APPENDIX F

APEX: 96163F

The Breeding and Feeding Ecology of Pigeon Guillemots at Naked Island in Prince William Sound, Alaska

Results of the 1996 field season

APEX Component 96163F

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January 1997

Study History: The field work for APEX subproject 96163F was conducted during the summer of 1996. Previous related field work was conducted during the summer of 1995 as part of APEX subproject 95163F. A similar effort was made in 1994 as Project 94173. Previous related projects have been funded by the Trustee Council. Oakley and Kuletz (1996) undertook a study in 1989-1990 to compare various population and reproductive parameters of pigeon guillemots before (Oakley and Kuletz 1979, Kuletz 1981, 1983, Oakley 1981) and after the spill. Also, Project 93034, an extensive survey of pigeon guillemot colonies throughout Prince William Sound, was conducted during the summer of 1993 (Sanger and Cody 1994).

Abstract: The objective of this component was to evaluate the breeding and feeding ecology of pigeon guillemots (*Cepphus columba*) with respect to the abundance and availability of forage fish in the near shore environment. We monitored the reproductive success of 50 guillemot nests at Naked Island, Prince William Sound. Data from numerous sources indicate that there has been a change in the Gulf of Alaska marine ecosystem that began around the late 1970s, which in turn has probably affected marine bird populations. The population of pigeon guillemots in Prince William Sound decreased from about 15,000 in the early 1970s to less than 5,000 in the 1990s. Study colonies at Naked Island and four neighboring islands in Prince William Sound have shown a similar trend since the late 1970s. During this period, the diet of pigeon guillemot chicks on Naked Island also changed. In the late 1970s Pacific sand lance (*Ammodytes hexapterus*), a schooling forage fish, dominated the chick diet. In the 1990s chick diet has been dominated by fish that live on or near the bottom, such as gunnels, pricklebacks, sculpins, and cod-like fish. The correlation between percent sand lance in the chick diet and the total guillemot population is strong, and we suggest that there is a link between the change in diet and the population decline.

Key Words: Alaska, *Ammodytes hexapterus,* breeding ecology, *Cepphus columba,* foraging ecology, Naked Island, oil spill, pigeon guillemot, population, predation, Prince William Sound, sand lance.

Project Data: Information was gathered on pigeon guillemot population and colony attendance, banding and morphometrics, nesting chronology and productivity. Also, chick provisioning, diet, growth, fledging weights, adult foraging effort, and fish types caught in traps and seines. The data is contained in either Paradox database, Quatro pro spreadsheet, or Word perfect programs, with accompanying graphs and figures. The permanent contact for the data is Dave Irons, 1011 East Tudor, Anchorage, Alaska, 99503. Phone: (907) 786-3376, Fax: (907) 786-3641. The data is available with permission.

Citation: Hayes, D.L. and T Spencer. 1997. The breeding and feeding ecology of pigeon guillemots at Naked Island in Prince William Sound, Alaska. Results of the 1996 field season, APEX Component 96163F, U.S. Fish and Wildlife Service, Anchorage,Alaska.

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Executive Summary

The objective of this component was to evaluate the breeding and feeding ecology of pigeon guillemots (*Cepphus columba*) with respect to the abundance and availability of forage fish in the near shore environment. We monitored the reproductive success of 50 guillemot nests at Naked Island, Prince William Sound. Using binoculars and spotting-scopes, we determined the diet of guillemot chicks by identifying fish carried to the nests by adult birds.

The population of pigeon guillemots in Prince William Sound decreased from about 15,000 in the early 1970s to less than 5,000 in the 1990s. Study colonies at Naked Island and four neighboring islands in Prince William Sound have shown a similar trend since the late 1970s. During this same period, the diet of pigeon guillemot chicks on Naked Island also changed. In the late 1970s Pacific sand lance (*Ammodytes hexapterus*), a schooling forage fish, dominated the chick diet. In the 1990s chick diet has been dominated by fish that live on or near the bottom, such as gunnels (*Pholididae*), pricklebacks (*Stichaeidae*), and sculpins (*Cottidae*). Also more prevalent are the cod-like fish (*Gadidae*) in chick diets. The correlation between percent sand lance in the chick diet and the total guillemot population is strong, and we suggest that there is a link between the change in diet and the population decline.

The productivity of guillemots at Naked Island was lower, but not significantly so, in the 1990s than it was in the late 1970s. After 1989, predation was more prevalent at our study colonies than it was previously, and was the cause of numerous failed nesting attempts. Guillemots at Naked Island are doing better than guillemots in other regions. The weighted average productivity of guillemots on Naked Island (0.81 fledgling/nest) is higher than the combined weighted average, from numerous studies, of guillemots in British Columbia, Washington, and Oregon (0.65 fledgling/nest). Thus low productivity for birds attempting to nest is not an obvious factor in the population decline in Prince William Sound.

Data from numerous sources indicate that there has been a change in the Gulf of Alaska marine ecosystem that began around the late 1970s, which in turn has probably affected marine bird populations. The populations of many species of piscivorous marine birds and mammals have declined in Prince William Sound since the early 1970s. This ecosystem shift and the accompanying changes in the food web may account for many of the observed population declines. Besides the 1989 oil spill, other possible contributing factors are winter mortality of adults and juveniles, and low proportions of birds attempting to breed. However, these factors are also likely food-related and thus linked to changes in the ecosystem.

In 1996, we observed more schools of sand lance and more seabird foraging flocks around Naked Island than in either of the two previous years. This may indicate a strong year class for sand lance and possibly future increases in their abundance. The percent of sand lance in the chick diet was 17% in 1996 compared to 10% for each of two the two previous years. This component of the APEX study will further investigate the link between the diet, population and productivity of guillemots and the abundance and distribution of forage fish in Prince William Sound.

The Breeding and Feeding Ecology of Pigeon Guillemots at Naked Island in Prince William Sound, Alaska

INTRODUCTION

During the 1996 breeding season, we studied the breeding and feeding ecology of pigeon guillemots nesting on Naked I. in the western part of Prince William Sound (PWS). Pigeon guillemots were chosen for study by Alaska Predator Ecosystem Experiment (APEX) and Nearshore Vertebrate Predator Project (NVP) because 1) they constitute an injured resource affected by the oil spill, 2) they forage near shore in shallow water on fish and invertebrates particularly vulnerable to oil accumulations, 3) there exists prespill data for this species in PWS, and 4) they are relatively easy to study for population, diet, and productivity data.

Pigeon guillemots (*Cepphus columba*) are cavity-nesting, pursuit-diving seabirds that forage mostly in the near shore environment on both demersal and schooling fish (Storer 1952). Guillemots nest in small scattered colonies or in solitary pairs in natural cavities along rocky shorelines. Unlike most other members of the family Alcidae, the pigeon guillemot typically lays a clutch of two eggs. The chicks are semiprecocial, usually spending about 35 to 45 days in the nest. During the daylight hours, they are fed by both parents, which return to the nest with one prey item (usually fish) at a time in their bills.

The population of pigeon guillemots in PWS has decreased from about 15,000 in the 1970's (Dwyer et al. ND) to less than 5,000 in the 1990's (Agler et al. 1994, Sanger and Cody 1994). There is some evidence suggesting that this population was in decline before the *T/V Exxon Valdez* oil spill in March of 1989 (Oakley and Kuletz 1996).

Demersal fish such as gunnels (Pholidae), pricklebacks (Stichaeidae), and sculpins (Cottidae) have always been an important component of chick diet, and their relative contribution has increased since 1989. The proportions of Gadidae and schooling fish such as Pacific herring (*Clupea harengus*) capelin (*Mallotus villosus*) and Pacific sand lance (*Ammodytes hexapterus*) have varied widely from year to year.

Numerous studies have shown that changes in the availability of prey species can result in widespread reproductive failure of seabirds (Vermeer et al. 1979, Anderson et al. 1982, Springer et al. 1986, Safina et al. 1988, Uttley et al. 1989, Furness and Barrett 1991; but see Burger and Piatt 1990). We hypothesized that pigeon guillemot numbers may be limited by the availability of suitable forage fish such as Pacific sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea harengus*) and capelin (*Mallotus villosus*). Adult survival, recruitment, breeding, and foraging parameters were investigated to try and determine if food availibility is a limiting factor to overall populations. Although results are still preliminary and more data from future years is planned, the correlation between percent sand lance in the chick diet and the total guillemot population at Naked Island is strong, and we suggest that there is a link between the change in diet and the population decline.

OBJECTIVES

1. Determine if availability of food is limiting reproductive success of guillemots by collecting the following kinds of data:
    a. Measuring breeding parameters, including phenology, chick growth rates, fledging weights, and reproductive success at several colonies on Naked I.
    b. Measuring foraging parameters, including diet and provisioning rates of chicks, and locations of foraging areas.

METHODS

Study Area

Our field season extended from 6 June through 22 August 1996. All of our study colonies were located on Naked I. in PWS (Fig. 1). We chose Naked I. in 1994 as one of our principal study sites and as a base of operations because of the high number of breeding pigeon guillemots present (almost one third of the population in PWS) and the accessibility of the nest sites. Also it has an excellent anchorage and it had been used previously as a base camp for other guillemot studies (Eldridge and Kuletz 1980, Oakley 1981, Kuletz 1983, Oakley and Kuletz 1996). The camp has been used consectutive seasons since 1994. Naked I. (ca. 3,862 ha) has a maximum elevation of 400 m and is part of a group of three main islands. Much of the shoreline of Naked I. is characterized by low cliffs and cobble or boulder beaches; higher, steep, exposed cliffs occur along portions of the eastern shore. The island is forested to its summit; the principal species of tree are Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and mountain hemlock (*T. mertensiana*). Naked I. is part of the Chugach National Forest.

Naked I., about 30 km southwest of the site where the *T/V Exxon Valdez* ran aground on Bligh Reef, was one of the first areas to be oiled (see Fig. 1, Kuletz 1996:772). Between 27 March and 2 April, 1989, portions of the eastern, northern, and northwestern shorelines were oiled. The prevailing winds moved most of the oil to the south, away from the island, but between 7 and 9 April, southerly winds brought the oil into contact with the southern and western shorelines of Naked I. again.

Censusing: Population and Colony Attendance

Pigeon guillemot populations at Naked, Peak, Storey, Smith, and Little Smith Islands (the Naked Island complex, Fig. 1) were censused by circumnavigating each island in a small boat at a distance of between 50 m and 100 m from the shore when the weather was good and the tides were near high. We censused Naked I. on 7 June and the other islands of the complex on 8 June. These censuses were conducted at approximately the same time of day (0600-1200

Alaska Daylight Time) and at the same time of year that previous censuses of the this area were made. Also, throughout the breeding season, but mostly during the chick-rearing period, we counted the maximum number of guillemots present at a particular colony at 15-minute intervals whenever that colony was being monitored from a boat or a blind. To examine colony attendance as a function of time of day , we made two continuous 24-h watches at the Nomad colony (12-13 and 18-19 June) from noon to noon on each watch. Observation shifts were four hours.

Nest Sites and Monitoring

We monitored those nests used in 1994 and 1995 plus several new ones found during the 1996 breeding season. Most were at colonies along the western shoreline. Because of their inaccessibility or our inability to determine their contents, some of these nests were monitored only during feeding observations and were not used as part of our productivity sample. Nest sites were classified according to one of three types of habitat in which they occurred: tree root systems, rock crevices, or talus piles.

To reduce the risk of nest abandonment due to our activities, we checked nests at five-day intervals (less frequently than during previous seasons) until near fledging. When a chick reached an age of 30 days, then that nest was checked and the chick weighed and measured on a daily basis until it fledged.

Banding and Morphometrics

Some adults were caught by hand at the nest or with a mist net as they attempted to deliver food to their chicks. Adults were banded on the left foot with a USFWS metal band (bottom) and a color plastic cohort band (top), and on the right foot with a unique combination of two color plastic bands. Chicks were banded on the right foot with a USFWS metal band (bottom) and a color plastic cohort band (top) and on the left foot with a unique combination of two color plastic bands. The 1996 cohort plastic band was white.

We measured all adults that we handled and all accessible chicks. We measured maximum wing chord and length of the fifth and outer primaries with a rule to the nearest millimeter. We weighed birds with Pesola™ spring scales (0-100 g x 1 g, 0-500 g x 5 g, or 0-1 kg x 10 g). Newly hatched chicks were marked on the right foot and on the down of their head with permanent markers to distinguish between alpha (first-hatched) and beta (second-hatched) chicks until they were large enough to be banded.

Nesting Chronology and Productivity

We did not have enough information on hatch dates to construct a complete nesting chronology as in previous years. However, we determined fledging dates for many chicks to within one day.

We estimated productivity only from those nests that were found in the egg stage and followed through fledging. During the incubation stage, a nest was considered to be active and included in our sample if it contained at least one egg and if an adult was seen in that nest at least once. If we knew two eggs had been laid in a nest but saw only one chick and no sign of the other egg, we assumed that both eggs hatched and one chick died. It seems unlikely that a predator entering an active nest would take only one egg and leave the other intact. Also, based on other guillemot studies (G. Divoky, pers. comm.; D.L. Hayes, pers. obs.), the proportion of two-egg nests in which only one egg hatches is fairly low.

Measures of productivity were defined as follows: hatching success (eggs hatched/eggs laid), fledging success (chicks fledged/eggs hatched), and overall productivity (chicks fledged/eggs laid). Thirty days is approximately the minimum time spent in the nest by guillemot chicks; the actual time is often much longer. For purposes of estimating fledging, however, any chick surviving in the nest for 30 days was assumed to have fledged. Other measures of productivity (mean clutch size, number of chicks hatched per nest, and number of chicks fledged per nest) were used for comparison with previous years' data from Naked I. and from other regions.

Predation

If eggs disappeared from nests between visits, we assumed that predation was the cause. If chicks too young to fledge (i.e., younger than 30 days) disappeared from nests between visits, we assumed predation was the cause only if we were reasonably certain that no chick was still in some hidden corner of the nest. In some instances, where the nest cavity was too long or labyrinthine, it was not possible to make this determination. If after repeated visits to this type of nest, we never saw the chick(s) again or never found direct evidence of predation, we listed the cause of failure as unknown.

Chick Growth and Fledging Weights

We calculated the growth rates of chicks as the change in body mass (g/d) during the linear phase of their growth, which is the period eight to 18 days after hatching (Koelink 1972). We estimated the age of some chicks by comparing their body mass to that of known-age chicks from the 1995 field season, or from other clues such as the appearance of the down. Fledging weight was assumed to be the last recorded weight of a chick that was measured within 24 hours of fledging.

Chick Provisioning and Diet

Either from blinds or from boats we observed adult guillemots bringing food items to their chicks throughout the chick-rearing period (total observation time = 256 h). Feeding watches ranged from 2 h to 18 h; shifts lasted up to 5 h. Usually only one observer was in the blind at a time. Binoculars and spotting scopes were used to identify prey items in the bills of guillemots to the lowest possible taxon or "type" of prey. When time and visibility permitted, we also estimated the length of the prey item as a multiple of the guillemot's bill to the nearest half-bill length. We recorded the time an adult returned to the colony with a fish or the time it was first seen with a fish on the water in front of the colony. We also recorded the time of each delivery and the number of the nest to which the prey was delivered. We obtained additional information about chick diet by retrieving fish found in the nests or by intercepting fish at or near the nest entrance with a mist net.

To test whether deliveries were distributed more or less evenly throughout the daylight hours, the day was divided into three equal periods: early (0600-1120), mid-day (1120-1640), and late (1640-2200). Although a few deliveries occurred very early and very late, when it was often too dark to make reliable observations, the period used for analysis was truncated at both ends in accordance with the times listed above. Using a Chi-square goodness-of-fit test, the actual number of deliveries observed during each of the three periods was compared to the expected number of deliveries in those periods if they had been distributed evenly throughout the day.

Provisioning rates were determined for chicks of 15-35 days of age at both one- and two-chick nests. Only deliveries recorded during continuous observations made between 0600 and 2200 were used in determining delivery rates.

Sampling of Fish

We occasionally sampled waters (< ca. 15 m) around Naked I. with fish traps set on or above the bottom to collect specimens for identification and laboratory analysis.

We used a beach seine at several beaches around the island (Fig. 1). Beach seining was conducted using a 14 ft inflatable boat. The net configuration was a 120 ft floating seine, 16 ft deep in the middle tapering to 5 ft at each end. Mesh size was 0.25 in the middle 30 feet and 0.5 in on the ends. Attached to each end was a bridle with a 110 ft length of .75 in polypropylene line. The net was usually deployed using the parallel method. This was accomplished by holding one length of the polypropylene line on shore while the boat reversed out 100 feet perpendicular to the shore. Then the net was set parallel to the shore and the trailing line brought back perpendicular to the shore. The net was pulled in evenly (two people on each end) to the beach. An alternative method (round haul) was sometimes used. One end of the net was anchored at the beach while the net was set perpendicular to the beach. While the outer end was still attached to the boat, the net was then swept through an arc of 90 degrees back to the beach. When space permitted, two sets on adjacent sections of shoreline were made. When large numbers of schooling fish were caught, numbers were estimated volumetrically with containers that held a known quantity of the fish. We kept subsamples from the fish traps and beach seines, releasing the remaining fish. We measured wet weight and standard length of all fish that were kept. Beach seine sets were usually made at or near high tide and at beaches having substrates not likely to snag the net as it was pulled in. The operation was not always smooth because of snagging or other problems and some schools may have escaped before we closed the net. Few benthic fish were caught in the nets, either because they could escape under the net, or because the beaches we selected were not the appropriate habitat. Therefore, results of beach seines should not be considered quantitative.

Data Analysis

Data from the 1996 field season were not compared statistically with that from any particular year in the past, but were tabulated with appropriate data from all previous years of study at Naked I. All means are reported as the mean plus or minus one standard deviation, unless otherwise noted. The level of significance was set at $\alpha = 0.05$.

RESULTS

Population Counts and Colony Attendance

In 1996, 809 pigeon guillemots were counted around the shorelines of the Naked Island complex during the censuses on 7 and 8 June (Table 1). Maximum counts of pigeon guillemots usually occurred in the early morning, shortly after first light, or sometimes later in the day at or around the high tide (Figures 2 and 3). After first light, the birds were typically detected in rafts a considerable distance from shore; then they gradually moved closer to the colony.

Nesting Chronology and Productivity

The median fledging date for guillemots on Naked I. in 1996 was 2 August (n = 30). The earliest fledging date was 27 July and the latest fledging date was 19 August.

The mean clutch size was 1.80 ± 0.38 (n = 41). Hatching success (chicks hatched/eggs laid) was 0.82. Of a total of 74 eggs, 61 hatched, three were depredated, three were abandoned, and seven were incubated but failed to hatch. Fledging success (chicks fledged/chicks hatched) was 0.49. Of a total of 61 chicks, 30 fledged, 11 were depredated, four were found dead in the nest, and the fate of 12 others was unknown (though predation was suspected for many of those). Four other chicks from two nests were found dead in the nest, their deaths probably being related to the death of a parent; an adult carcass with wounds to the neck was found in each of these nests. Overall productivity (chicks fledged/eggs laid) was 0.41. Twenty-three of the 41 nests (0.56) in our productivity sample at Naked I. produced at least one fledgling. The most successful type was rock crevice. The proportion of successful nests (i.e. those from which at least one chick fledged) for each nest type was as follows: rock crevice (15/23 = 0.65), tree root (6/12 = 0.50), and talus (2/6 = 0.33).

In 1996, the mean number of hatchlings per nest was 1.49 ± 0.12 (n =41) and the mean number of fledglings per nest was 0.73 ± 0.12 (n = 41). Mean clutch size and number of hatchlings per nest were slightly higher, while mean number of fledglings per nest was slightly lower than in 1995. These values are within the range of values reported for Naked I. in previous years (Table 2).

Predation

Of the 41 nests monitored from the egg stage through fledging, eggs were depredated in two and one or both chicks were depredated in nine. Also, of nine other nests that failed for unknown reasons, predation was suspected as the cause of failure for eight. Thus the predation rate was at least 27% and may have been as high as 46%. We observed other nests not in our productivity sample that also showed clear signs of predation. The Tuft colony at the southwest end of Naked I. was devastated by predation in 1996. At two nests, guillemot adults were found dead in the nest. The carcasses were intact except for small puncture wounds to the neck. In both nests, the chicks died too, in most instances probably from starvation, as the adult carcass was blocking the nest entrance. In one of these nests, however, one chick had also been bitten in the neck. Guillemots at the Tuft colony nest sympatrically with parakeet auklets (*Cyclorrhynchus psittacula*). Several auklet carcasses were found in the area, either intact, except for the head being cleanly chewed off, or with feathers scattered in the vicinity.

Chick Growth and Fledging Weights

The mean growth rate during the linear phase of growth (i.e. 8 - 18 days posthatch) of chicks at Naked I. was 20.9 ± 5.4 g/d (n = 20, range = 11.6 - 32.0 g/d; see Table 3 for comparison with growth rates from previous years). The mean fledging weight of chicks at Naked I. was 456 ± 58 g (n = 23, range = 328 - 560 g; see Table 4 for comparison with fledging weights from previous years).

Chick Provisioning

Collectively, guillemots delivered fish to their chicks throughout the daylight hours at Naked I. (n = 535 total, n = 492 between 0600 and 2200; Fig. 4). The distribution was not significantly different from a theoretical even distribution of deliveries made throughout the day ($\chi^2 = 3.671$, df = 2, $P > 0.10$).

Based on nine feeding observations lasting at least 17.5 h, delivery rates to guillemot nests ranged from 0.22 to 1.56/nest/h for chicks of any age. For chicks between the ages of 15 and 35 days, the mean delivery rate was 0.67 ± 0.16/nest/h (n = 10, range = 0.33 - 0.89/nest/h) to one-chick nests and 0.88 ± 0.34/nest/h (n = 13, range = 0.44 - 1.56/nest/h) to two-chick nests. At any particular nest, there were sometimes periods of several hours in which no deliveries were made.

The mean time that guillemots spent on the water between arrival at the colony with a fish and delivery of that fish was 13.5 minutes (SD = 19.5 minutes, range = 0 - 215 minutes, n = 650). The time between consecutive deliveries to the same nest was not considered.

Chick Diet

In 1996, the diet of pigeon guillemot chicks at Naked I. was dominated by demersal fish (Fig. 5). Schooling fish, mostly sand lance, accounted for about 21% of the chick diet. The proportions of sand lance, sculpins, and gadids in the chick diet was higher than in 1995, while the proportions of herring/smelt and blennies was lower. A relatively large proportion (ca. 22% in 1996) of fish could not be identified. Crescent gunnels, then sand lance were the most common types of fish recovered from, or intercepted at, the guillemot nests (Table 5).

Chick Diet Relative to Population Size

At Naked I., the percent of sand lance in the diet of chicks was positively related to the number of guillemots ($R^2 = 0.74$, $P = 0.013$; Fig. 6) over the years in which population and diet data was available. The number of active nests ($R2$ =n 0.69, $P = 0.010$; Fig. 7) was also positively related to the percent of sand lance in the diet.

Foraging

During observation periods, pigeon guillemots at Naked I. sometimes foraged directly in front of their colony in water less than 15 m deep. However, usually they flew out of sight to nearby bays or to the broad, shallow-water (< 25 m deep) shelf surrounding Naked I to forage. These distances were typically more than 2 kilometers away.

Fish Types Caught in Traps and Beach Seines

Shrimp (mostly *Pandalus danae* and *Eualus gaimardii*) were the most frequently taken animal in the fish traps at Naked I. Arctic shannies (*Stichaeus punctatus*) and crescent gunnels (*Pholis laeta*) were the most likely fish to be caught in traps, except when traps were set among some eel grass beds in Cabin Bay, where crescent gunnels and pricklebacks (*Lumpenus* spp.) were most commonly caught.

Relatively few benthic fish were caught with the beach seines. Sand lance, gadids (mostly Pacific Tomcod *Microgadus proximus*), and herring (*Clupea harengus*) were the most frequently caught fish with beach seines in descending order of frequency of occurrence (Table 6; see Fig. 1 for locations of beach seine sets).

DISCUSSION

Censusing

King and Sanger (1979) considered the pigeon guillemot to be one of the birds that is most vulnerable to oil spills because of its near shore foraging habits. Several studies have reported sublethal toxic effects of oil on marine birds (Peakall et al. 1980, Peakall et al. 1982, 1983 as cited in Oakley and Kuletz 1996). Marked declines in populations of the pigeon guillemot or its congener, the black guillemot (*C. grylle*) have been attributed to oil pollution (Ainley and Lewis 1974, Asbirk 1978, Ewins and Tasker 1985). Over 600 guillemot carcasses were recovered throughout the spill zone (135 in PWS) after the spill, but this might represent only 10-30% of the actual number killed (Piatt et al. 1990). Based on censuses taken around the Naked Island complex (Naked, Peak, Storey, Smith, and Little Smith Islands), prespill counts (ca. 2,000 guillemots) were roughly twice as high as postspill counts (ca. 1,000 guillemots; Oakley and Kuletz 1996). Also, on Naked I., the relative decline in the numbers of guillemots was greater along oiled shorelines than along unoiled shorelines (Oakley and Kuletz 1996).

However, censusing data in 1980 indicates that standardized early season counts of pigeon guillemots in the Naked Island complex suggest that their population had decreased considerably from counts in 1978 and 1979 before the oil spill (Table 1). This decline in guillemot numbers appears to be continuing through 1996 counts. Vermeer et al. (1993a) reported that the optimal time to determine the population of nesting guillemots was at high tide in the morning. Observed colony attendance patterns of guillemots at Naked I. during the 1994-

1996 seasons also indicate that the time of day can be important when conducting pigeon guillemot censuses. Replicate counts at the appropriate time of day and tidal cycle, and perhaps starting slightly earlier in the breeding season would increase our confidence in our estimates of the numbers of guillemots in the Naked Island complex.

Nesting Chronology

The median fledging date at Naked I. in 1996 was earlier than in 1995 and earlier than in 1994. Nesting chronology data obtained for black-legged kittiwakes (*Rissa tridactyla*) in PWS during the 1996 season indicate that the median hatching date for this species was earlier and the median fledging date was earlier than in 1995 (R. Suryan, pers. comm.).

Productivity

The ideal and most straightforward method of calculating productivity is from a sample of known nests that are followed from before egg-laying through fledging. We did have known nests on Naked I. that had been found in 1994 and 1995, but because of when we arrived at the study sites (6 June, when some eggs had already been laid), we had to include nests monitored from incubation through fledging as well. It is important to note that the nests used for measuring productivity do not constitute a "sample" in the true sense of the word. On Naked I., they represent all of the nests that we were able to find and then reach, not a random sample of nests on the island. We can only assume that they are fairly representative of the island as a whole.

Productivity (as measured by number of fledglings per nest) of pigeon guillemots at Naked I. in recent years is lower than what it was in the late 1970s (Table 2). After 1989, predation was more prevalent than it was previously, and was the cause of numerous failed nesting attempts. The weighted average productivity of guillemots for 10 years at Naked I. was 0.81 fledglings/nest (n = 215). The combined weighted average in British Columbia, Washington, and Oregon was 0.65 fledglings/nest (n = 941; Ewins 1993 and references therein). At the Farallon Islands off California, productivity averaged 0.9 fledglings/nest for a period of 13 years, but was extremely variable from year to year, the birds failing to breed in one of the years (Ainley and Boekelheide 1990). This comparison suggests that guillemots at Naked I. are doing relatively well compared to their conspecifics in other regions. However, the populations may be declining in these other regions as well.

In addition to predation, investigator disturbance may be responsible for some of the decline in productivity. More intensive research efforts at the Naked I. colonies in recent years have probably increased the level of disturbance. Several investigators at guillemot colonies elsewhere have observed reduced productivity that was apparently associated with human disturbance (Bergman 1971, Cairns 1980, Vermeer et al. 1993b).

Predation

Since the oil spill, and especially in the last few years, predation has become a factor contributing to the lower reproductive success of guillemots on Naked I. (Hayes 1995, 1996, Oakley and Kuletz 1996). Studies at other guillemot colonies have related lowered productivity or emigration to the presence of mammalian predators (Asbirk 1978, Petersen 1979, Cairns 1985, Ewins 1985, 1989).

Oakley and Kuletz (1996) noted that the primary difference in productivity of pigeon guillemots on Naked I. that they observed following the oil spill was lowered nesting success, which was the result of nest predation during the chick stage. Increased predation pressure relative to that in the past appears to be a continuing problem on Naked I. (Table 7).

Potential nest predators include the river otter (*Lutra canadensis*), mink (*Mustela vison*), northwestern crow (*Corvus caurinus*), common raven (*C. corax*), Steller's jay (*Cyanocitta stelleri*), glaucous-winged gull (*Larus glaucescens*), and black-billed magpie (*Pica pica*). Bald eagles (*Haliaeetus leucocephalus*), peregrine falcons (*Falco peregrinus*), and other raptors might be predatory on adult and fledgling guillemots.

Although we have witnessed only avian predation, the available evidence strongly suggests that mammalian predators are responsible for some of the disappearances of eggs or young guillemot chicks. River otters were seen frequently in the vicinity of our study colonies in all years and are the most likely mammalian predator, but evidence found in 1996 indicates that mink may also be involved. Intact carcasses of guillemot adults and chicks with wounds to the neck and headless carcasses of parakeet auklets in the same area are suggestive of mink predation. Ewins (1985) reported that on the island of Mousa in Shetland, otters (*Lutra lutra*) killed both chicks and incubating adults, and that decapitated carcasses were a sure sign of these predators. Ewins also noted that there were few nests inaccessible to them. Crows and magpies are the likeliest avian predators on eggs and chicks. Other studies indicate that crows are a major source of egg predation and sometimes take young chicks as well (Emms and Verbeek 1989, Ewins 1989). Adults, and especially fledglings, are probably sometimes taken by large raptors. Bald eagles are known predators of adult guillemots in British Columbia (Vermeer et al. 1989 as cited in Ewins et al. 1993). Beaks of guillemots were found beneath an eagle's nest on Naked I. during a previous study (K. Kuletz, pers. comm.). Predators can affect local population levels of guillemots (Asbirk 1978, Petersen 1979, Cairns 1984).

Chick Growth

In 1996, our estimates of growth rates (20.9 g/d) during the linear phase of growth were similar to those of Oakley and Kuletz (1996) at Naked I. (range = 16.6 - 23.8 g/d), as were our estimates of fledging weights. Growth rates were slightly higher than those reported by Koelink (1972) for Mandarte Island (15.9 g/d) and Ainley and Boekelheide (1990) for the Farallon Islands (16.5 g/d). It is important that caution be used when making comparisons based on these data; the sample sizes are relatively small in most instances.

Chick Provisioning

Members of the genus *Cepphus* typically lay two eggs. Most other alcids lay only a single egg, but the near-shore foraging habits of guillemots probably account for their ability to raise two chicks. Mehlum et al. (1993) maintain that long-distance foraging by black guillemots, which typically raise two-chick broods and have a high wing loading relative to most other seabirds, is too energetically demanding and might exceed their maximum sustainable working level. In Iceland, artificial triplets fledged at lower mean weights than chicks from normal broods (Petersen 1981 as cited in Harris and Birkhead 1985). Koelink (1972) argues this same point for chick-rearing pigeon guillemots. In his study, although artificial broods of three were successfully raised to fledging, there was a proportional decrease in the amount of food delivered per chick throughout the nestling period.

Our measured rates of food deliveries to individual nests (range = 0.33 - 0.89/nest/hr at one-chick nests; range = 0.44 - 1.56/nest/h at two-chick nests) are comparable to those of other studies of *Cepphus* guillemots (Thoresen and Booth 1958, Bergman 1971, Asbirk 1979 as cited in Harris and Birkhead 1985, Cairns 1981, 1987, Kuletz 1983). However the mean delivery rate of 0.67 ± 0.16/nest/h and ($n = 10$, range = 0.33 - 0.89/nest/h) to one-chick nests are somewhat lower than pre spill years. The values we used to calculate the means reported above represent minimum delivery rates as it is likely that we occasionally missed deliveries.

Foraging

The maximum diving depth of black guillemots is about 50 m (Piatt and Nettleship 1985). The pigeon guillemot probably has similar diving capabilities, and if foraging on benthic fish must be limited to using the broad, shallow-water shelf surrounding Naked I. and the neighboring islands (see Fig. 14 in Hayes 1995). Kuletz (1983) reported that the guillemots breeding on Naked I. generally foraged around the island, usually within about 600 m of the shore and in water shallower than 25 m. Benthic fish in this environment probably constitute a more dispersed though less ephemeral resource. In the absence of large schools of forage fish, guillemots might have to compete for these benthic resources. After numerous hours of observing guillemots on their foraging grounds, however, we saw few interactions between conspecifics that would suggest they were competing for a resource or defending a feeding territory.

At the Igloo colony on the east side of Naked I., we saw most of the adults flying away from the colony through the narrows between Naked and Peak Islands, presumably to forage. Most deliveries to the Igloo colony came from this direction and consisted of mostly demersal fish. This behavior seemed surprising to us because our regular beach seining efforts as well as anecdotal observations consistently indicated the presence of a large concentration of sand lance in MacPherson Bay just to the south of the Igloo colony. This suggests that guillemots have preferred foraging areas as noted with tagged birds in previous studies (Kuletz, 1983).

Chick Diet

Since the late 1970s and early 1980s there has been a dramatic change in the diet of pigeon guillemot chicks at Naked I. In the years 1979-1981 Pacific sand lance were the single largest component (42%) of the diet, while in the five years 1989-1990 and 1994-1996, sand lance accounted for a much smaller fraction (13%) of the diet. The increase in the proportion of gadids has been equally dramatic, from 4% to 21% for these same periods. Demersal fish such as gunnels (Pholidae), pricklebacks (Stichaeidae), and sculpins (Cottidae) have always been an important component of the diet although their relative contributions have varied widely from lance accounted for a much smaller fraction (13%) of the diet. The increase in the proportion of gadids has been equally dramatic, from 4% to 21% for these same periods. Demersal fish such as gunnels (Pholidae), pricklebacks (Stichaeidae), and sculpins (Cottidae) have always been an important component of the diet although their relative contributions have varied widely from year to year.

The proportion of high-quality forage fish such as sand lance, herring, capelin, and smelt in the diet of chicks might be related to the ephemeral nature of schools of these fish and their presence within the foraging range of guillemots. Their capture might occur only coincidentally when behavioral factors (e.g., spawning) or oceanographic factors (e.g., currents, up welling) bring these prey into shallower near shore waters. On a broader time scale though, these fish may not be as abundant in PWS as they were previously, suggesting that a possible shift in the marine ecosystem has occurred. Data from numerous sources indicate that there has been a change in the Gulf of Alaska marine ecosystem that began around the late 1970s, which in turn has probably affected marine bird populations (Piatt and Anderson 1996 and references therein).

Guillemots forage near their colonies and in shallow water less than about 50 meters. This limits foraging adults at Naked Is. to the broad, shallow-water shelves surrounding the Naked Island complex when foraging on demersal fish. Demersal fish in this limited area may not be abundant enough to support higher numbers of breeding guillemots (Hayes and Kuletz, 1996). When sand lance numbers are low, switching to alternate demersal prey species has allowed breeding Naked Is. guillemots to maintain their productivity. However, guillemot population declines appear to be related to availability or abundance of sand lance. This relationship between sand lance in chick diet and population suggest that availability of high-quality forage fishes are important for maintaining large, productive colonies of pigeon guillemots in Alaska (Hayes and Kuletz, 1996). Also, guillemots that specialized in sand lance (and perhaps other surface fish), did not easily switch to alternative prey, so as the availability of sand lance declined in the late 1980s, the guillemot population could not maintain historic numbers (Kuletz and Hayes, 1996).

Fish Types Caught in Traps and Seines

Although arctic shannies were the most common fish caught in the traps, they were infrequently seen being delivered to guillemot chicks and were not among the samples obtained at the nests. Aside from crescent gunnels,which were consistently captured, the catch in fish traps did not correlate to chick diet. Only when traps were placed in eel grass did the benthic fish captured (more gunnels and pricklebacks) resemble chick diets more closely. Schooling fish (mostly sand lance) dominated the catch in beach seine sets. Over 20% of chick diets for Naked Island included schooling fish, so the correlation between seine catch and diet seems better. However, because of bias in sampling due to problems retaining fish (especially benthic) in the seine, overall abundance of species can not be inferred from this.

Compared to other areas with long stretches of sand or gravel beaches, the shoreline of Naked I. had few beaches suitable for seining. If seining is continued in the future around Naked I., we suggest that it be limited to locations A, B, C, F, and possibly I (Fig. 1). The substrate at these beaches seemed relatively suitable for seining and fish were frequently caught when we seined there. The other beaches either yielded very little fish or the substrate was such that it was particularly difficult to seine there and the chance of fish escaping was high.

CONCLUSIONS

The population of pigeon guillemots at Naked I. and four neighboring islands have shown a decreasing trend since the late 1970s similar to that of PWS guillemot population. During this same period, the diet of pigeon guillemot chicks on Naked I. also changed from one that was previously dominated by sand lance to one that is now dominated by demersal fish. We believe there may be a link between the change in chick diet and the population decline.

The productivity of pigeon guillemots was lower, but not significantly so, in the 1990s than it was in the late 1970s. After 1989, predation was more prevalent at our study colonies than it was previously, and was the cause of numerous nesting failures. However, the pigeon guillemots on Naked I. appear to be doing better than their conspecifics in other regions. Thus low productivity is not likely to be the cause of the population decline.

The Gulf of Alaska ecosystem shift may account for the observed decline in populations of pigeon guillemots and other piscivorous marine birds. Switching to alternate prey species, however, has allowed remaining guillemots at Naked I. to maintain their productivity. Chick diet, seine attempts, aerial surveys by Evelyn Brown, and anecdotal evidence indicate an increase in the numbers of sand lance around Naked Island. If the trend continues, we can track this sand lance increase and see if the population of guillemots changes in response to it. Also, if the guillemot population does increase with increasing sand lance abundance, we can monitor if and when they reach historical population levels.

ACKNOWLEDGMENTS

We thank Mark Russell and Bryan Duggan for their help in the field and Burt Pratte for help with logistics during the 1996 field season. The U.S. Forest Service granted us permission to use Naked Island as our base of operations while in the field. We also thank Steve Kendall for making the maps. Discussions with David Duffy, George Divoky, David Irons, Kathy Kuletz, and Dan Roby regarding various aspects of this project have been most helpful.

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FIGURE CAPTIONS FOR 1996 APEX GUILLEMOT REPORT

Figure 1. Naked Island complex (Naked, Peak, Storey, Smith, and Little Smith Islands), Prince William Sound, Alaska. Distribution of pigeon guillemot study colonies (circles) and beach seining locations (triangles) on Naked Island. Study colonies: Igloo (1), Nomad (2), Thumb (3), Row (4), North Cabin (5), South Cabin (6), Outer Cabin (7), North Outside (8), Inside Outside (9), Hook (10), Tuft (11). Beach seining locations: MacPherson Isthmus (A), MacPherson Narrows (B), East Bob Day Bay (C), North Cabin Bay (D), Division Point (E), Fuel Cache Beach (F), Outer Cabin Bay (G), Outer Cabin Point (H), Inside Outside Bay (I), East Outside Bay (J), West Outside Bay (K), and Hook II (L).

Figure 2. Attendance patterns of pigeon guillemots at Nomad and Thumb colonies on Naked Island, Prince William Sound, Alaska (12-13 June, 1996).

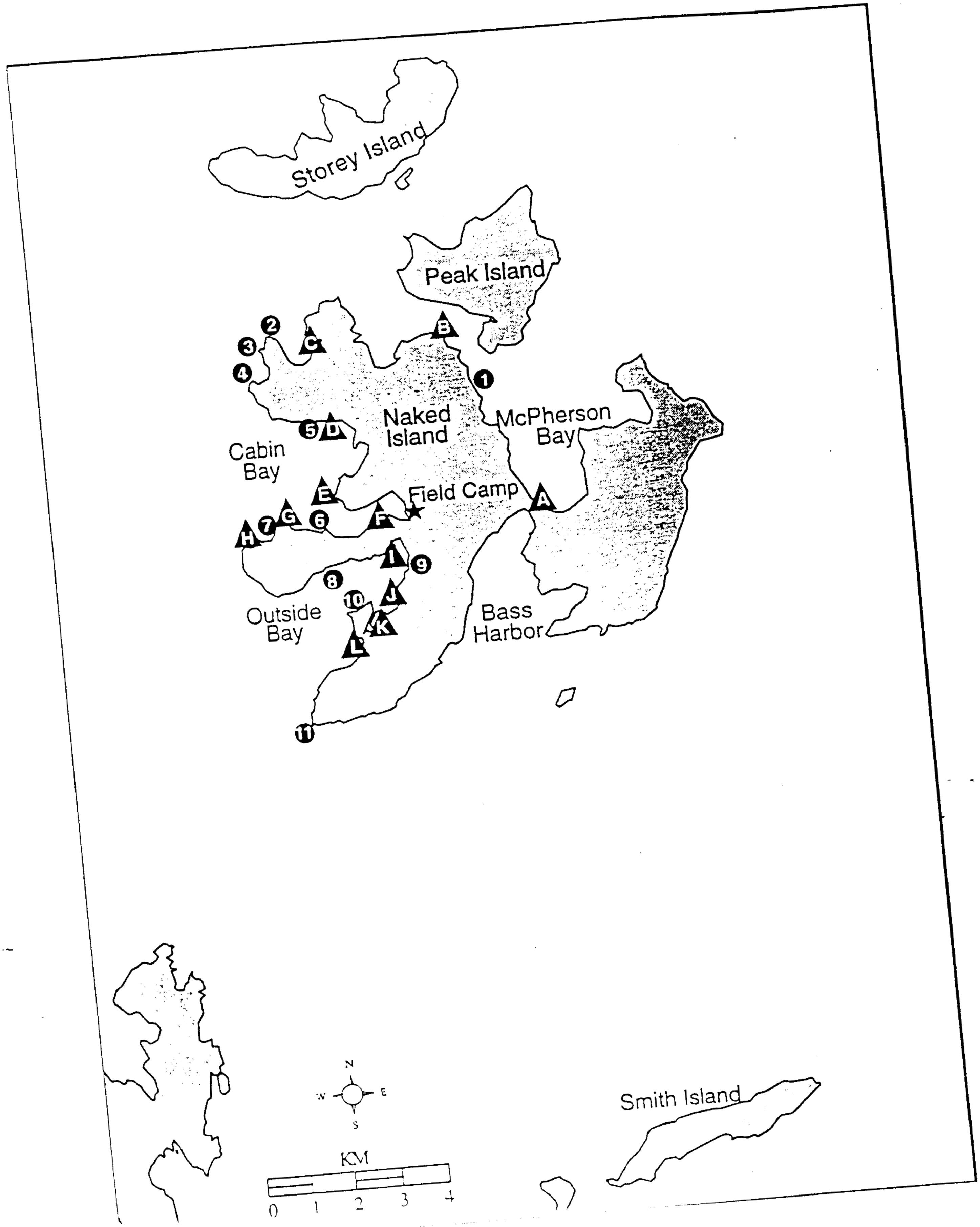
Figure 3. Attendance patterns of pigeon guillemots at Nomad and Thumb colonies on Naked Island, Prince William Sound, Alaska (18-19 June, 1996).

Figure 4. Temporal distribution of food deliveries (n = 535) by adult pigeon guillemots at several colonies on Naked Island, Prince William Sound, Alaska. Observations made between 3 July and 7 August, 1996 (9 colony-days, 43 nest-days). Sampling effort was not equal for periods before 0600 and after 2200.

Figure 5. Diet history of pigeon guillemot chicks on Naked Island, Prince William Sound, Alaska. Numbers above bars are sample sizes. Blennies include mostly gunnels and pricklebacks. Other includes flatfish, greenling, sandfish, rockfish, and a few other types.

Figure 6. Regression of pigeon guillemot population on percent of sand lance in chick diet for Naked Island, Prince William Sound, Alaska.

Figure 7. Regression of number of active pigeon guillemot nests on percent of sand lance in chick diet for Naked Island, Prince William Sound, Alaska.


Storey Island
Peak Island
Naked Island
McPherson Bay
Cabin Bay
Field Camp
Outside Bay
Bass Harbor
Smith Island
N
W
E
S
KM
0 1 2 3 4
A
B
C
D
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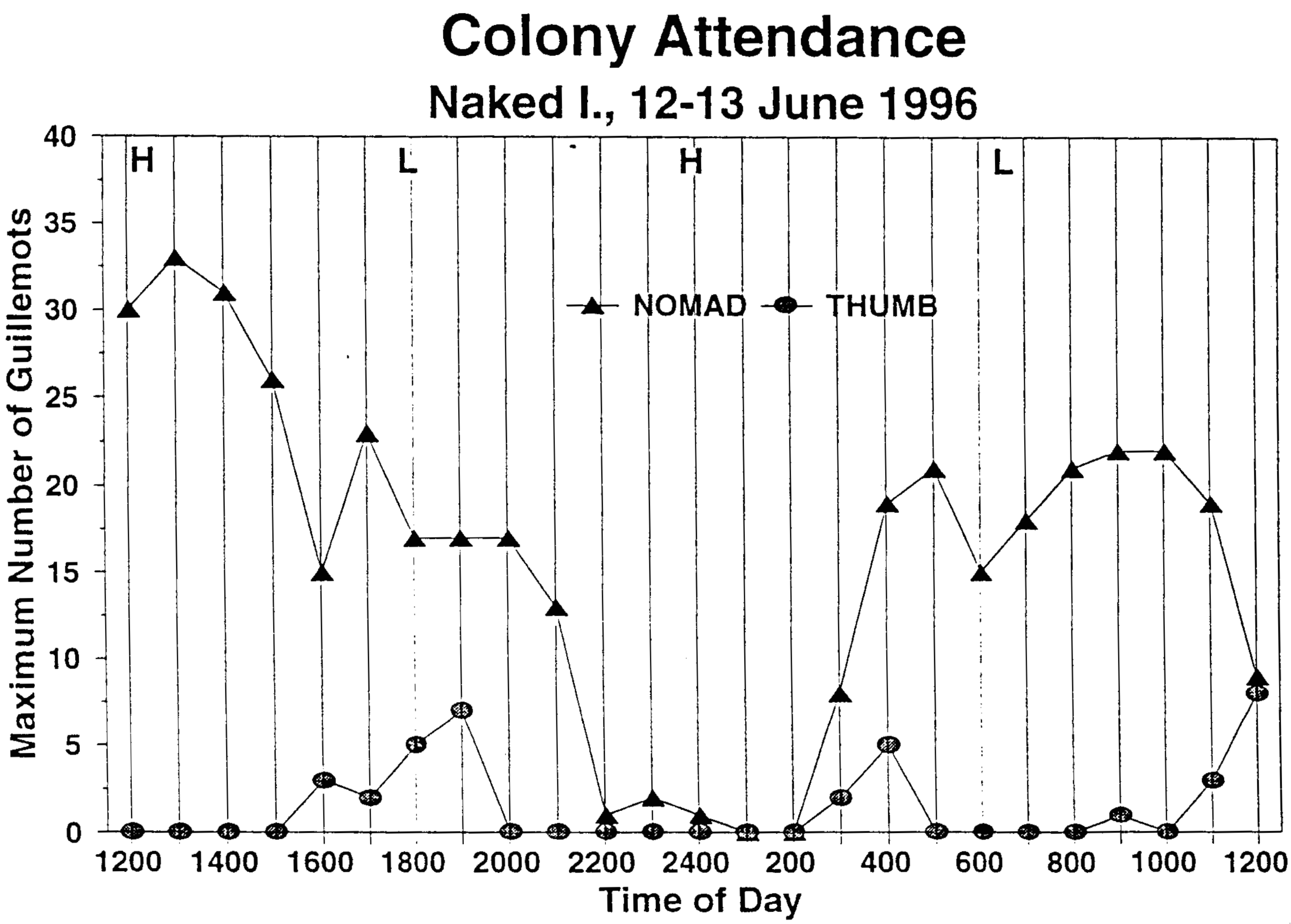
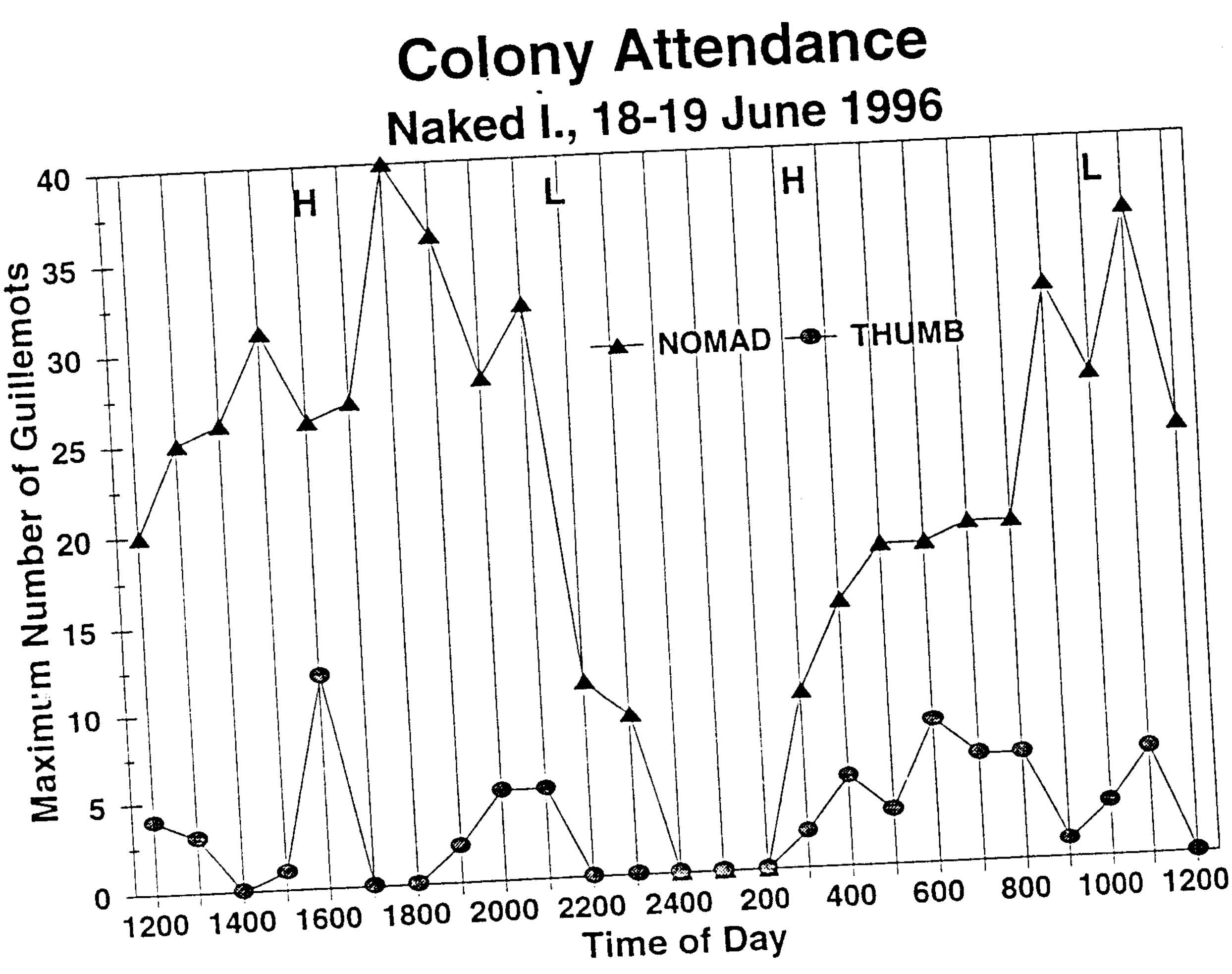


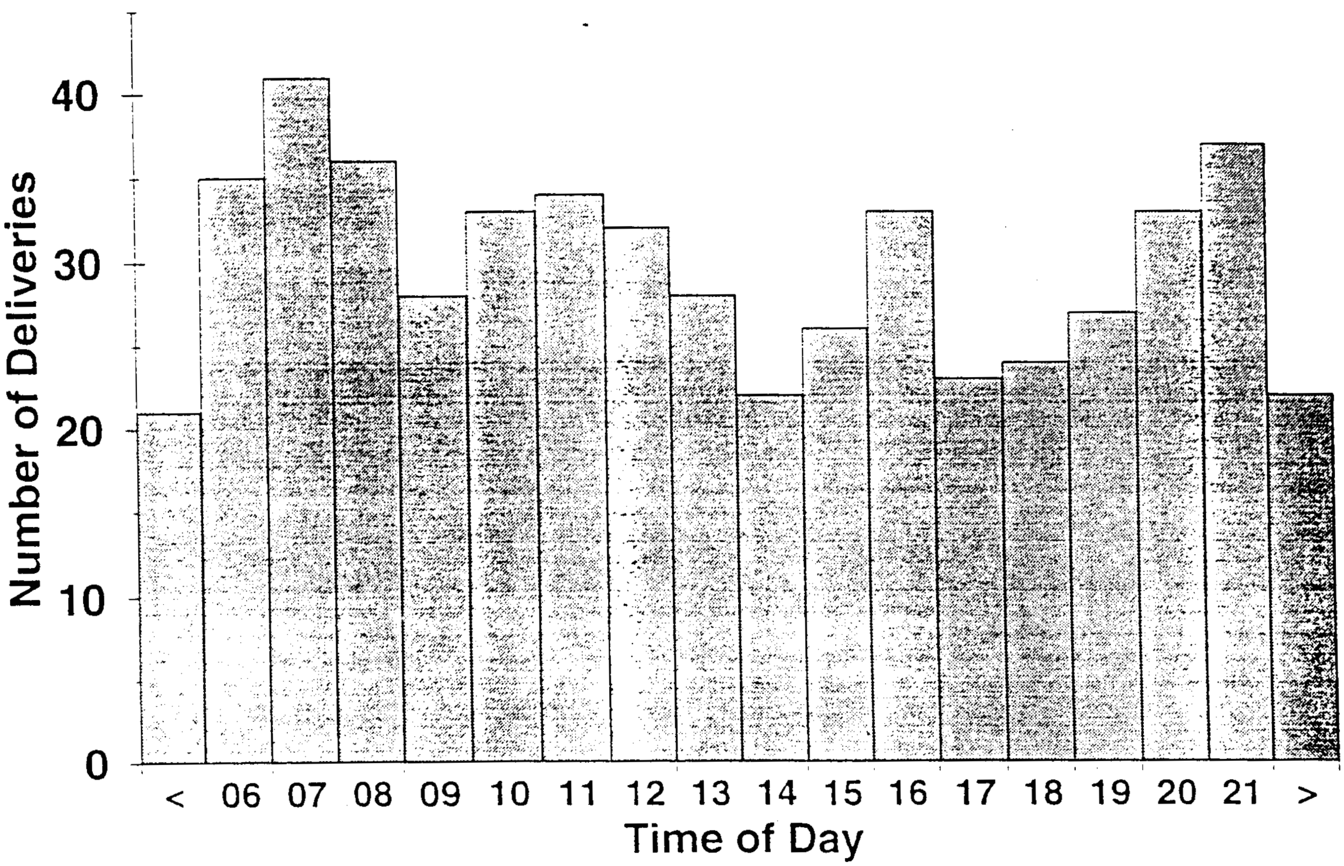
Colony Attendance
Naked I., 12-13 June 1996
H
L
H
L
NOMAD
THUMB
Maximum Number of Guillemots
40
35
30
25
20
15
10
5
0
1200
1400
1600
1800
2000
2200
2400
200
400
600
800
1000
1200
Time of Day

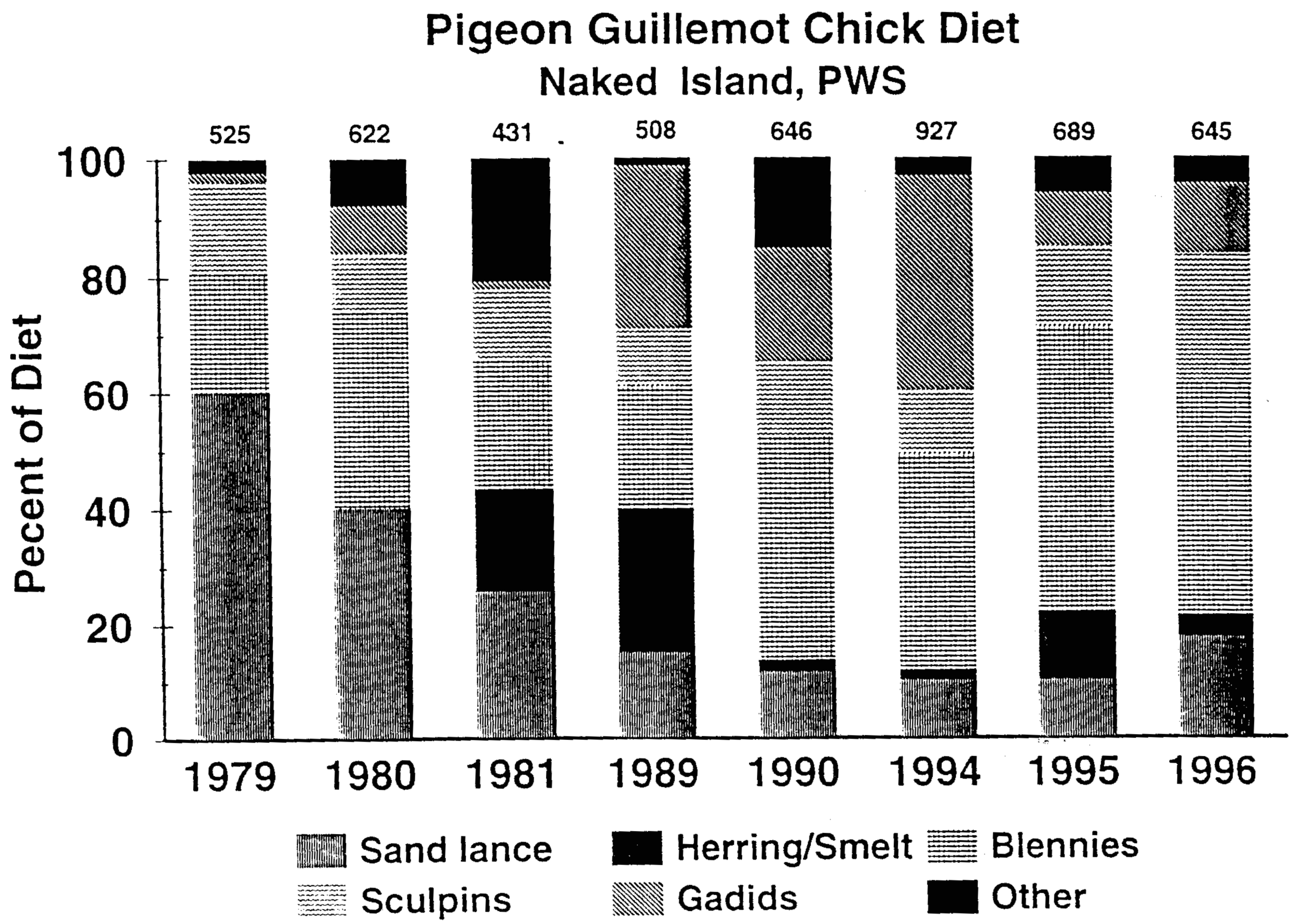


Colony Attendance
Naked I., 18-19 June 1996
Maximum Number of Guillemots
Time of Day
NOMAD
THUMB
H
L
H
L
0
5
10
15
20
25
30
35
40
1200
1400
1600
1800
2000
2200
2400
200
400
600
800
1000
1200

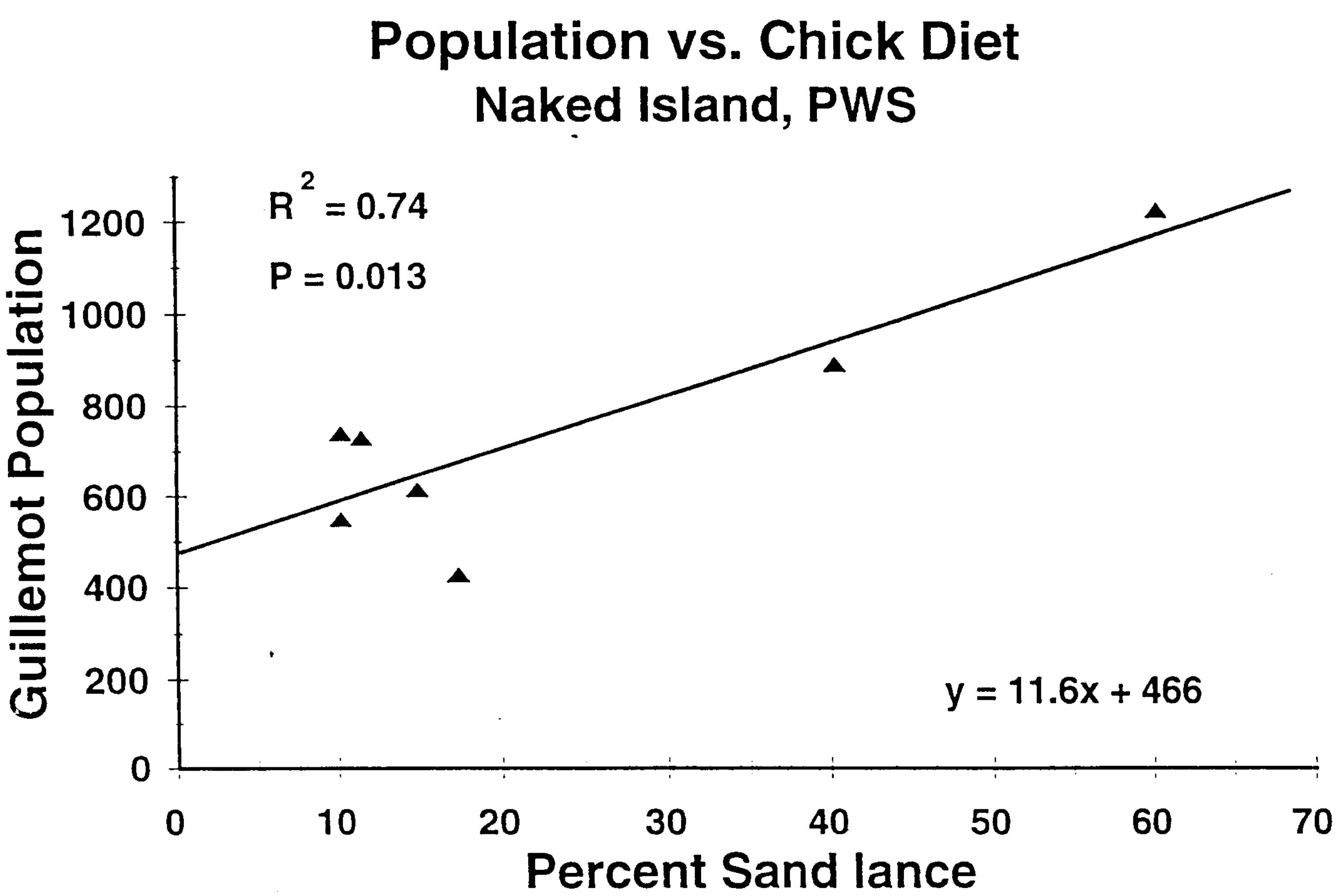
Temporal Distribution of Deliveries

Naked Island -- 1996





Pigeon Guillemot Chick Diet
Naked Island, PWS
525
622
431
508
646
927
689
645
100
80
60
40
20
0
Pecent of Diet
1979
1980
1981
1989
1990
1994
1995
1996
Sand lance
Herring/Smelt
Blennies
Sculpins
Gadids
Other


Population vs. Chick Diet
Naked Island, PWS
$R^2 = 0.74$
P = 0.013
y = 11.6x + 466
Guillemot Population
0
200
400
600
800
1000
1200
0
10
20
30
40
50
60
70
Percent Sand lance

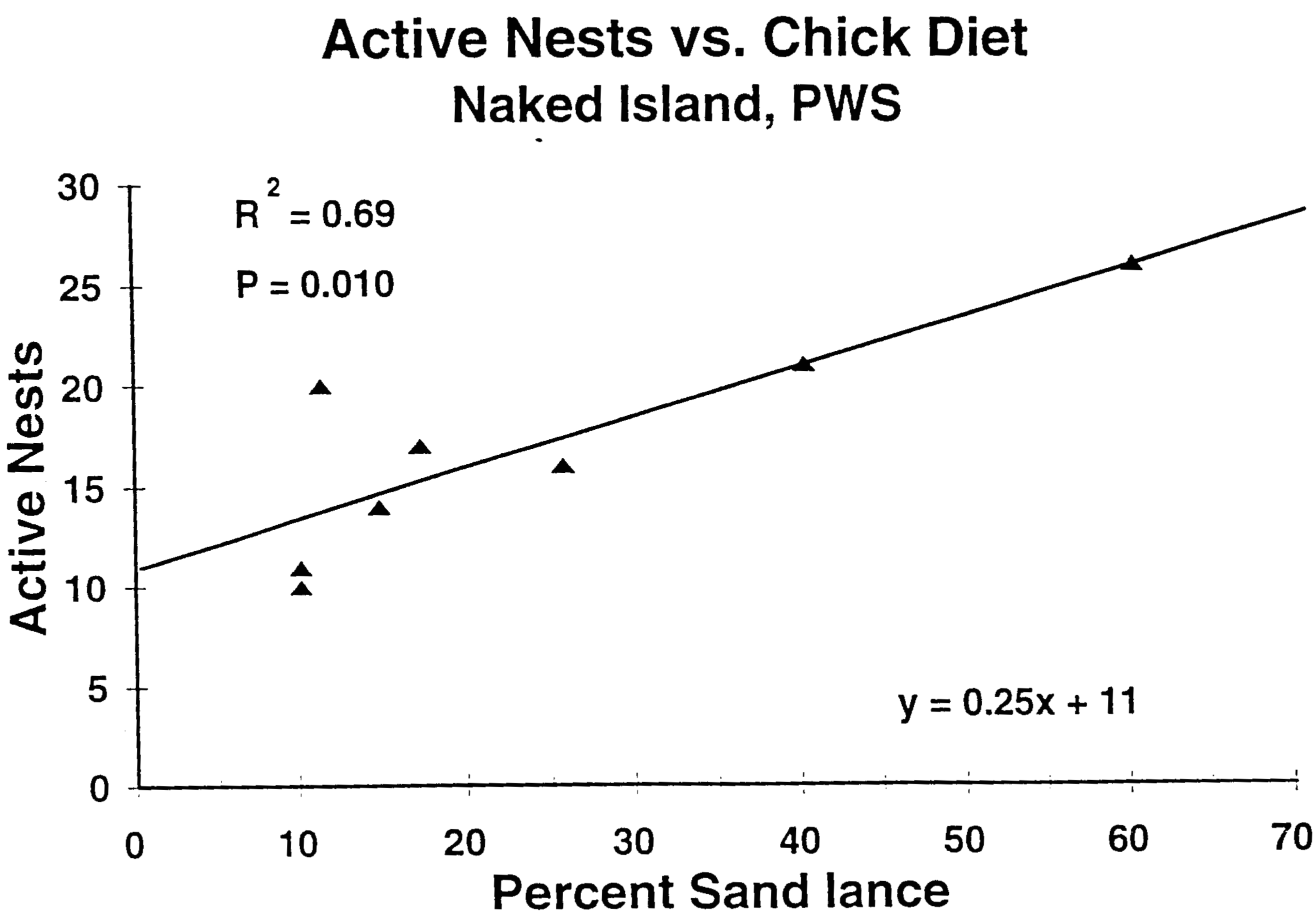

Active Nests vs. Chick Diet
Naked Island, PWS
R 2 = 0.69
P = 0.010
y = 0.25x + 11
Active Nests
Percent Sand lance
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70

Table 1. Counts of pigeon guillemots during early season censuses at Naked, Peak, Storey, Smith, and Little Smith Islands, Prince William Sound, Alaska. Censuses conducted in the morning between 30 May and 14 June unless otherwise noted. Dashes indicate no surveys were conducted.

Year	Naked Island	Storey Island	Peak Island	Smith Island	Little Smith Island	Total
1978	1115	392	94	175	72	1848
1979	1226	495	150	301	58	2230
1980	891	--	--	--	--	--
1989	615	193	73	--	--	--
1990	729	293	102	124	31	1279
1991	755	293	102	76	35	1261
1992	586	266	87	100	23	1062
1993[a]	385	242	94	75	32	828
1994	739	298	81	121	23	1262
1995	550	165	38	111	23	887
1996	428	185	57	116	23	809

[a]Not all counts made in the morning.

Note: Data for 1978-1992 from Table 1 (Oakley and Kuletz 1996).

Table 2. Mean clutch size, mean rates of hatching (hatchlings/nest) and fledging (fledgings/nest) of pigeon guillemots on Naked Island, Prince William Sound, Alaska.

	Clutch Size			Hatching Success			Fledging Success		
Year	Mean	n	SE	Mean	n	SE	Mean	n	SE
1978	1.54	13	0.14	1.22	9	0.28	1.25	8	0.20
1979	1.85	33	0.06	1.34	32	0.15	1.13	30	0.13
1980	1.78	27	0.08	1.05	20	0.20	0.61	18	0.20
1981	1.59	22	0.11	1.14	21	0.17	0.74	19	0.17
1984	1.86	7	0.14	1.43	7	0.37	1.00	7	0.28
1989	1.57	7	0.20	1.43	7	0.30	0.50	6	0.34
1990	1.78	27	0.10	1.28	25	0.16	0.68	24	0.16
1994	1.70	23	0.10	1.52	23	0.15	0.78	23	0.17
1995	1.77	39	0.07	1.41	39	0.13	0.77	39	0.13
1996	1.80	41	0.06	1.49	41	0.12	0.73	41	0.12

Table 3. Growth rates of pigeon guillemot chicks raised on Naked Island, Prince William Sound, Alaska.

Year	Number of Chicks	Mean Growth Rate (g/d)[a]	SE	Minimum Growth Rate (g/d)[a]	Maximum Growth Rate (g/d)[a]
1978	15	19.6	1.4	7.4	31.7
1979	16	23.8	1.2	17.1	32.0
1981	11	19.2	1.8	11.4	34.3
1989	5	18.1	2.5	11.5	23.4
1990	12	16.6	1.2	10.1	23.6
1994	10	15.7	2.1	5.0	29.0
1995	13	19.5	1.2	11.8	26.7
1996	20	20.9	1.2	11.6	32.0

[a]Mean number of grams gained per day during the linear phase of growth (8-18 days posthatching; Koelink 1972).

Table 4. Fledging weights[a] of pigeon guillemot chicks raised on Naked Island, Prince William Sound, Alaska.

Year	Number of Chicks	Mean Fledging Weight (g)	SE	Minimum Fledging Weight (g)	Maximum Fledging Weight(g)
1978	29	467	9	291	542
1979	17	506	12	427	590
1980	2	517	52	466	569
1981	13	428	29	202	546
1989	10	507	16	420	570
1990	13	438	16	310	510
1994	17	453	13	357	525
1995	22	455	16	311	561
1996	23	456	12	328	560

[a] Fledging weight was considered to be the last weight obtained within one week (1978-1994) and within 24 hours (1995-1996) of fledging.

Table 5. Types of fish and numbers (n=67) recovered from or intercepted at guillemot nests on Naked Island, Prince William Sound, Alaska, in 1996.

Pacific Sand Lance (*Ammodytes hexapterus*)	13
Slender Eelblenny (*Lumpenus fabricii*)	3
Crescent Gunnel (*Pholis laeta*)[a]	24
Daubed Shanny (*Lumpenus maculatus*)	3
Snake Prickleback (*Lumpenus sagitta*)	5
Black Prickleback (*Xiphister atropurpureus*)	1
Ribbed Sculpin (*Triglops pingeli*)	1
Lingcod (*Ophiodon elongatus*)	1
Pacific Sandfish (*Trichodon trichodon*)	1
Shrimp (*Pandalus* sp.)	1
Walleye Pollock (*Theragra chalcogramma*)	2
Rex Sole (*Glyptocephalus zachirus*)	3
Northern Ronquil (*Ronquilus jordani*)	1
Slim Sculpin (*Radulinus asprellus*)	1
Tidepool Sculpin (*Oligocottus maculosus*)	6
Plain Sculpin (*Myoxocephalus jaok*)	1

[a]Most Crescent Gunnels were collected from the same nest (NO1 in Outside Bay).

Table 6. Fish caught in beach seine sets made around Naked Island, Prince William Sound, Alaska, in 1996. SAN=sand lance, GAD=gadids, SAL=salmonids, SND=sandfish, HEX=Hexagrammidae, HER=herring, SCU=sculpins. See Figure 1 for locations.

LOCATION	TIME	SAN	GAD	SAL	SND	HEX	HER	SCU	OTHER
A									
06 JUL	1520	3100							1
01 AUG	1445	2					12	3	
13 AUG	1750	3385	1					1	
B									
01 AUG	1601	29					62		
13 AUG	1830	7				2	78		5
C									
01 AUG	1320	3					79		
D									
14 JUL	1625		1	3		1			
E									
14 JUL	1550	1							
F									
28 JUN	1630		7	141				2	2
14 JUL	0950	1	4	1	3			1	3
21 JUL	2000	97						4	1
22 JUL	0815	46						2	1
22 JUL	1205	18	2	3		1			8
22 JUL	1605	10000							
22 JUL	1955	31							
27 JUL	1035	5500							
13 AUG	1940	3				1			3
G									
14 JUL	1530	7			2		1		
H									
27 JUL	1126			3					
I									
14 JUL	1215		61		106	17	2	1	
28 JUL	1927		417	1	1	18			19
J									
28 JUL	1835		2	1	3			1	4
K									
28 JUL	1900								0
L									
14 JUL	1110			2					
28 JUL	1755								1
Total		22230	495	155	115	40	234	15	48

Table 7. Causes of nesting failure of pigeon guillemots at Naked Island, Prince William Sound, Alaska.

		Number of nests in which at least one egg failed to hatch or at least one chick failed to fledge.					
Year	Number of Nests	Unhatched Egg[a]	Young Chick Death[b]	Predation of Egg	Predation of Chick	Starvation or Exposure	Unknown Reason
1978	32	4	0	0	0	0	2
1979	30	6	1	2	1	1	4
1980	19	5	0	2	0	4	2
1981	22	6	1	2	0	6	0
1989	15	3	1	1	4	0	0
1990	38	2	1	3	4	1	5
1994	23	1	1	2	7	1	4
1995	39	7	2	3	1	3	9[c]
1996	41	7	0	2	9	1	9[d]

[a]Includes eggs which failed to hatch due to infertility, embryo death, or nest desertion.

[b]Refers to chicks, less than one week old, dying in the nest for no apparent reason.

[c]Predation suspected in 8 instances.

[d]Predation suspected in 6 instances.