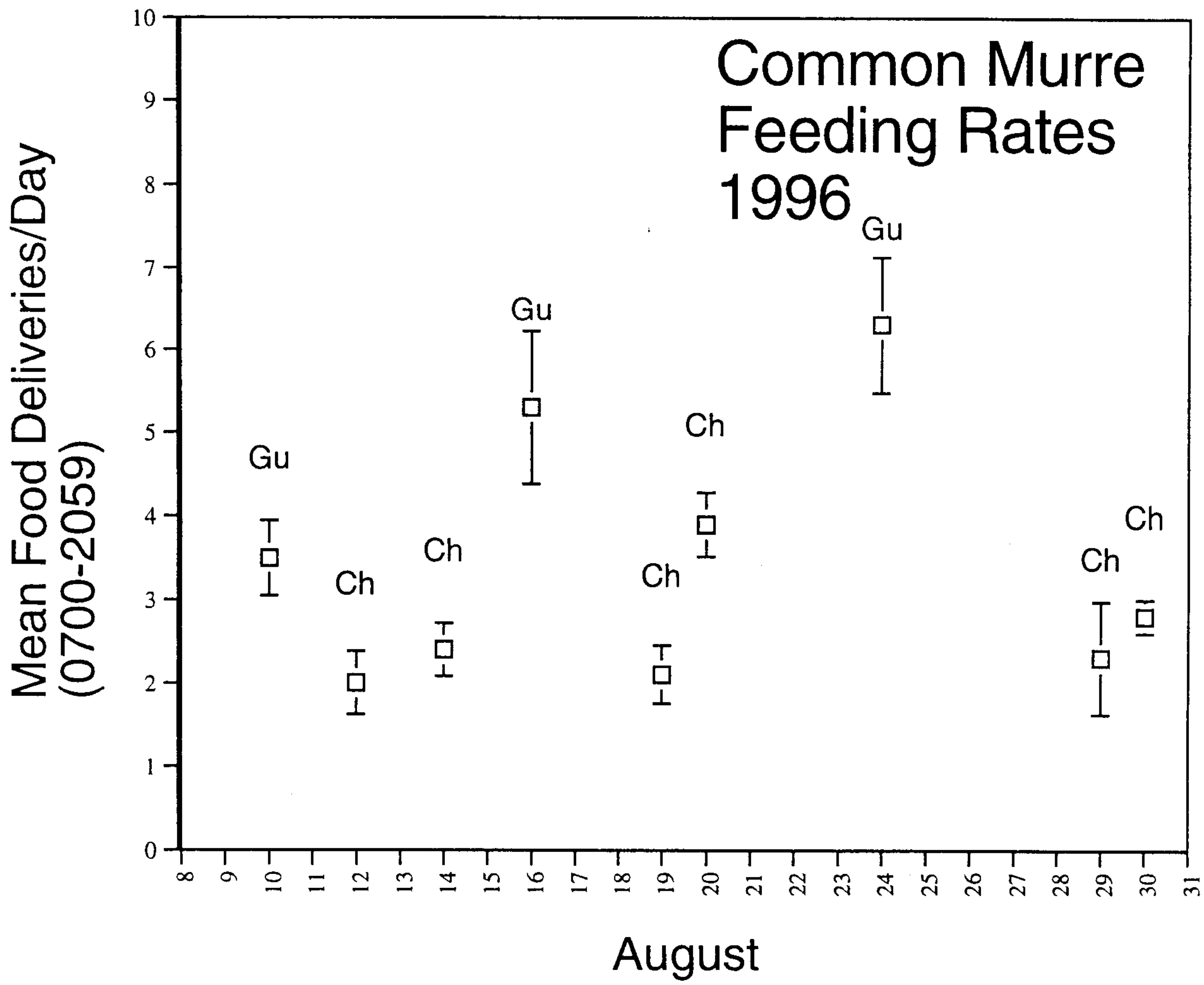

Fig 8. Mean number of food deliveries (± s.e.) to common murre chicks at Chisik and Gull Islands.

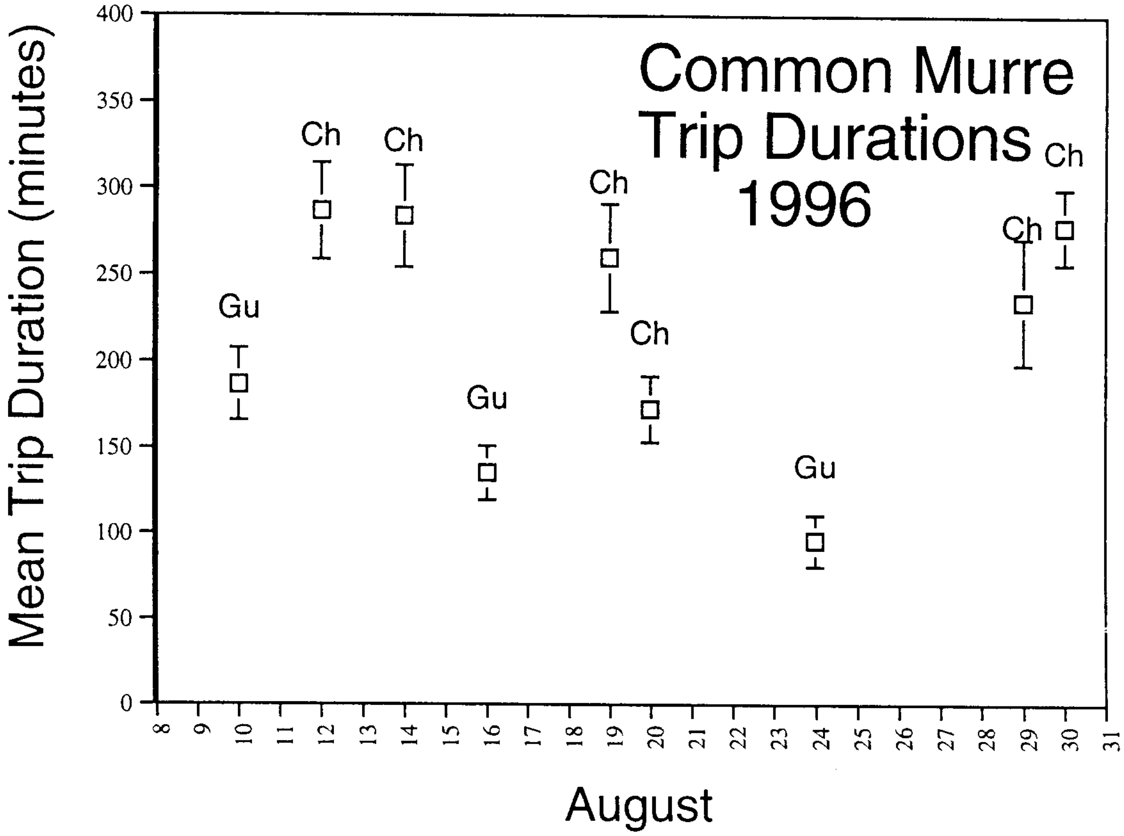

Fig 9. Mean length of time (± s.e.) spent away from nest sites by common murres at Chisik and Gull Islands.

ppendix 1. Productivity summary 1996

	Plots	Total Nests	Nests/plot	Mean Clutch Size	Hatching Success	Productivity	Median Hatch Date	Hatch Range	Index Prod	Nests	Count Dates	
HISIK ISLAND												
LKI	9	111	(6-19)	1.85 (0.02)	0.71 (0.05)	0.05 (0.03)	2-Jul	6/27-7/25	0.05	2489	8/6,6/27	
OMU	7	110	(8-21)	x	0.82 (0.04)	0.78 (0.04)	10-Aug	(7/28-8/20)	x	x	x	
ECO	x	note a	x	x	x	1	note b	x	x	x	x	
CCO	x	8	x	x	x	1.71(max)	x	note c				
WGU	x	32	x	x	1.81 (0.16)*	x	note d	(?-6/29)	x	x	x	
OPU	4	55	(7-18)	x	0.86 (0.07)	0.66 (0.07)	23-Jul	(7/15-8/5)	x	x	x	
ULL ISLAND												
LKI	10	261	(22-35)	1.69 (0.05)	0.71 (0.04)	x	8-Jul	(6/28-7/29)	0.56	5152	8/4,6/29	
	10	220	(16-28)	x	x	0.87 (0.10)						
OMU	7	84	(7-15)	x	0.92 (0.03)	0.87 (0.05)	13-Aug	(8/3-9/3)	0.22 (e)	103, 69	27-Aug	
ECO	x	18	x	3.1 (0.25)	0.88	1.83	10-Jul	(7/8-8/5)	1.66	87	8/23,7/5	
WGU	5	124	(18-33)	2.37 (0.08)	0.68 (0.03)	x	2-Jul	(6/28-7/18)	x	x	x	
					1.19 (0.10)*							
FCO	x	8	x	x	x	x			1.8	5	8/23,7/5	Gorilla Rock only
IGU	x	60	x	1.80(0.05)	x	x	28-Jun	(6/21-7/23)				
	x	55	x	x	0.54	x						
	x	50	x	x	x	0.59						

Time-budgets of Common Guillemots (Uria aalge) at declining and increasing colonies in Alaska

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INTRODUCTION

Common Guillemots Uria aalge and Atlantic Puffins Fratercula arctica have non-linear, threshold foraging responses to fluctuations in prey density (Piatt 1987, 1990). Cairns (1987, 1992) proposed that other parameters such as adult survivorship, breeding success, colony attendance, and adult time-activity budgets should also exhibit non-linear responses to fluctuating food supplies. In support of this, Burger and Piatt (1990) showed that Common Guillemots were able to buffer against effects of variable prey abundance and maintain high levels of productivity by adjusting foraging effort. When prey are abundant, adult Guillemots spend more time attending nest sites (Furness and Barrett 1985, Burger and Piatt 1990). Conversely, when prey are scarce, Guillemots increase time spent foraging at the expense of time spent ashore (Monoghan 1994). In a companion study, Uttley (1994) showed that the largest difference in time-activity budgets between years with varying food supply was reflected in time spent at the colony by the non-brooding adult.

We investigated patterns of parental attendance in two Guillemot colonies, one in which the population has been declining and one in which the population has been expanding during the past 20 years (Slater et al 1995). Evidence suggests that these trends are due to differences in food availability between the two colonies, which are located about 100 km apart on opposite sides of Cook Inlet, Alaska (Piatt and Roseneau 1996). We tested the hypothesis that Guillemots in the declining colony would reflect food stress by minimizing time spent at the colony. We expected to find higher parental attendance by Guillemots in the expanding colony.

METHODS

The study was conducted on Gull and Chisik Islands in lower Cook Inlet, Alaska. These islands support large breeding populations of Common Guillemots, Black-legged Kittiwakes

Rissa tridactyla, Glaucous-winged Gulls Larus glaucescens, and, on Chisik Island, Horned Puffins Fratercula corniculata. Chisik Island (60° 09' N, 152° 34' W) is located in an area of shallow water on the western side of Cook Inlet. Guillemot populations at Chisik Island have declined by about 90% during the past 20 years (Slater et al. 1995, J.F. Piatt, unpubl. data). Gull Island (59° 35' N, 151° 19' W) is located on the eastern side of the inlet, in Kachemak Bay, an area of deep water and variable bathymetry. Guillemot populations at Gull Island have increased by about 80% during the same time period (Slater et al. 1995, J.F. Piatt, unpubl. data).

On Chisik Island, continuous diurnal activity watches were conducted from 0700 - 2100 h on incubating and brooding guillemots by observers alternating shifts in a blind 8 - 30 m away. Observations of arrivals, departures, incubation and brooding shift exchanges, feeding, and prey type and size, if possible, were made with 8 X 42 or 10 X 42 binoculars. On Gull Island, a high-quality time-lapse video camera was used to record Guillemot activities. The camera was positioned to include 6 - 8 viewable Guillemot sites within the picture frame, and the connected video recorder taped four still frames per second. Personnel programmed the camera to record at appropriate time intervals and retrieved the videotape when taping was complete. The tapes were later reviewed with an editing machine equipped with a color monitor.

Watches were conducted at each island once during early/mid incubation (July) and once during late incubation (early August). During the chick-rearing stage (late August), watches were conducted twice at Gull Island and three times at Chisik Island. Total numbers of arrivals, departures, chick feedings, and nest duty exchanges were recorded for each site each day. Hourly attendance was recorded in bird-minutes, derived from the total number of minutes each adult spent at the nest site in an hour (e.g., a site continuously occupied by 1 - 2 adults would have a range of 60 - 120 bird-minutes of attendance). Nest exchanges that occurred between two adults within one minute were not recorded as additional nest attendance. Seasonal and diurnal patterns of adult attendance were analyzed for each site for each watch. Adult trip durations were calculated from the time elapsed between departures and arrivals at each site. Feeding rates were calculated for each chick from the mean number of food deliveries per hour.

All statistical analyses were performed using SigmaStat (v. 2.0, Jandel Scientific Software). Differences in attendance patterns were tested with Kruskal-Wallis analysis of variance (ANOVA) on ranks. Correlations with time were tested by Pearson Product Moment Correlations. All means are reported ± 1 s.e.

RESULTS

Patterns of adult attendance at nest sites showed striking differences between colonies. Nest sites at Chisik Island were rarely occupied by more than one adult. Overall mean attendance at Chisik Island was 65.44 ± 0.59 bird-minutes ($n = 70$), while at Gull Island was 75.41 ± 1.65 bird-minutes ($n = 56$). Guillemots breeding at Gull Island spent significantly more time at their nest sites than those at Chisik Island(Kruskal-Wallis ANOVA, $p = <0.001$) (Fig. 1).

Mean daily attendance at Gull Island varied significantly over the season (Kruskal-Wallis ANOVA, $p = <0.001$) and decreased as the season progressed ($r^2 = -0.303, p = 0.023$). The same patterns were observed at Chisik Island. Attendance varied significantly (Kruskal-Wallis ANOVA, $p = 0.005$) and decreased as the season progressed ($r^2 = -0.346, p = 0.003$). Attendance at Gull Island during the late chick-rearing period dropped sharply. Mean attendance at Gull Island at the end of the season was not significantly different from daily values at Chisik Island throughout the season.

Attendance at Gull Island during incubation and early chick-rearing was higher and more variable in the latter half of the day (Fig. 2). Mean hourly attendance was positively correlated with time of day ($r^2 = 0.445, p = <0.001$, differences in means n.s.). In the late chick-rearing stage, the diurnal attendance pattern at Gull Island resembled those at Chisik Island throughout the season. Hourly mean values did not vary significantly at Chisik Island and tended to decrease with time of day (r^2 = -0.332, p = 0.005).

We detected no significant differences between chick feeding rates or trip durations at each island. Chicks at Gull Island were fed 0.34 ± 0.02 fish per hour (n = 13 nests) while those at Chisik Island were fed 0.26 ± 0.02 fish per hour (n = 16 nests). Guillemots at Gull Island left their nest sites for 120 ± 14.21 minutes per trip (n = 49), while those at Chisik Island left their nest sites for 154 ± 16.04 minutes (n = 55).

DISCUSSION

Investigations of seabirds as indicators of marine resources are growing in scope and number (Burger & Piatt 1990, Cairns 1987, 1992, Hatchwell 1991, Monaghan et al. 1989, 1994, 1996, Springer et al. 1996, Utteley et al. 1994, Williams & Rothery 1990). The non-linear relationships between seabird parameters and prey availability must be described to predict seabird responses to changes in their prey base. Responses vary in time and scale. Population trends may reflect large-scale changes in food supply which have long-term effects on adult survivorship and recruitment. Breeding success can provide a measure of food supply over a single breeding season. However, this parameter will only reflect extremes in food supply in species where adult behavior can ameliorate the effects of changes in prey availability (Burger & Piatt 1990). Adult behavior, measured in attendance at the colony and activity at sea, can reflect daily changes in prey availability and provide a more sensitive measure of current foraging conditions (Burger and Piatt 1990, Cairns 1987).

We are currently investigating forage fish abundance in lower Cook Inlet, within potential foraging range of birds nesting at Gull and Chisik Islands. Preliminary results suggest more prey is available to birds from Gull Island than from Chisik Island. Differences in forage fish abundance were found in mid-water trawls conducted on targets identified on acoustic surveys

[Gull: 345.3 fish/set (n = 16); Chisik: 92.0 fish/set (n = 6)]. Beach seines showed similar patterns [Gull: 511 fish/set (n = 238); Chisik: 33 fish/set (n = 30)]. Hydro-acoustic surveys indicated that relative biomass was approximately an order of magnitude greater around Gull Island than around Chisik Island (J.F. Piatt, in prep). These differences have been observed over two years (1995, 1996) and are consistent with the seabird population changes observed in each area.

We predicted correctly that Guillemots nesting in the declining colony at Chisik Island would reflect food stress by minimizing time spent at the colony. Rarely did more than one adult Guillemot attend each nest-site at Chisik Island. In contrast, during incubation and chick-rearing both members of breeding adult pairs at Gull Island spent considerable time together at the nest site, especially during the latter half of the day. Gaston & Nettleship (1982)observed that the attendance of Brünnich's Guillemot (Uria lomvia) also varied with food availability: attendance decreased as distance to prey increased. Uttley et al.(1994)observed both seasonal and annual differences in attendance at a Guillemot colony during two years of varying food supply. Off-duty birds spent more time at the colony in the year of greater prey abundance.

Although time spent at the colony is not a direct (inverse) measure of foraging effort, it is a direct measure of time not devoted to foraging. Our data suggest Guillemots nesting at Gull Island devoted less time to foraging than those at Chisik Island. Guillemots at Gull Island appear to be less stressed and have more discretionary time ashore than those at Chisik Island. Attendance in the latter half of the day at Gull Island appeared to be "loafing" time, which was redirected to foraging when chick food demands increased.

The decline in attendance through the season at both colonies suggests that energetic demands on the adults increased as they began to provision chicks. However, consistently low daily attendance at Chisik Island suggests the birds were approaching a limit in foraging effort. When chicks were largest and energetic demands on the adults greatest, the attendance pattern at Gull Island dropped to levels resembling patterns at Chisik Island throughout the season. However, Guillemots at Chisik Island were able to maintain similar chick feeding rates to those at Gull Island. Guillemots in Shetland in a year of extremely low prey availability were not able to provision chicks successfully (Uttley et al. 1994). Prey availability was below a threshold limit where increased time spent foraging could not buffer the effects of poor food supply. Food stress was reflected at the colony: attendance, fledging rates, and chick weights were lower than when food supply was higher.

We expected to find differences in adult trip durations between colonies. Two reasons may have contributed to the lack of significant difference: (1) Sample sizes may have been too small to detect differences; or (2) activity budgets at sea may have differed. Guillemots at Gull Island may have spent more time "loafing" away from the colony. We did not investigate activity budgets at sea.

Differences in attendance clearly suggest Guillemots are adjusting their time and activity budgets to reflect food supply and maximize reproductive success (Burger and Piatt 1990). With further confirmation of the correlation between colony attendance and food supply, attendance can serve as a valuable monitoring tool. Attendance is a relatively simple and inexpensive parameter to measure and is sensitive to daily, seasonal, and annual changes in prey availability. Studies of colony attendance may augment or substitute for at-sea research in areas where marine work is prohibitively expensive or logistically impossible.

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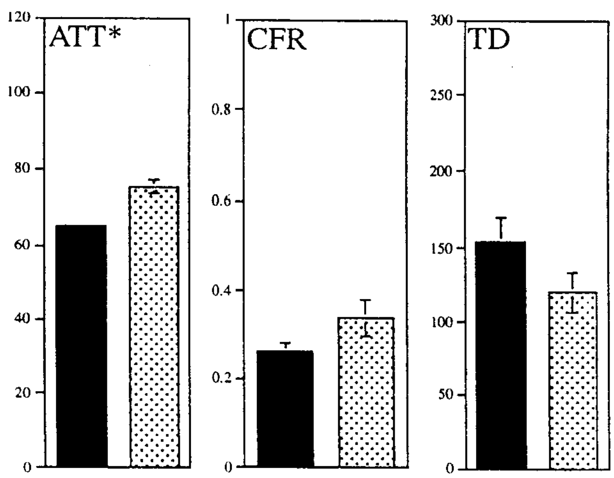
Figure 1. Attendance (ATT) in mean bird-minutes, chick feeding rates (CFR) in mean fish chick^{-1} hour^{-1}, and adult trip durations (TD) in minutes at Chisik Island (solid histogram) and Gull Island (shaded histogram), Alaska, in 1995. Means are shown ± 1 s.e. Significant difference is denoted with an asterisk.

Figure 2. Representative attendance patterns during incubation (17 Jul - 11 Aug), early-chick-rearing (17 Aug), and late chick-rearing (29 Aug) at Chisik and Gull Islands, Alaska, in 1995. Means are shown ± 1 s.e.


ATT*
CFR
TD
120
100
80
60
40
20
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0.8
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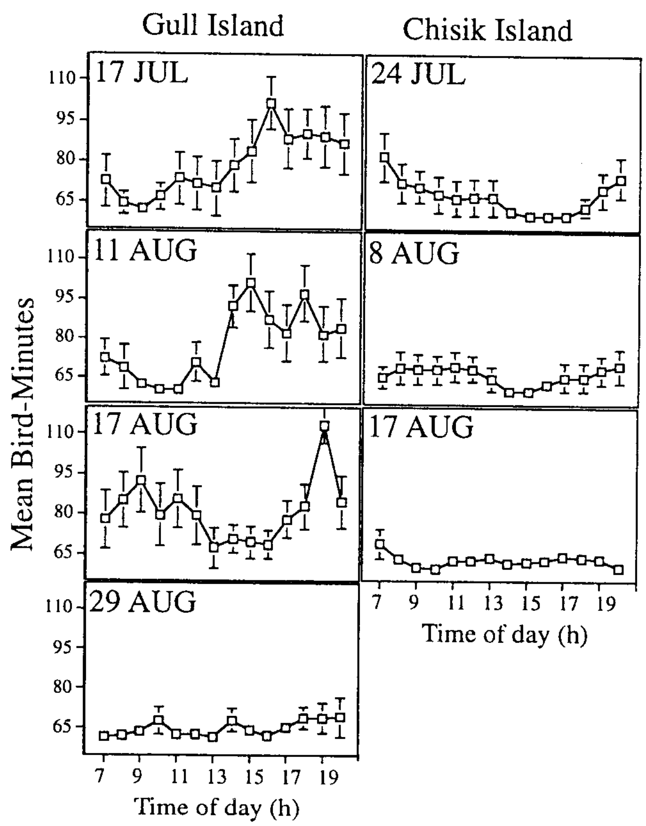

Gull Island
Chisik Island
17 JUL
24 JUL
11 AUG
8 AUG
17 AUG
17 AUG
29 AUG
Mean Bird-Minutes
110
95
80
65
7 9 11 13 15 17 19
Time of day (h)

Breeding Biology and Feeding Ecology of Pigeon Guillemots at Kachemak Bay, Alaska, in 1996

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Abstract

We studied the breeding biology and chick diet of pigeon guillemots *Cepphus columba* nesting in Kachemak Bay, Alaska, in summer 1996, while simultaneously assessing the availability of forage fish around study colonies using beach seines and bottom trawls. Average breeding success was 0.56 chicks fledged per nest. Productivity was higher in areas where the diet included pacific sandlance *Ammodytes hexapterus*, but nest predation may have been more important than diet in determining reproductive success. Nest abandonment during incubation was also an important influence on reproductive success. Average growth was 17.4 g/d for chicks age 8-18 days. The average mass of 30 day old chicks (± 1 day) was 395.7 g. Non-schooling benthic fish made up 57% of chick diet, based on visual observations. Sandlance ranged from 45% to 0% of the diet at different colonies. Breeding adults rested more during chick provisioning in areas where sandlance were available. Beach seines were useful in assessing near shore forage fish communities, and our bottom trawl data established a baseline for monitoring benthic fish populations around guillemot colonies. We began color-banding chicks to collect data on annual survival and recruitment, and began a guillemot population-monitoring program based on repetitive colony counts.

Introduction

The Pigeon Guillemot (*Cepphus columba*) is a small crevice-nesting seabird of the family Alcidae. Guillemots may lay either one or two egg clutches, and their nests may be aggregated into small colonies or widely dispersed. Guillemots forage near shore on benthic and schooling fish within a few kilometers of their nests (Drent 1965).

Six hundred pigeon guillemot carcasses were recovered in Prince William Sound after the Exxon Valdez oil spill (EVOS), and this probably represents a small fraction of the total killed by the spill (Hayes 1995; Piatt and Ford 1996). Attempts to understand the effects of the spill on guillemot populations are complicated because these populations may have already been declining at the time of the spill (Oakley and Kuletz 1996). Populations may have declined in response to long term changes in forage fish populations throughout the Gulf of Alaska (Piatt and Anderson, 1996). Recent research on pigeon guillemots in Alaska has focused on how changes in forage fish populations may have affected guillemot populations.

We examined the breeding biology of guillemots nesting in Kachemak Bay, Alaska while studying aspects of their feeding ecology and the abundance of prey in their foraging areas. Chick diet was determined by visual observations and by collecting fish that were delivered to nests by adults. Forage fish populations were assessed with minnow traps, beach seines, and bottom trawls. We developed a censusing protocol for the area to assess future population trends, and examined the effect of diet by measuring breeding success and chick growth rates. In order to assess the behavioral response of guillemots to variable forage fish populations, we measured colony attendance, breeding phenology, chick provisioning rates, and adult time budgets.

Although nesting guillemots were studied over a large area in Kachemak Bay, data on chick diet and provisioning rates were obtained at three colonies: Moosehead Point, Yukon Island, and Seldovia Bay (Fig. 1). Since guillemots at these three sites have different diets, comparisons of the effects of different foraging regimes are possible from a single year's data. Guillemots in Kachemak Bay were also the subject of a University of Alaska, Fairbanks study in 1994 and 1995 (Prichard

1996). Most of the colonies and nest sites that we followed were located during the course of that study, and additional comparisons with data from that study are presented in Appendix 1.

Methods

Study Area

Kachemak Bay is located in south-central Alaska, on the eastern shore of lower Cook Inlet. The southern shore of the bay is bordered by mountains and glaciers, and this rugged coastline is characterized by cliffs and rocky headlands which provide suitable nesting habitat for pigeon guillemots. We studied guillemots from Seldovia Bay in the west to Mallard Bay in the east (Fig. 1). Our three main study areas were chosen because they offered relatively accessible nest sites, and locations where we could observe provisioning at several nests simultaneously. The nests that we studied at Seldovia Bay were all within 100 meters of each other. Growth data for the Yukon Island colony all came from nests within one kilometer of each other. We included data on clutch size and egg survival from nearby Hesketh Island in our analysis of productivity at Yukon, since the two groups are close and have had similar diets in past years (Prichard 1996). We included nests in China Poot Bay with our analysis of Moosehead Point birds because we observed that breeding adults from both colonies forage in the same area.

Population Monitoring

We counted guillemots along the south shore of Kachemak Bay between Seldovia Bay and Bear Cove from during 8-10 June, 1996, following the methods of Sanger and Cody (1996). Sadie Cove and Tutka Bay were excluded from the survey because of time constraints and the low numbers of guillemots observed in these bays in earlier years. We surveyed guillemots along the coast, using a small skiff traveling at 4-8 knots approximately 50m from shore. All guillemots on land and within 100 meters of shore were counted. This one-time survey was used to compare with data collected by Prichard (1996) in 1995.

We also conducted repetitive colony counts during the incubation period (31 May - 9 July). Standard census zones (n= 26) were established around colonies from Mallard Bay in the east to roughly two nautical miles west of Pt. Naskowhak in the west. We counted guillemots on land and within 100 meters of shore in these zones. Counts were taken either within two and a half hours of a morning high tide or within one and a half hours of an afternoon high tide, when attendance is known to peak (Prichard 1996). Between six and nine replicate counts were made for each area.

Banding

All chicks that survived to age 25 days were banded with a steel U.S.F.W.S. band on the right leg. These chicks were also banded with a brown plastic color band above the steel band to mark their cohort year, and a unique color band combination on the left leg.

Productivity and Phenology

During incubation (May and early June) we observed guillemot colonies during high tide to locate active nest sites. In order to minimize disturbance and nest abandonment, we visited nests only once during incubation to confirm that they were active. Nests were generally accessed by rappelling from the cliff top. Regular nest checks were begun in late June, when we expected the first eggs to begin hatching. We attempted to visit nests every five days throughout the chick rearing period to assess their status.

Because we began following most nests just before hatching, we necessarily missed nests that failed early in the incubation stage, and therefore our productivity estimates could be biased. To account for this bias, we employed the Mayfield method to estimate productivity (Johnson 1979). This method compares the number of eggs lost with the number of days that eggs have been exposed to risk to calculate a daily survival rate (DSR) using the following formula:

$$DSR = 1 - (\text{Number of Losses} / \text{Number of Exposure Days})$$

The chance of an egg surviving incubation was calculated as:

$$\text{Chance of Survival} = DSR^{\text{length of incubation (days)}}$$

We used 31 days as the standard incubation period for our calculations.

Productivity was estimated as the product of three variables: the chance of an egg surviving incubation, the chance that a surviving egg would hatch, and the chance of a chick surviving to fledge. We considered any bird that was missing from the nest after age 30 days to have fledged unless there was evidence of predation. We did not use the Mayfield Method to calculate nestling survival because we discovered all but one of the nests in this study before eggs had hatched.

The chance of an egg hatching was estimated by dividing the number of eggs that survived incubation but failed to hatch by the total number of eggs that survived incubation. Eggs that failed to hatch were considered exposed to risk a maximum of 31 days for purposes of the Mayfield Method. If one egg in a clutch failed to hatch it was considered exposed to risk until two days after the other egg hatched.

Growth Rates

We weighed and measured chicks every five days, and known-age birds that survived to fledge were also weighed at 30 days (± one day) to obtain a standard measurement of peak nestling mass. Chicks were weighed with 100g, 500g, or 1kg Pesola scales. We also measured flattened wing chord and the length of the tenth primary from its emergence from the skin to the tip, excluding down.

Growth rates at different colonies were compared using three methods. The first was to compare growth rates during the linear phase of chick growth, 8-18 days (Koelink 1972). Growth rates during this period were calculated for every nestling as the slope of the least squares fit of the regression of mass on age.

Growth rates were also compared by considering mass as a function of wing chord during the period that these two variables share a linear relationship (35mm - 140 mm). Rates for each chick were again calculated as the slope of the least-squares regression line. This method allows us to use more data than the first because unknown-age chicks can be used, and more measurements are used from each chick.

It is possible to linearize the relationship between mass and wing chord for the entire nestling period by comparing the square root of mass with the square root of the natural log of wing chord (Prichard 1996; Roby et al 1995). We used the resulting slope of mass on wing chord as the third method for assessing growth rates. This method allows the use of all growth data.

No measurements were made of adults.

Chick Diet and Provisioning Rates

When provisioning their chicks, pigeon guillemots carry fish singly in their bills, and often spend long periods of time on the water in front of the colony before delivering to the nest. We observed guillemots provisioning their chicks from land (Moosehead Point) and anchored skiffs (Seldovia Bay and Yukon Island). Using binoculars and a spotting scope, we identified fish to the lowest possible taxonomic level as they were being carried by birds, and estimated prey size to the nearest half bill length. For each nest we recorded delivery time and the time elapsed between arrival on the water in front of the colony and delivery. Delivery rates were calculated for nests containing chicks aged 8 to 30 days. We observed provisioning either all day (0600-2200) or in eight hour blocks starting at 0600 or 1400. Additionally, we attempted to identify fish that we saw during the course of other field activities. Unsuccessful attempts to identify fish were recorded to avoid biasing our diet composition estimates towards easily identified species.

Some fish were collected in order to confirm our visual identifications. We employed two methods: intercepting delivering adults with scraps of mist net placed across nest entrances, and preventing chicks from swallowing fish with choke collars made from pipe cleaners. These fish were sent to Kathy Turco, University of Alaska Fairbanks, for species identifications and proximate body composition analysis. We also collected fish that we found while visiting nests to collect other data.

Prey Assessment

Minnow traps were occasionally placed in shallow water near colonies to capture locally available benthic fish. Additionally, a number of sites near guillemot colonies were sampled with beach seines (47 meter net) throughout the chick rearing period. Salmonids, larval sandlance, and larval sculpins were excluded from our analysis of beach seine data because these three groups are almost entirely absent from guillemot chick diets. Some beach seines were also conducted in 1995. A Pearson Product Moment correlation was used to compare the proportion of sandlance in beach seines with the proportion of sandlance in the diet of chicks at nearby colonies in 1995 (Prichard 1996) and 1996. A similar comparison was made between seasonal changes in diet and catches at Moosehead Point in 1996. Beach seine catches were also used for a qualitative assessment of the availability of various demersal fishes to guillemots.

Benthic fish in deeper water were sampled by bottom trawling on 8-9 August in waters less than 25 meters deep where we suspected that guillemots foraged. We used a 3.05 m plumbstaff beam trawl with a 7 mm square mesh net and a 4 mm mesh codend liner. Each fish was identified to the lowest possible taxonomic level, usually species, and total body length was measured. Representative size classes for analysis were chosen based on the lengths of fish collected at nests: *Lumpenus* spp. 40 - 250 mm; all others, 40 - 150 mm. Raw data from these trawls were extrapolated to obtain an estimate of catch per unit effort (CPUE, number per 1000 m^2 area trawled).

Blood Samples

We took blood samples from known-age chicks as a continuation of a Minerals Management Service project to identify the response of marker proteins to hydrocarbon contamination (L. Duffy, Univ. Alaska Fairbanks). We took blood by puncturing the brachial vein with a hypodermic syringe and letting the blood flow into an eppendorf container. When possible, each chick was bled at age 20, 25, and 30 days. Blood samples were spun down in a centrifuge and the plasma was separated and frozen for later analysis. Most samples were 1 cc, but we took 2 cc from some 30 day old chicks.

Results

Population Monitoring

We counted 467 guillemots during our one-time survey of the southern shore of Kachemak Bay. Five hundred and eighteen individuals were counted in the same area in 1995 (Prichard 1996). Results of our repetitive colony counts are presented in Table 1.

Banding

We banded thirty four chicks. If this effort continues, information on recruitment, survival rates, nest-site tenacity, and colony fidelity may eventually be available.

Phenology

Eggs hatched between 21 June and 23 July, with a median hatch date of 28 June. Based on a 31 day incubation period, we estimate median laying date as 27 May. Since we were visiting nests every five days, no accurate information on fledging dates is available.

Productivity

We were able to determine the fate of sixty nests. Productivity for Kachemak Bay as a whole in 1996 was 0.31 chicks fledged per egg laid. By multiplying by the average clutch size (1.80), we estimate productivity to be 0.56 fledglings per breeding pair. Clutch size did not vary significantly among colonies (ANOVA, $df_{1,59}$, F= 0.963, P= 0.468). Hatch success was 0.49, chick survival was 0.64., and these values varied among different locations (Table 2). Productivity at Moosehead was significantly higher than at Yukon (z-test, z = 1.992, P = 0.046).

Hatch failure and egg predation accounted for roughly two thirds of nest failures (Figure 2). Chick mortality was distributed throughout the nestling period (Figure 3). Moosehead Pt. did better Yukon I. and Seldovia Bay in terms of hatch success (z-test, z = 2.220; P = 0.026) and chick survival (z = 2.364, P = 0.018). Neptune Bay, a productive area in previous years (Prichard 1996), experienced widespread nest abandonment and low overall productivity (0.10 chicks fledged per egg). Nest abandonment was also a cause of low productivity in Seldovia Bay. Of the four chicks that hatched at the colony, two were preyed upon and one died of other causes. Birds in Halibut Cove also fared poorly (0.20 chicks fledged per egg).

Survival was higher in two chick nests (0.69, n = 36 chicks) than in one chick nests (0.20, n = 5 chicks), but the difference was not significant (z test, z = 1.655, P = 0.098).

Growth Rates

The mean growth rate for all chicks in Kachemak Bay during the linear growth phase was 17.36 g/d (s.d.= 5.11, n = 37). Rates for individual colonies differed (Table 3), but an ANOVA detected no significant differences between colonies ($df_{3,25}$, F= 0.761, P = 0.528). A t-test detected no significant difference between the colony with the highest growth rate, Moosehead Point, and all other colonies as a group ($t= 1.262$, $P = 0.219$).

The average slope of mass as a function of wing length during the linear period (35 - 140mm) for all chicks was 2.68 (s.d.= 0.946, n = 34.) The three areas with the largest sample sizes were indistinguishable from each other (Moosehead, Yukon/Seldovia, Kasitsna/Herring, ANOVA, $df_{2,27}$, $F< 0.001$, $P = 1.00$).

The average slope of transformed mass and wing chord data was 30.72 (s.d. = 0.39, n = 49). Again, there was no significant difference between areas (ANOVA, $d.f._{3,39}$, $F= 0.451$, $P = 0.718$).

The mean peak nestling weight was 395.67 g (s.d. = 88.53, n = 15). At Moosehead Point the mean peak was 403.73 g (s.d.= 82.90, n = 11), at Kasitsna Bay it was 434.50 (s.d. = 17.68, n = 2), and on Yukon Island it was 312.50 (s.d.= 152.03, n = 2). There was no significant difference between these colonies (ANOVA, $df_{2,14}$, $F= 1.144$, $P = 0.351$).

Chick Diet

Non-schooling benthic fish accounted for 57% of guillemot diets during our observations (n= 592). The most prevalent benthic fish were gunnels and pricklebacks (Stichaeidae and Pholidae, 35%), sculpins (Cottidae, 6 %), and flatfish (Pleuronectiformes, 6%). Schooling fish, primarily sandlance (*Ammodytes hexapterus*) accounted for 36% of observations. We were unable to identify 6% of the fish we saw. Greenling (Hexagrammidae) accounted for the remaining 1%.

The percentage of various fish species in guillemot diets differed at the three study locations (Figure 5). The proportion of sandlance in the diet was significantly higher at Moosehead Point (45%) than at Yukon Island (0%, z-test, $z= 6.9$, $P< 0.01$) or Seldovia Bay (21%, $z= 3.7$, $P< 0.01$).

Twenty nine fish were collected from nests (Table 4). Since no systematic effort was made to gather samples equally from different areas, and because diet varied so much within Kachemak Bay, no comparison was made between the composition of this collection and our observations.

Adults delivered food to one-chick nests at an average rate of 0.81 fish per hour (s.e = 0.17, n = 6 nests), and to two-chick nests at an average of 0.97 fish an hour (s.e.= 0.15, n = 10 nests). There was no significant difference between one- and two-chick nests, and no significant difference between the three study locations (ANOVA, $df_{2,15}$, $F=0.551$, $P= 0.593$).

Average resting time for each observation period is presented in Figure 9. Birds spent more time on the water with fish towards the end of the day; rest time and time after sunrise were significantly correlated (Pearson correlation, $r^2= 0.115$, $P= 0.032$). Tide also had a significant effect on loaf time (Kruskall-Wallis, $H= 32.691$, $P< 0.001$). Birds rested on the water less during high and ebb tides than they did during low and flood tides. There was also significant geographic variation in resting time (ANOVA, $df_{2,285}$, $F=4.419$, $P= 0.013$). Moosehead Point birds rested an average of 14.87 minutes (s.e.= 1.30, n= 189) and Yukon Island birds an average of 8.12 minutes (s.e.= 1.27, n= 61). The difference is significant (Tukey, $q=4.053$, $P< 0.05$). The average resting time in Seldovia Bay was 10.97 minutes (s.e.= 2.26, n= 36).

Prey Assessment

Beach seine results from 1995 and 1996 are compared in Figure 6. The sites that we seined around Moosehead Pt. were well distributed in the area where we observed local birds foraging, and seine catches could accurately predict chick diet at this colony: the proportion of sandlance in nestling diet and seine catches was significantly correlated through the season (Pearson Product Moment, $r^2=$

0.967, P= 0.033, Figure 7). Sculpins declined from 1995 to 1996 in both seines and chick diet and Moosehead and Yukon. The highest proportions of flatfish in seines and diet both occurred in Seldovia Bay.

Bottom trawls can be replicated in future years and CPUE values used to assess changes in demersal fish populations around guillemot colonies. A comparison of diet and trawl data for Moosehead Point and Yukon Island from this year indicates that guillemots prey on gunnels and pricklebacks more often than sculpins, even though sculpins were more common at our trawl stations (Figure 8). The same pattern was also seen in seine and diet data from Seldovia Bay.

Discussion

Productivity

Predation and nest abandonment were the biggest influences on reproductive success in Kachemak Bay this year. Suspected predators include northwestern crows (*Corvus caurinus*), ravens (*C. corax*), black-billed magpies (*Pica pica*), mink (*Mustela vison*), and river otters (*Lutra canadensis*). Overall breeding success (0.31 chicks fledged per egg) was slightly higher than in 1994 and 1995 (0.19 and 0.25, respectively, Prichard 1996), but this average value conceals large differences among colonies within Kachemak Bay.

Although we observed no egg predation at Neptune Bay, hatching success was estimated at 0.308, largely because of nest abandonment. Nests were visited less often during incubation this year than in previous years, so our activity cannot account for the increase in abandonment.

Moosehead Point birds did significantly better than Yukon birds in terms of hatch success and chick survival, and it is tempting to explain these differences as the result of the presence of high-lipid sandlance in the diet of chicks at the former colony and their absence in the diet at the latter. However, the nests at Moosehead are on much higher cliffs than those on Yukon, and height above the water has been shown to have a significant positive correlation with nesting success (Prichard 1996), so the Moosehead birds may simply be better protected from predation.

Growth Rates

The linear phase growth rate that we observed (17.4 g/day), falls in the middle of the range of reported values from Prince William Sound in 1994 and 1995 (15.7 - 20.3 g/day, Hayes 1995, 1996). Chicks at Moosehead Point on average grew three grams a day faster during this phase than birds at Yukon Island. This difference was not significant (probably because of small sample sizes), but it follows the trend of differences between Moosehead Point and Outer Kachemak Bay observed in 1994 and 1995 (Prichard 1996), and may reflect the presence of sandlance in the diet at Moosehead. Sandlance have the highest lipid content and energy value of all guillemot forage fish in Kachemak Bay (Roby et al, 1995).

Although we were unable to record actual fledging mass, we did weigh chicks at age thirty days as a measure of peak mass. These results will allow for comparisons with other areas and other years in Kachemak Bay.

Chick Diet and Provisioning

There were clear differences between the diets fed to chicks at the three main study locations.

Sandlance were the most common species in the diet of Moosehead Point birds, even though they made up less than half of the diet. Sandlance made up less of a quarter of the diet in Seldovia Bay and were absent at Yukon Island. Gunnels and Pricklebacks were the dominant benthic group in Moosehead and Yukon diets, but were less common than flatfish and sculpins in Seldovia Bay.

Hayes (1996) found that pigeon guillemots in Prince William Sound fail to provision two-chick nests at twice the rate of one-chick nests. Presumably this means that singleton chicks are being fed at an optimal rate, but that both chicks in a two chick nest are not. We found that one-chick and two-chick nests were not provisioned at significantly different rates, which suggests that forage conditions were sub-optimal around all three study colonies.

It has been demonstrated that Common Murres (*Uria alge)* have flexible time budgets that allow breeding birds to respond to changing forage fish availability with changes in time spent foraging (Burger and Piatt 1990). In contrast, Black-legged Kittiwakes (*Rissa tridactyla*) in Cook Inlet have no such flexibility; even when forage fish are plentiful, breeding adults have little or no resting time at the colony (Piatt et al, unpublished data). We measured the time elapsed between a guillemot's arrival on the water in front of the colony and delivery to the nest in an attempt to determine if this resting time was part of a flexible time budget during chick provisioning. If time spent foraging and resting are inversely related and fluctuate in relation to prey availability, then resting time would provide an index of foraging effort and foraging conditions.

Provisioning birds spent significantly more time resting in front of the colony at Moosehead Point than at Yukon Island. This is consistent with observations that Moosehead birds have a ready supply of concentrated schooling fish (sandlance) to feed on, whereas Yukon birds rely on dispersed benthic fish. However, the higher Moosehead value is the result of the very high average resting time (36.67 minutes) recorded on 4 August. If this watch is excluded, there was no significant difference between colonies in resting time (Kruskall-Wallis, $H= 5.15$, $P= 0.08$). In any case, comparisons with data from future breeding seasons should demonstrate whether resting time has any value as an index of foraging effort.

Prey Assessment

The strong correlation between sandlance proportions in seines and chick diets at Moosehead Point suggests that seines can be used to follow seasonal changes in the availability of schooling fish. Seine catches also reflected the decrease of sandlance in the diet at Moosehead from 1995 to 1996 (Appendix). Seines also have some usefulness in measuring benthic fish availability. Beach seines correctly reflected declines in sculpin consumption by guillemots at Moosehead Point and Yukon Island in 1995 and 1996 (Appendix), and the high incidence of flatfish in the diet in Seldovia Bay in 1996.

Bottom trawling is a promising method of sampling benthic fish, since it operates in deeper water further from shore. The trawl stations that we established this year will allow us to monitor benthic fish populations in future years. Data from this year indicate that although sculpins were more common than gunnels and blennies around Moosehead and Yukon (trawl data) and Seldovia (seine data), guillemots fed chicks blennies more often than sculpins at all three colonies. Blennies have a higher energetic value than sculpins (Roby et al, 1995), and guillemots may preferentially seek out these higher quality prey items when foraging for their chicks. It is also possible that sculpins' large heads and spines make them unpalatable prey.

Population Monitoring

The results of our one-time survey of the south shore of Kachemak Bay are slightly lower than those from the 1995 count, but this difference cannot be evaluated statistically. We established a protocol for repetitive colony counts to more accurately monitor population trends. These counts were made at high tide, when colony attendance peaks in Kachemak Bay (Prichard 1996) and they will provide a baseline for future monitoring efforts. Because of the variability in counts, the maximum number of guillemots counted may be a good measure of each colony's population. A comparison of the mean and maximum counts provides an index of colony attendance. Changes in the relationship between these two value could represent changes in colony attendance, and might provide an index of foraging effort and food availability during incubation.

Conclusions and Recommendations

1) Because feeding ecology varies markedly between colonies, Kachemak Bay is an ideal locale to study the interactions between pigeon guillemots and their prey. Future research should concentrate on the three main study colonies in order to increase sample sizes for statistical comparisons. Data on breeding biology and diet have been collected in Kachemak Bay for three consecutive years, providing an excellent baseline for future study. Additionally, prey populations have been assessed around guillemot colonies for the past two years.

2) One-time counts are inadequate to monitor population changes, so we have established a protocol of repetitive colony counts which will allow us to accurately monitor population trends throughout Kachemak Bay on a fine spatial scale. These counts also provide an index of foraging effort during incubation.

3) Differences in breeding biology may be related to diet, as birds with access to sandlance were more successful then those relying on benthic fish. However, predation is also an important factor influencing reproductive success, and more study is needed to distinguish the effects of diet and predation. Chick growth rates were not significantly different between colonies, but larger sample sizes may help elucidate the relationship between diet and nestling growth.

4) Beach seines and bottom trawling are both useful in assessing prey abundance, though both methods have limitations. Future research should increase sampling effort around the three main study areas and synchronize sampling with guillemot diet watches. Alternate methods such as scuba and video may allow prey populations to be accurately quantified.

5) Foraging effort during incubation and time budgets during chick provisioning may provide useful indices of the predator/prey relationship. Birds at Moosehead Point spent more time at rest during chick provisioning than birds at the other study sites, and this may reflect the local abundance of sandlance. Better comparisons of time budgets at the three key study areas could be obtained by establishing simultaneous all-day watches at the three sites. This would require the efforts of at least six observers. Better data on time budgets could be obtained if we marked wing patches to identify individual birds. Radio telemetry would provide data on foraging effort and would allow us to

determine the foraging range of birds at the three study areas and to focus our prey sampling efforts in these areas.

6) The banding program that we began this year will eventually allow us to monitor annual adult survival and chick recruitment, and to compare these population parameters in the context of different foraging regimes.

Acknowledgments

This study was made possible by logistical support and funding from the EVOS trustees, the Institute of Marine Science and Institute of Arctic Biology (University of Alaska), and the Minerals Management Service. Many individuals also contributed their time and skill: Mike and Connie Gaegel kindly shared the lessons of their years living on Kachemak Bay. Martin Robards led beach seining efforts around colonies. Tom Van Pelt dealt with logistics in Anchorage, and Bradford Keitt helped with logistical support in the field. Stephani Zador helped with colony counts and made many helpful suggestions on field protocol. Alissa Abookire helped with bottom trawls and fish identification. Dan Roby provided advice and guidance during the field season, and D. Lindsey Hayes shared his experience with pigeon guillemots. Pam Seiser and Cynthia Restrepo assisted with blood collection and most every other kind of field work. A large group of volunteers also helped out in the field: Jared Figurski, Anne Meckstroth, Mark Kosmerl, Holly Ober, Dave Black, Alice Chapman, and Kali Mangel. And finally, our thanks to Alex Prichard for the generous contribution of his knowledge of Kachemak Bay guillemots.

Appendix: Inter-annual Comparisons

Introduction

Pigeon guillemots in Kachemak Bay were the subject of a Minerals Management Service study during the summers of 1994 and 1995 (Prichard 1996). Although that study concentrated on the response of blood marker proteins to hydrocarbon exposure in an attempt to develop guillemots as a bio-indicator species for marine oil pollution, data on feeding ecology and reproductive success were also collected. These data included chick diet composition and provisioning rates, chick growth rates, and productivity estimates. Reliable diet data aren't available for 1994, so this comparison will concentrate on results from the 1995 and 1996 field seasons.

Results and Discussion

Productivity

Estimates of breeding success in Kachemak Bay as a whole were 0.19 chicks fledged per egg in 1994, 0.25 in 1995, and 0.31 in 1996 (Figure 10). These averaged values conceal dramatic changes in productivity at individual colonies (Figures 11-14). Productivity at Moosehead Pt. increased from 0.18 fledglings/egg in 1995 to 0.54 fledglings/egg in 1996 (z-test, $z= 2.963$; $P= 0.003$). This increase is probably the result of decreased nest abandonment during incubation and decreased nest predation. Productivity values were not significantly different in nests from Yukon I. to Seldovia Bay (1995= 0.16, 1996= 0.21, $z= 0.254$; $P= 0.800$). Productivity declined at Halibut Cove (1995= 0.51, 1996= 0.20, $z= 1.499$; $P= 0.134$) because of increased egg predation and nest abandonment. Breeding success also declined at Neptune Bay (1995= 0.60, 1996= 0.08, $z= 2.566$; $P= 0.010$). Fifty seven percent of the nests at this colony were apparently abandoned during incubation in 1996.

Chick Growth

Because of low productivity at Halibut Cove and Neptune Bay in 1996, sample sizes were adequate for statistical inter-annual comparisons of chick growth only at Yukon I. and Moosehead Pt. (Figure 15). The mean slope of transformed mass and wing chord data at Moosehead Pt. declined from 31.06 in 1995 (s.e.= 0.64, n= 17) to 28.67 in 1996 (s.e.= 1.02, n= 15, $t= -2.04$, $P=0.05$). There were no significant differences in outer Kachemak Bay (Yukon I.-Seldovia Bay).

Chick Diet

The results of diet watches in 1995 and 1996 are presented in Figure 16. The most obvious difference between years was the sharp decline in sandlance in the Moosehead Point diet, from 83% of observations to 45% (z test, $z= 8.832$, $P< 0.001$). This decline was accompanied by an increased reliance on gunnels and pricklebacks, and the appearance in the diet of significant numbers of sculpins. This shift from sandlance to benthic fish represents a decline in the lipid content and energy density of prey items being fed to chicks (Roby et al, 1995).

Inter-annual variation at Yukon Island probably has more to do with the way data were collected than differences in what chicks were being fed. In 1994 diet observations were generally divided into four categories: sandlance, gunnel/prickleback, sculpin, and flatfish. In 1995 we made a more concerted effort to identify different taxonomic groups in the diet, and found that fish that probably would have been placed in the gunnel/prickleback category in 1994 included gadids, ronquils, searchers, and greenlings. Therefore we placed gunnel/prickleback observations from 1994 in the unidentified demersal fish category. The only apparent change in chick diet between the two years was the decline in sculpins, from 24% to 6% (z-test, $z = 2.565$; $P = 0.010$).

Conclusions

1) Low predation pressure was responsible for an increase in productivity at Moosehead Pt. in 1996. Nest abandonment during incubation was a significant factor in reproductive failure elsewhere in Kachemak Bay. Future research on foraging effort and prey availability during incubation may elucidate the relationship between food availability and nest abandonment.

2) Chicks grew more slowly when sandlance were less prevalent in the diet at Moosehead Pt. At Yukon I., where there was no apparent change in the energetic quality of available forage fish, there was also no change in chick growth rates.

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Table 1. Pigeon guillemot repetitive colony count results, Kachemak Bay, summer 1996.

Census Area	Maximum	Mean	SE	n (counts)
Moosehead Pt.				
China Poot	14	7.86	1.40	7
Motherload	51	35.86	4.53	7
N. Moosehead	19	11.00	2.13	7
Peterson Side	47	41.29	1.92	7
Yukon I.				
Hesketh I.	41	29.88	4.34	8
S.W. Yukon	11	3.63	1.05	8
Yukon I.	26	12.25	3.13	8
Sub-Yukon	14	2.75	1.68	8
Seldovia Bay				
Naskowhak Pt.	16	10.75	1.15	8
Lemon Cliffs	4	3.33	0.33	6
Gray Cliffs	16	9.25	1.47	8
Seldovia Bay	34	26.25	1.49	8
Sub-Seldovia	20	12.67	1.84	9
Seldovia Pt.	45	28.89	4.54	9
Other Areas (East to West)				
Mallard Bay	16	13.14	0.94	7
Goshawk	5	2.88	0.44	8
Triangle Rock	18	10.88	1.55	8
Sea Cliff	7	3.88	0.93	8
Ismailof	7	3.25	1.01	8
Peterson Pt.	9	2.50	0.96	8
E. Peterson	8	5.13	0.81	8
The Nose	8	5.75	0.67	8
N. Neptune	43	30.17	2.90	6
S. Neptune	14	8.43	1.29	7
Kasitsna Cliffs	15	7.44	1.30	9
Guillemot Meadows	50	33.88	3.30	8

Table 2. Pigeon guillemot productivity in Kachemak Bay, 1996. Hatch success is based on Mayfield estimates of egg survival and the percentage of surviving eggs that hatched. Chick survival rates were obtained by the traditional cohort method.

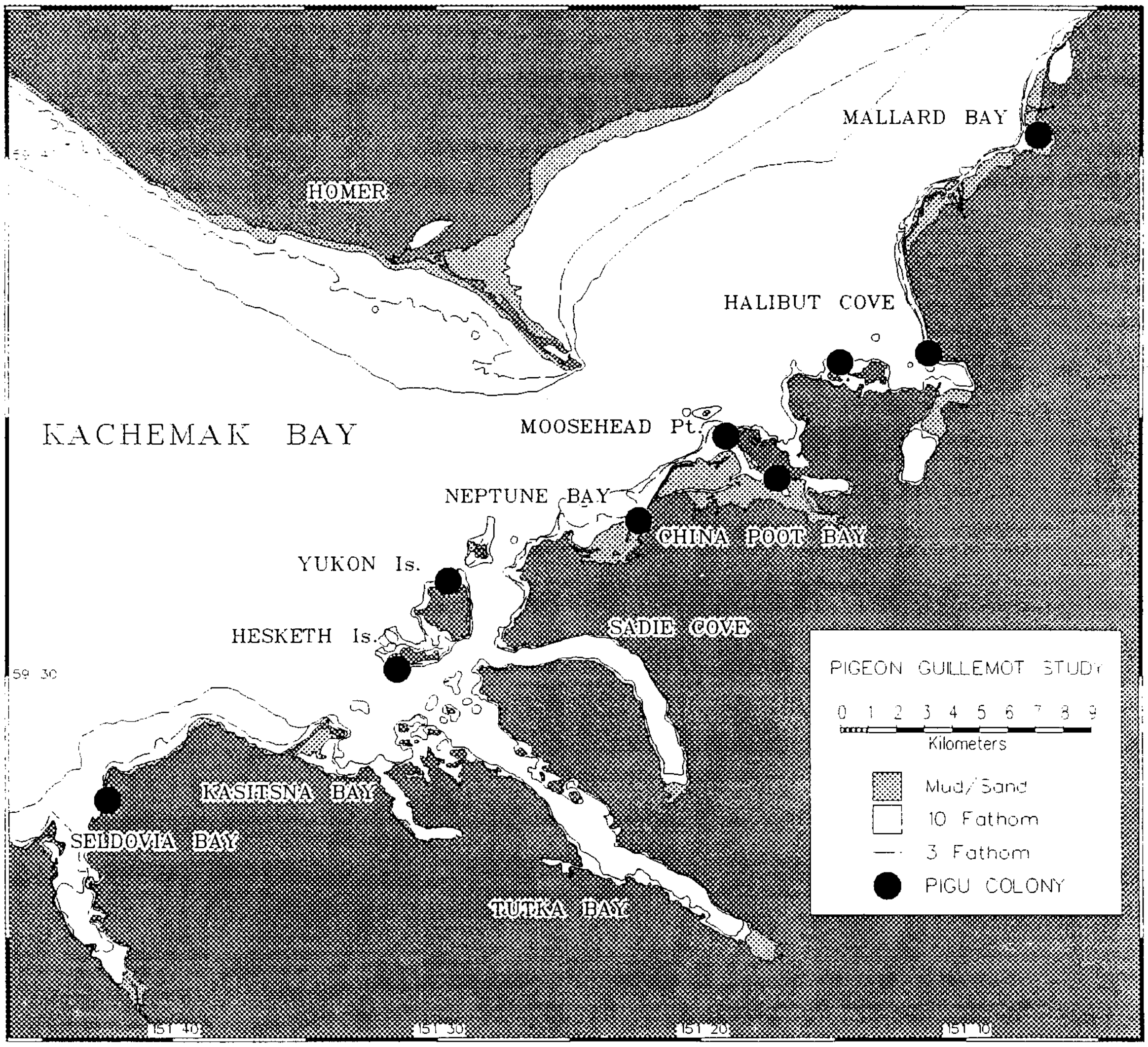
Colony	Mean Clutch Size (SE)	n (nests)	Hatch Success	n (eggs)	Chick Survival	n (chicks)	Chicks Fledged per Egg	Chicks Fledged per Nest
Moosehead Pt.	1.84 (0.09)	19	0.64	29	0.85	20	0.54	1.00
Neptune Bay	1.86 (0.14)	7	0.31	13	0.25	4	0.08	0.14
Yukon I., Hesketh I.	1.91 (0.09)	11	0.35	18	0.33	6	0.12	0.22
Kasitsna Bay	1.50 (0.50)	2	1.00	3	0.67	3	0.67	1.00
Herring Is.	1.67 (0.33)	3	0.41	5	0.75	4	0.31	0.51
Halibut Cove	1.67 (0.17)	9	0.26	15	0.80	5	0.20	0.34
Seldovia Bay	2.00 (0.00)	5	0.27	12	0.33	3	0.09	0.18
Mallard Bay	1.50 (0.29)	4	0.80	7	0.00	2	0.00	0.00
Kachemak Bay	1.80 (0.05)	60	0.49	104	0.64	47	0.31	0.56

Table 3. Three methods of assessing growth rates of pigeon guillemot nestlings in Kachemak Bay, 1996. The linear phase method relies on known age birds, which results in a smaller sample size.

	Linear Rate (g/day)			Transformed Slope			Slope of Mass on Wing Length (35-140 mm)		
Colony	Mean	SE	n	Mean	SE	n	Mean	SE	n
Moosehead Pt.	18.43	1.45	15	28.67	1.02	15	2.68	0.21	19
Neptune Bay				30.89	2.34	2	3.43	0.56	2
Yukon Island	15.42	1.98	5	29.14	2.64	5	2.86	0.67	3
Seldovia Bay				35.98	4.19	2	2.58		1
Kasitsna Bay	13.63	2.38	2	28.84	1.75	3	3.27	0.12	2
Herring Is.	17.43	3.05	3	28.00	1.20	3	2.81	0.16	3
Halibut Cove				32.71	0.31	4	3.80		1
Mallard Bay							1.64		1
Kachemak Bay	17.36	0.84	25	29.60	0.67	34	2.68	0.17	32

Table 4. Taxa and standard length of fish collected from pigeon guillemot nests, Kachemak Bay, summer 1996

Taxon	Standard Length (mm)
Flatfish	107
Flatfish	242
Flatfish	107
Flatfish	93
Flatfish	97
Flatfish	97
Flatfish	99
Gunnel	
Gunnel	
Gunnel	188
Gunnel	145
Gunnel	157
Gunnel	102
Gunnel	145
Gunnel	188
Lumpenus sp.	221
Lumpenus sp.	155
Lumpenus sp.	242
Lumpenus sp.	243
Ronquil/Searcher	136
Ronquil/Searcher	
Ronquil/Searcher	106
Ronquil/Searcher	152
Ronquil/Searcher	85
Sandlance	134
Sandlance	134
Sculpin	102
Sculpin	102
Sculpin	107



KACHEMAK BAY
HOMER
MALLARD BAY
HALIBUT COVE
MOOSEHEAD Pt.
NEPTUNE BAY
CHINA POOT BAY
YUKON Is.
HESKETH Is.
SADIE COVE
KASITSNA BAY
SELDOVIA BAY
TUTKA BAY
59 30
151 40
151 30
151 20
151 10
PIGEON GUILLEMOT STUDY
0 1 2 3 4 5 6 7 8 9
Kilometers
Mud/Sand
10 Fathom
3 Fathom
PIGU COLONY

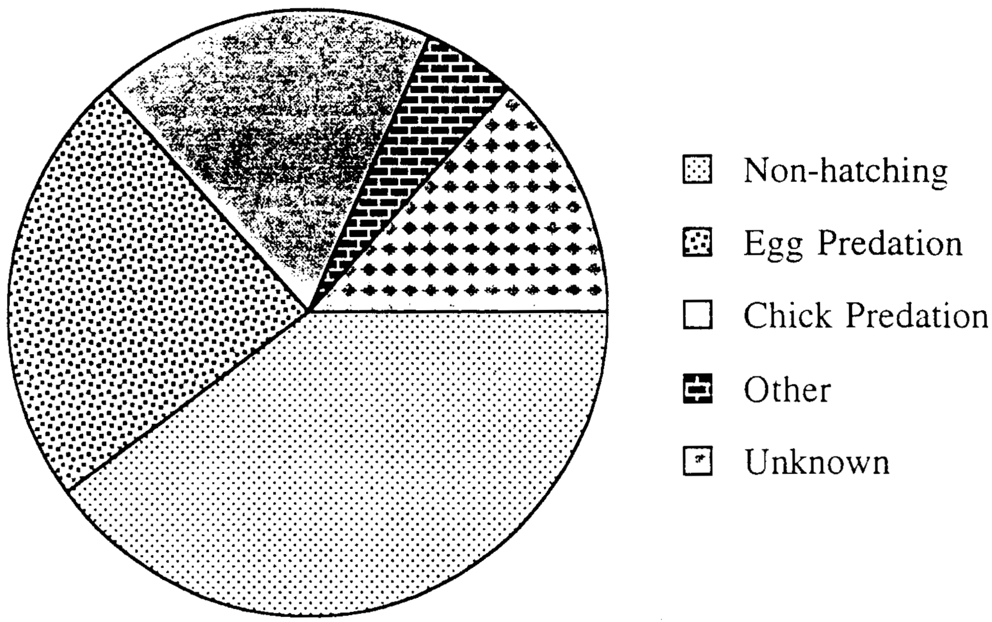


Figure 2. Causes of failure for pigeon guillemot nests in Kachemak Bay, 1996 (n= 63 eggs and chicks).

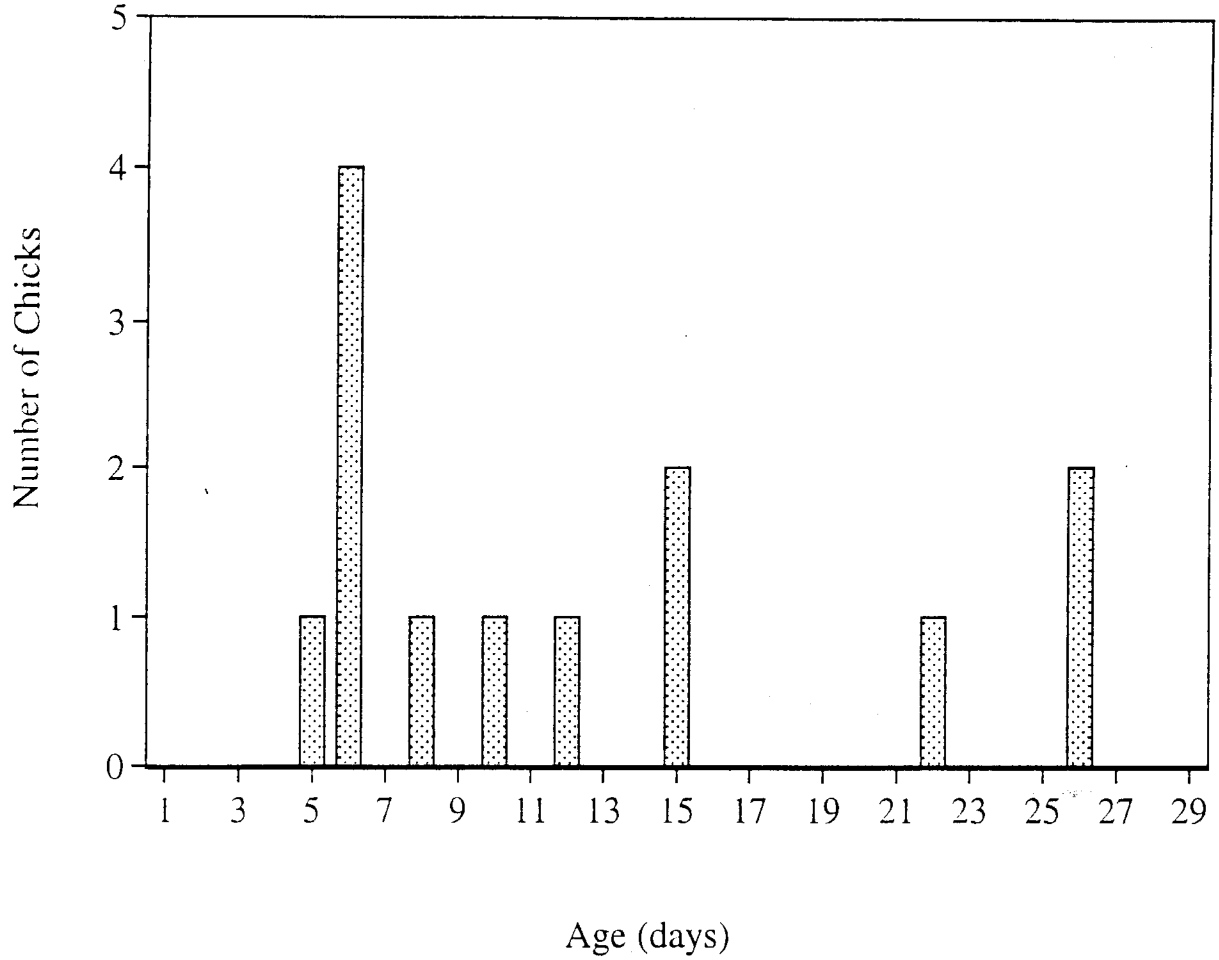


Figure 3. Pigeon guillemot chick mortality by age, Kachemak Bay 1996.

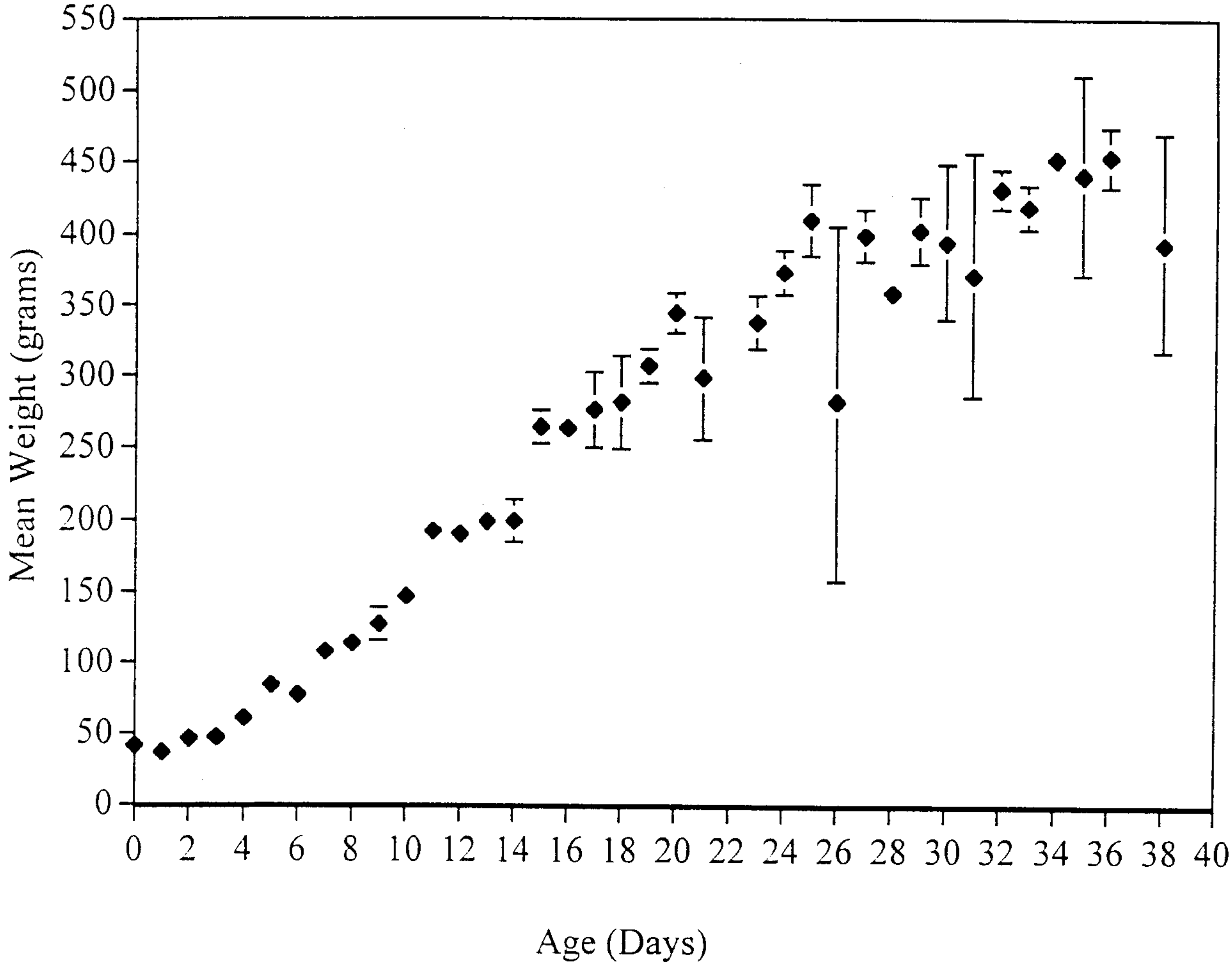


Figure 4. Growth curve of known-age pigeon guillemot nestlings in Kachemak Bay, summer 1996. Error bars equal one standard error.

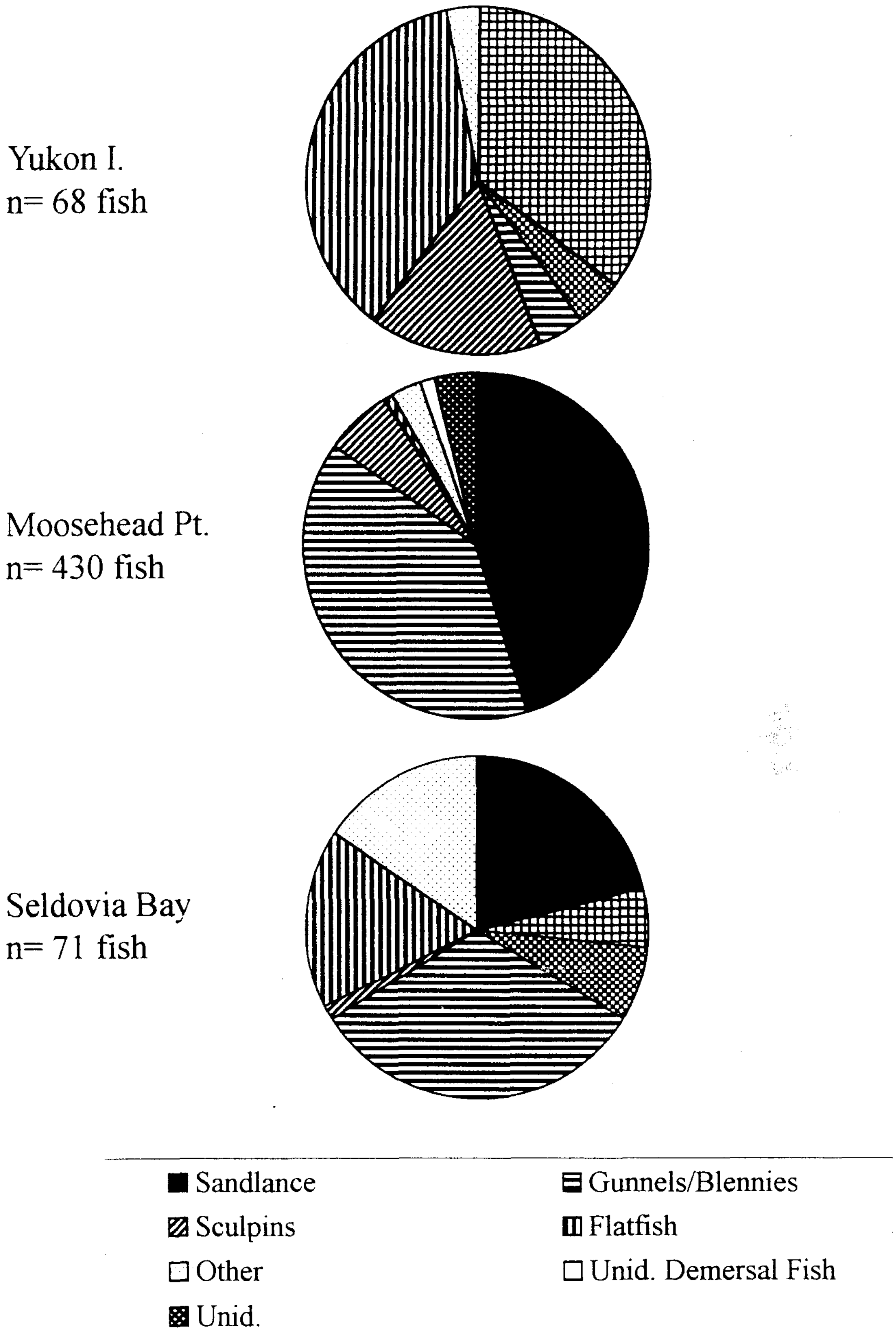


Figure 5. Pigeon guillemot nestling diet in Kachemak Bay, summer 1996.

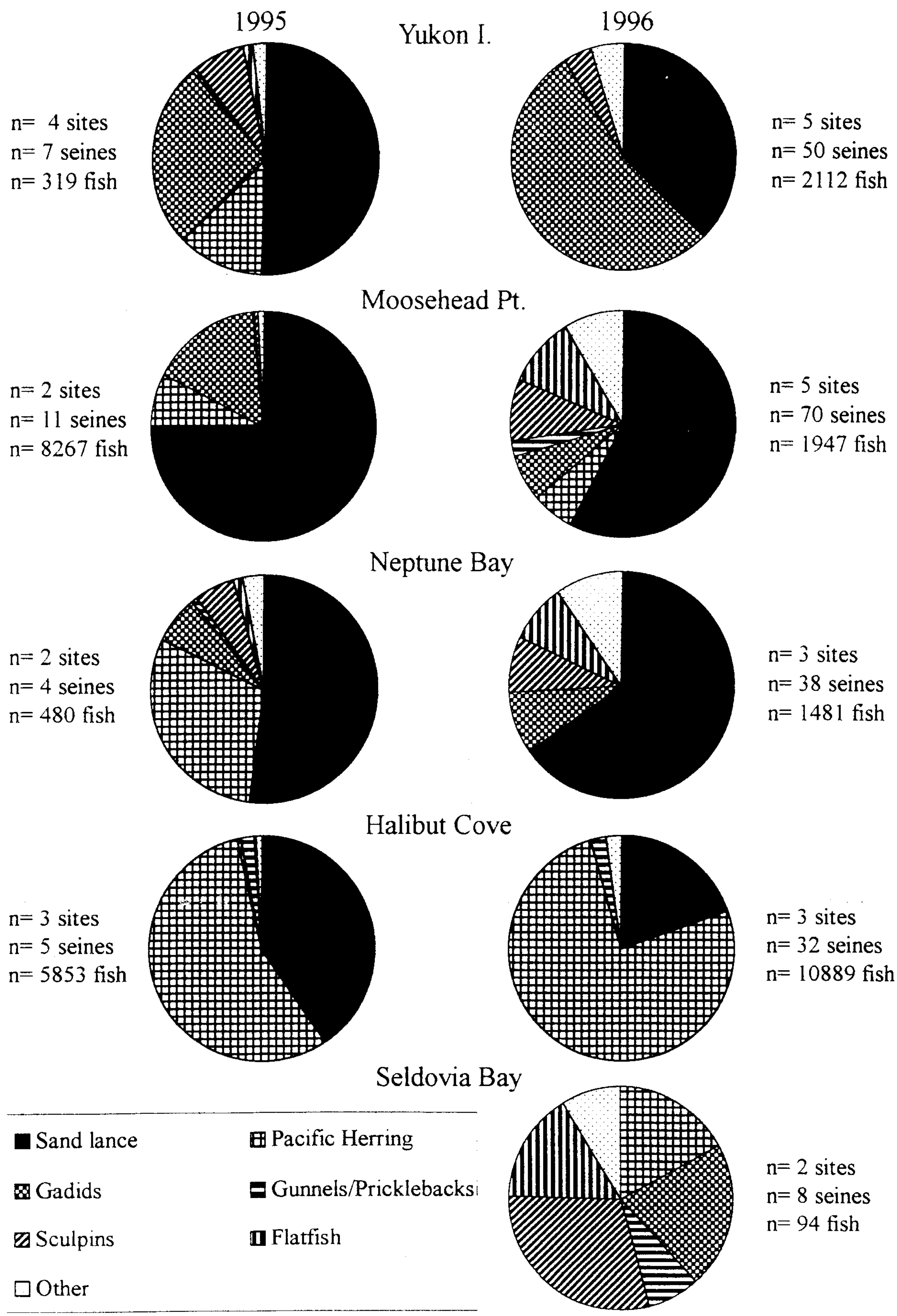


Figure 6. Beach seine results around Kachemak Bay pigeon guillemot colonies, 1995-1996.

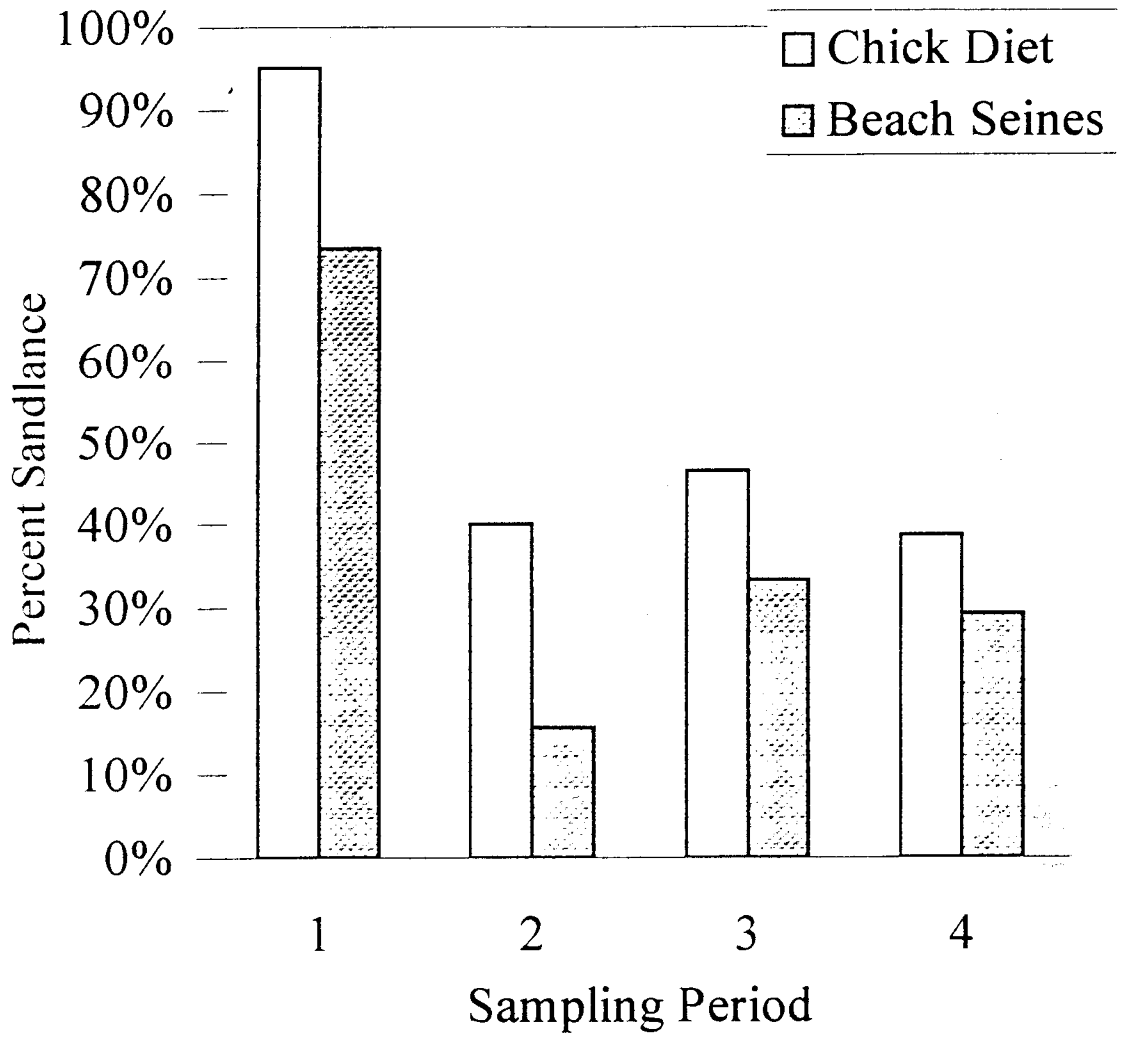


Figure 7. Sandlance in pigeon guillemot nestling diet at Moosehead Pt. and nearby beach seines, Kachemak Bay, summer 1996. Sampling periods: 1= 2-6 July (n= 19 chick meals, n= 4 seines, n= 328 fish caught), 2= 22-25 July (n= 115 meals, n= 7 seines, n= 64 fish), 3= 31 July - 4 August (n= 97 meals, n= 4 seines, n= 6 fish), 4= 10-12 August (n= 43 meals, n= 12 seines, n= 359 fish).

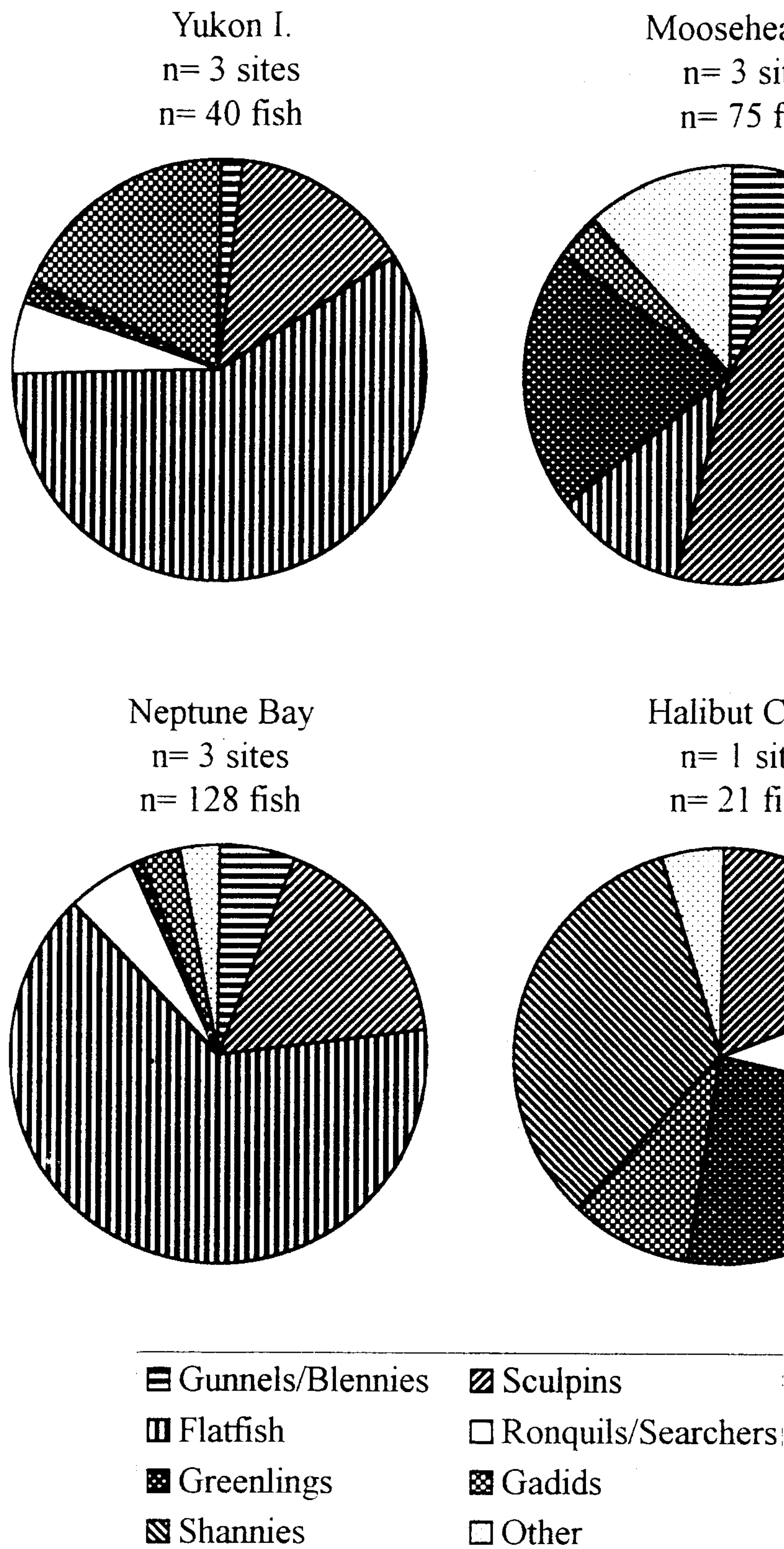


Figure 8. Bottom trawls around pigeon guillemot colonies in Kachemak Bay, 8-9 August, 1996. Includes *Lumpenus* spp. 40-250 mm total length, all other fish 40-150 mm total length.

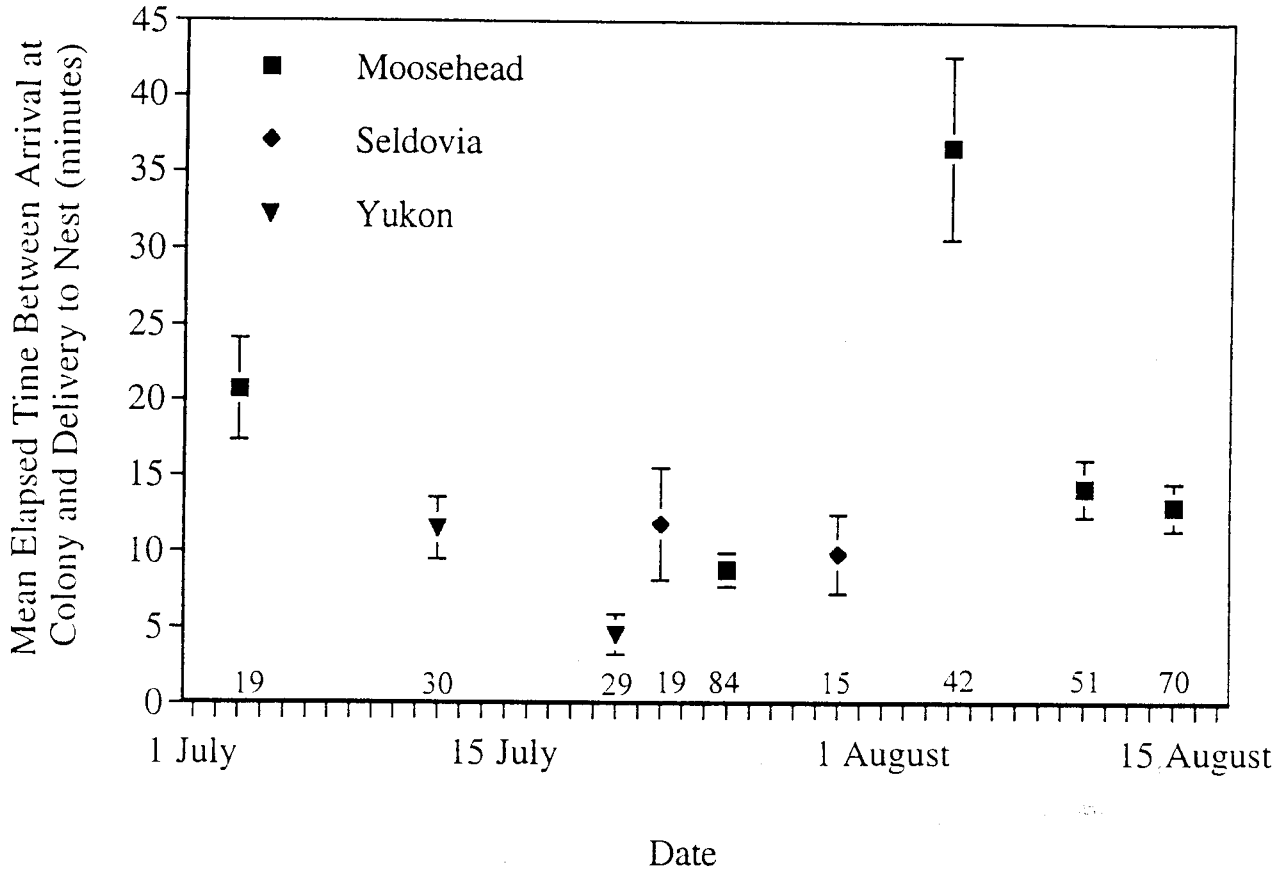


Figure 9. Pigeon Guillemot resting time during chick provisioning, Kachemak Bay, 1996. Error bars are one standard error, and sample sizes (number of deliveries observed) are shown along the x axis.

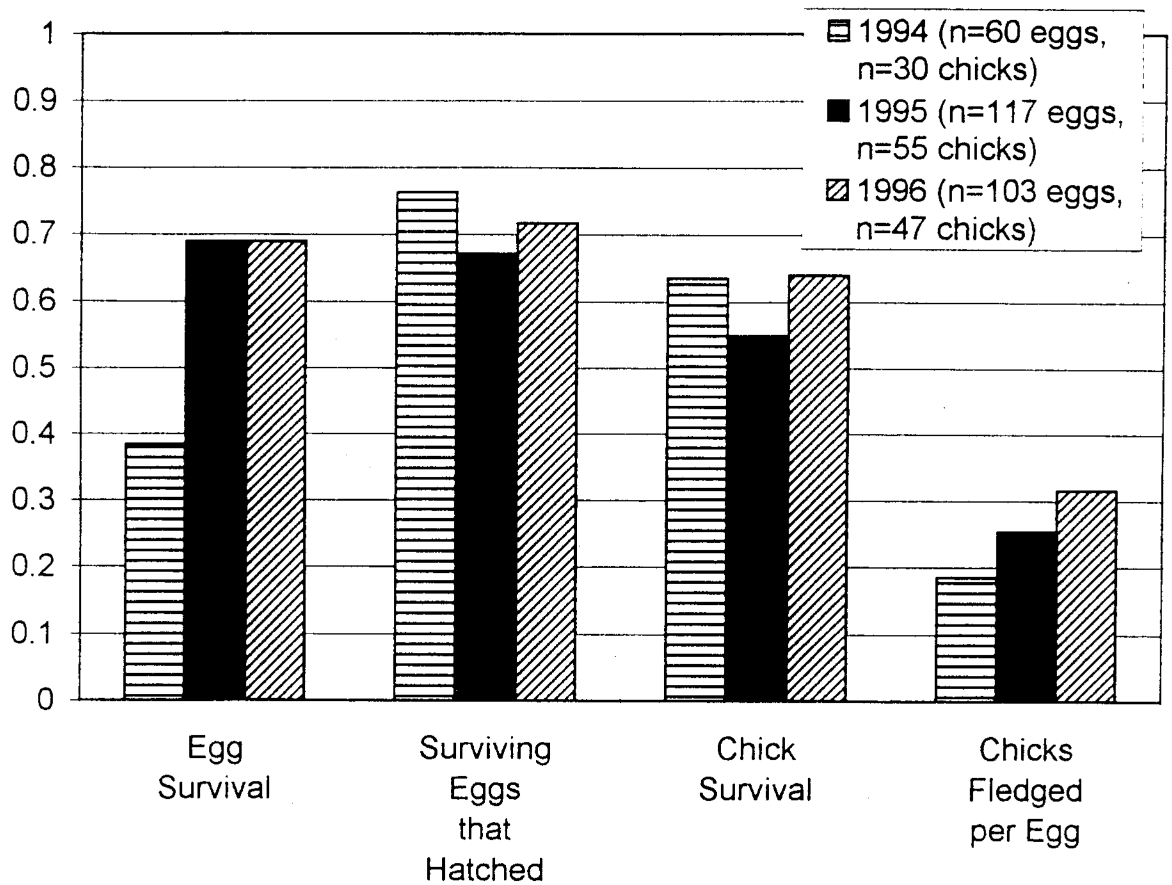


Figure 10. Pigeon guillemot breeding success in Kachemak Bay, 1994-1996.

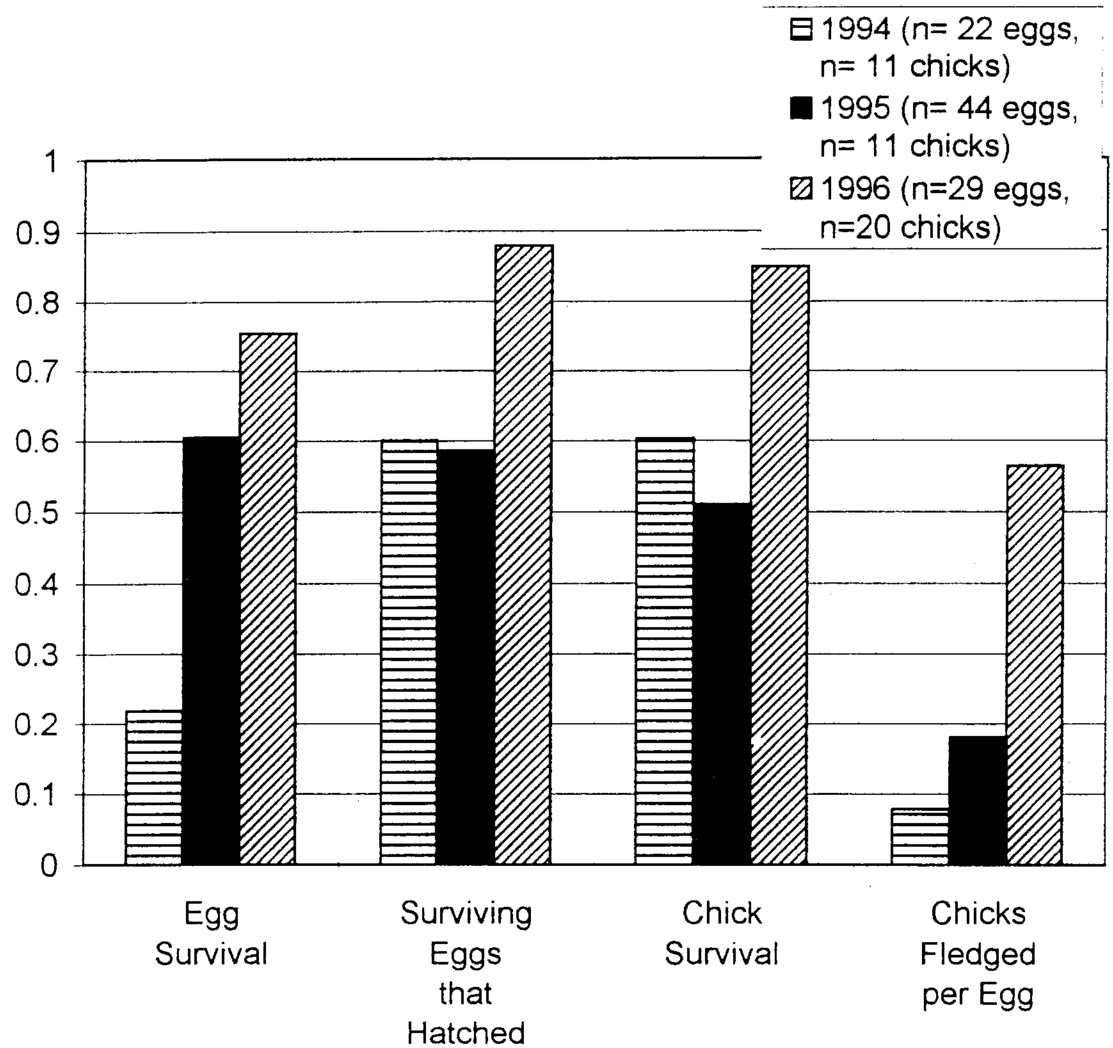


Figure 11. Pigeon guillemot breeding success at Moosehead Point, 1994-1996.

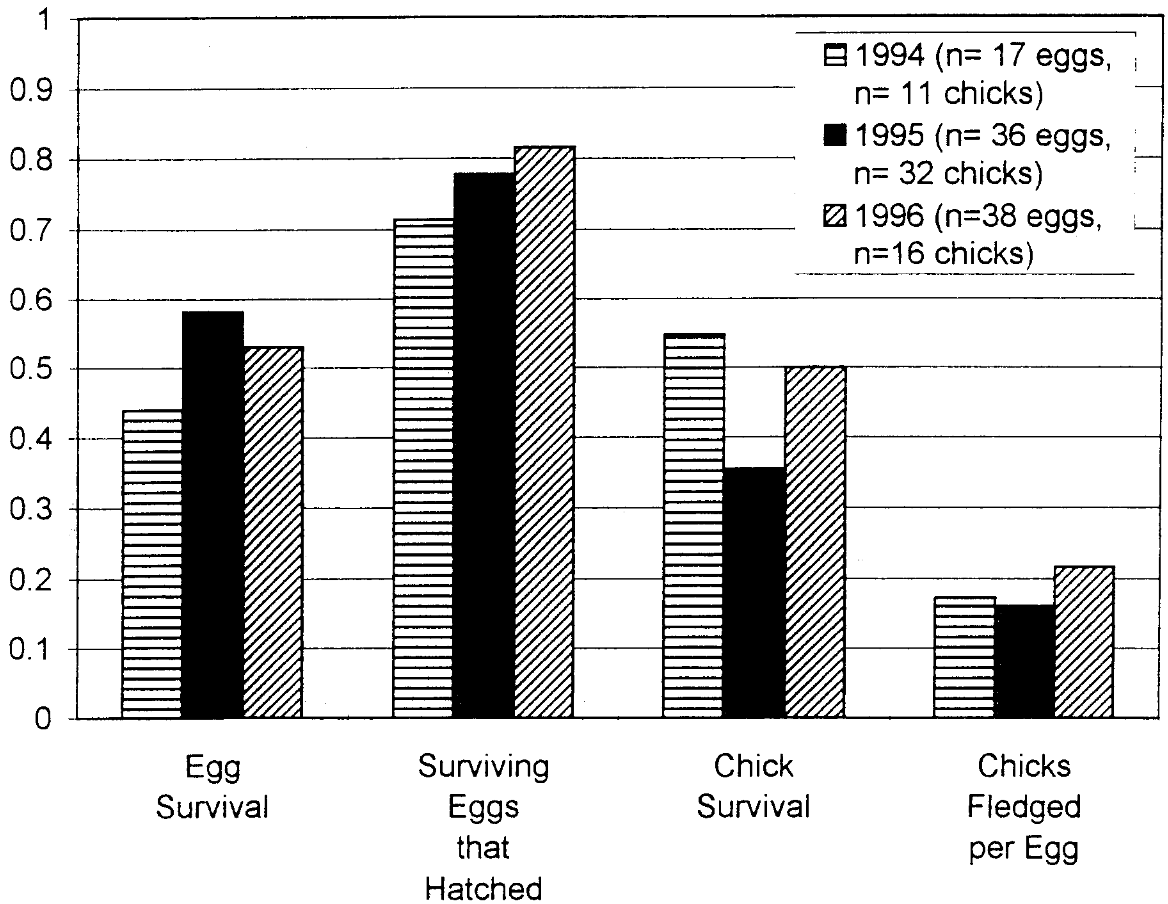


Figure 12. Pigeon guillemot breeding success in outer Kachemak Bay (Yukon I. to Seldovia Bay), 1994-1996.

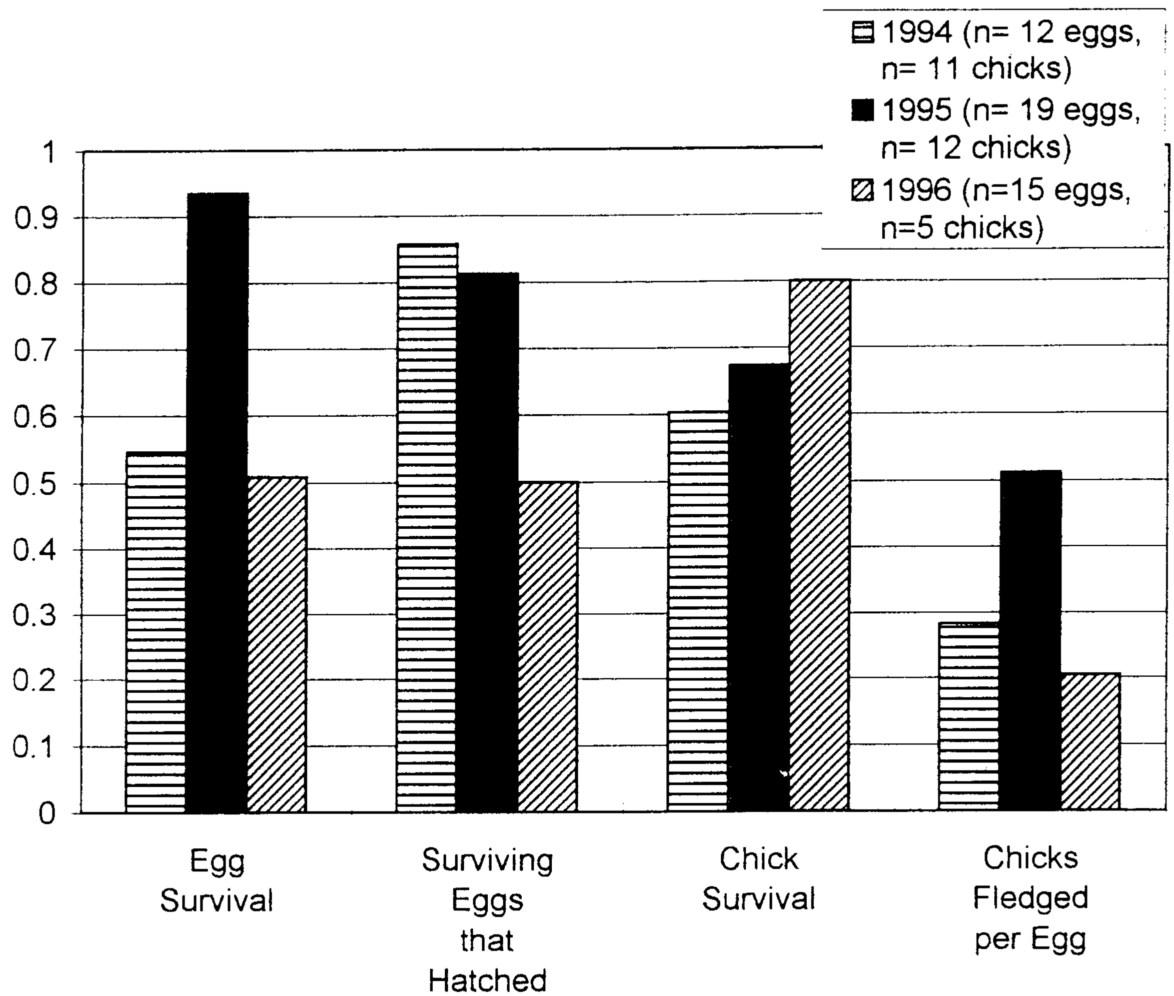


Figure 13. Breeding success of pigeon guillemots in Halibut Cove, 1994-1996.

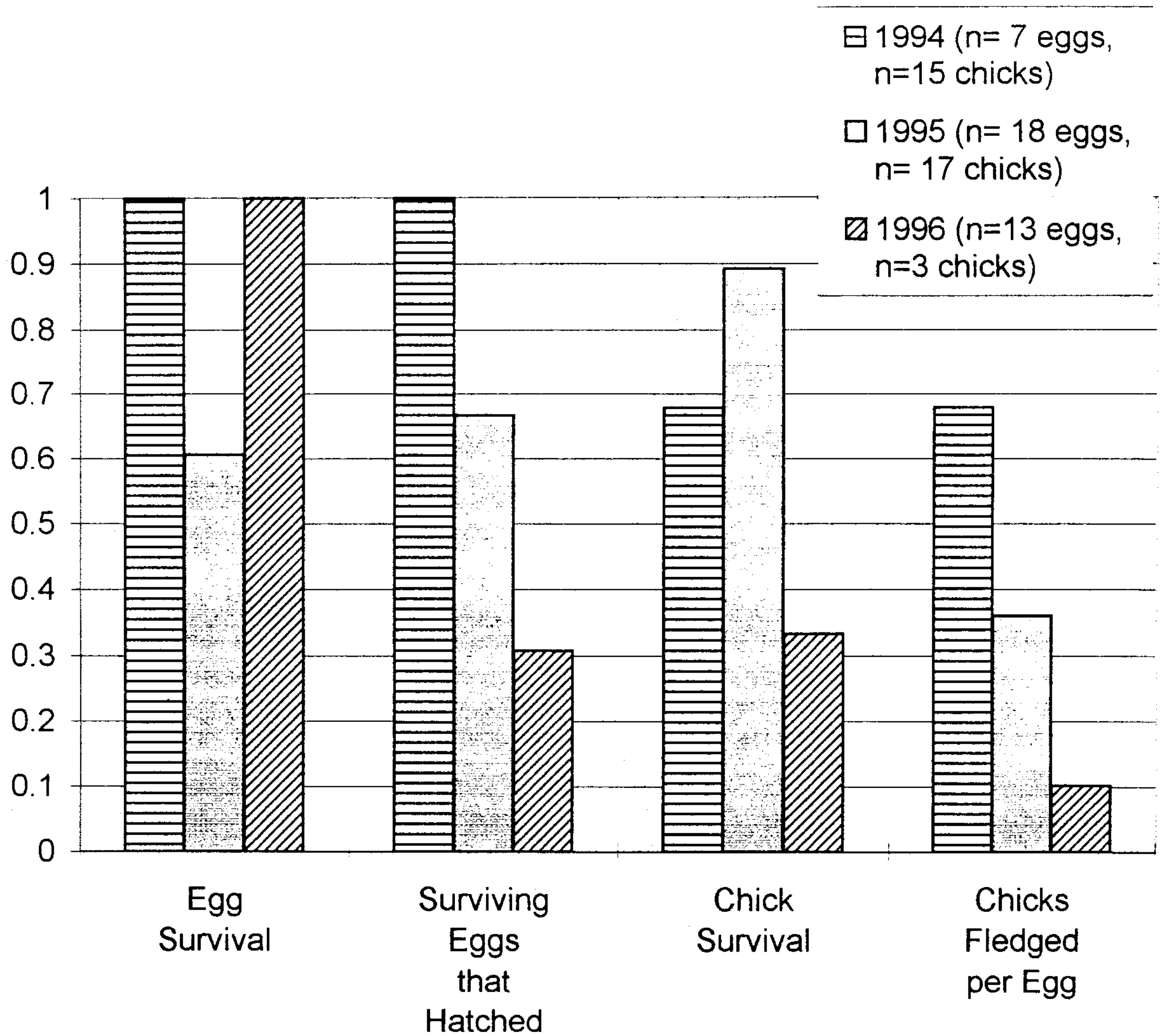


Figure 14. Pigeon guillemot breeding success in Neptune Bay, 1994-1996.

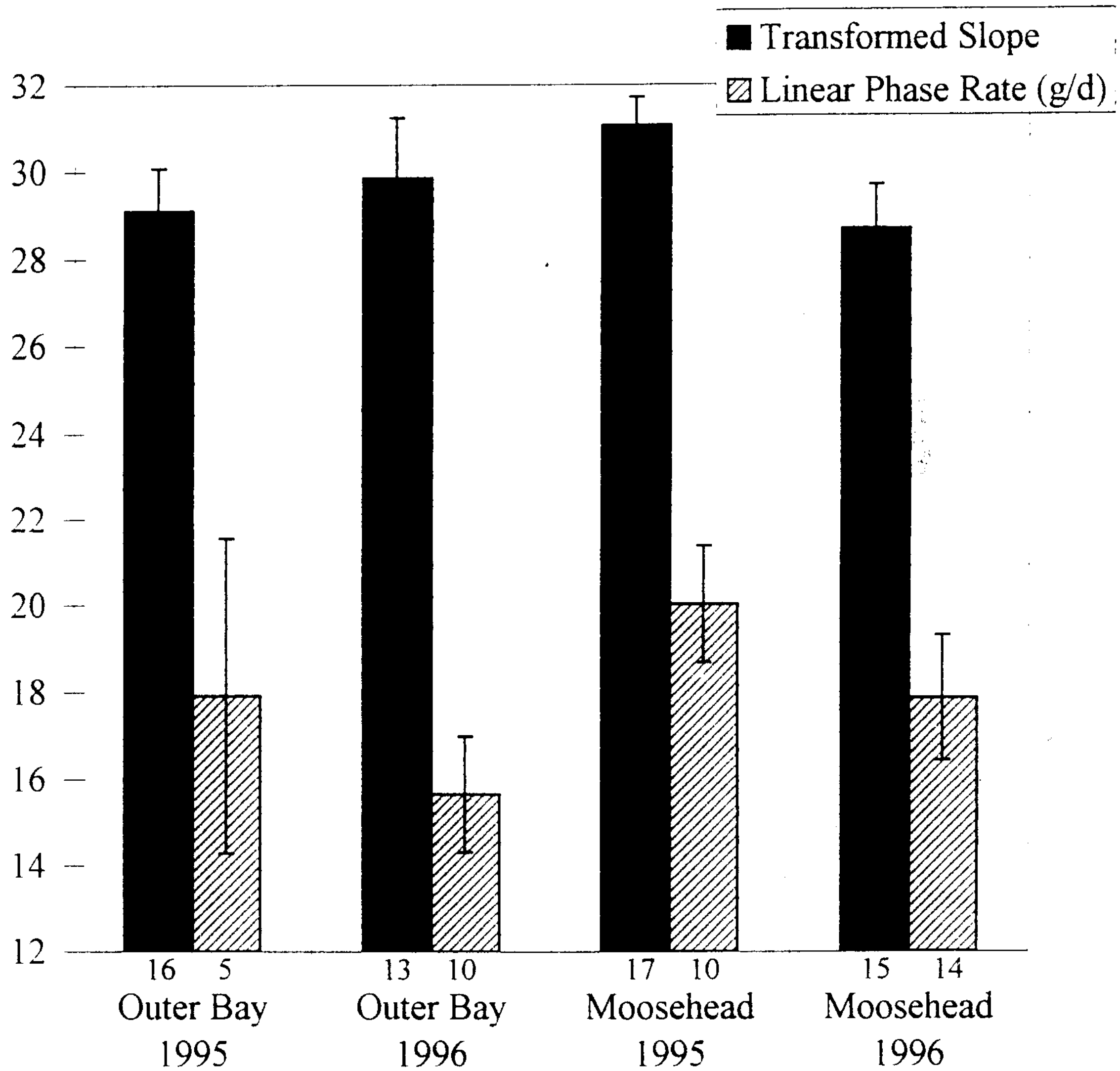


Figure 15. Pigeon guillemot nestling growth in Kachemak Bay, 1995-1996. Outer bay includes nests from Yukon I. to Seldovia Bay. Sample sizes are given at the base of each column. Error bars equal one standard error.

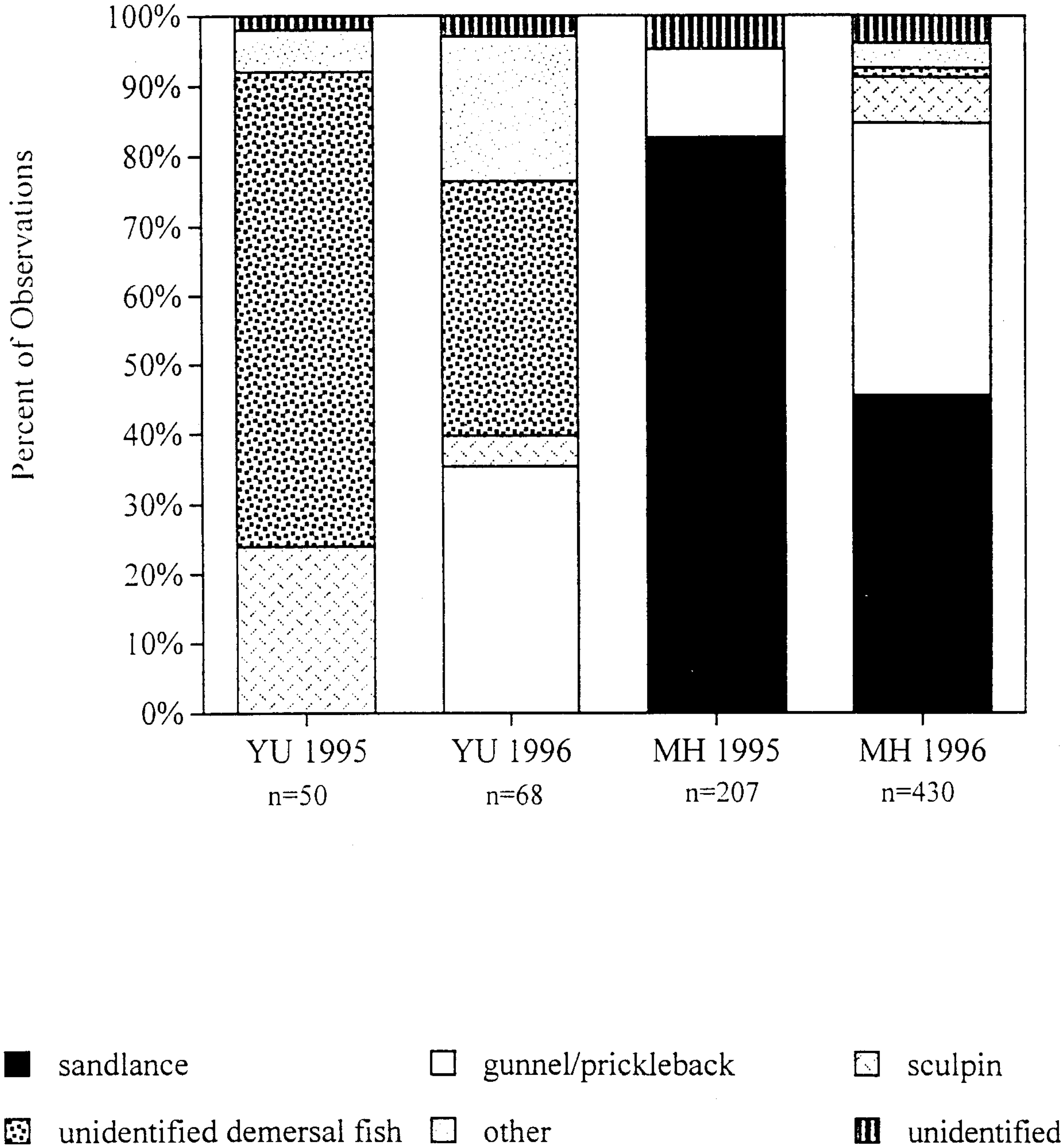


Figure 16. Diet composition at Yukon Island and Moosehead Point in 1995 and 1996.