OCS STUDY
MMS 85-0068

Ecological Research Associates

POPULATION ESTIMATION, PRODUCTIVITY AND FOOD HABITS OF NESTING SEABIRDS AT CAPE PEIRCE AND THE PRIBILOF ISLANDS, BERING SEA, ALASKA

FINAL REPORT

Edited by

Stephen R. Johnson, Ph.D.

LGL Ecological Research Associates, Inc.
1410 Cavitt Street
Bryan, Texas 77801

for

U.S. Department of Interior
Minerals Management Service
P.O. Box 101159
Anchorage, Alaska 99510

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DISCLAIMER

EXECUTIVE SUMMARY

The U.S. Minerals Management Service (M MS) has begun to monitor populations of seabirds in the Bering Sea in order to determine if any future population changes that occur are caused by OCS petroleum development operations. MMS desires that the initial monitoring studies investigate seabird abundance, productivity and diet; compare new findings with findings of previous studies; discuss the significance of population trends observed; and develop strategies for future monitoring. Seabird colonies at Cape Peirce on the Alaska mainland and at the Pribilof Islands have been designated to be the focus of initial investigations. Several studies have been conducted at each location in the past, but the results of past studies are frequently not suitable for long-term monitoring studies because of different objectives.

Eleven species of seabirds are common in the colonies of interest (including both sites); the Pribilof Island colonies support a more diverse species assemblage than does Cape Peirce. Species potentially useful for population monitoring include black-legged and red-legged kittiwakes; thick-billed and common murres; red-faced, pelagic and double-crested cormorants; and parakeet, crested and least auklets.

Black-legged kittiwakes number from 1-4 million in the eastern Bering Sea in summer and fall. They nest abundantly at both Cape Peirce and the Pribilofs, varying greatly in reproductive success from year to year. Non-breeders are widely dispersed in the Bering Sea in summer; most move south in winter. They feed mainly on fish at or near the surface.

Red-legged kittiwakes nest abundantly (88$ of the world population of 250,000) at the Pribilofs, but do not nest at Cape Peirce. Their breeding success is highly variable annually. Feeding birds in summer concentrate south and west of the Pribilofs, most moving south in winter. These birds feed mainly on fish at or near the surface.

About 5.3 million murres breed in the eastern Bering Sea; common murres are the only species at Cape Peirce and thick-billed murres predominate on the Pribilofs. Murres are long-lived, slow-reproducing birds with less annual variability in breeding success than the kittiwakes. In summer most concentrate to feed near the colonies; most also winter in the Bering Sea. Both species eat mainly fish; common murres depend largely on nearshore mid-water fishes and thick-billed murres depend largely on demersal fishes and crustaceans in deeper waters.

Of the cormorant species, the red-faced cormorant is the only one nesting at the Pribilofs, and pelagic cormorants dominate at Cape Peirce. Red-faced cormorants are year-round residents at the Pribilofs. All the cormorant species feed largely on fish, which they catch by diving in waters near their breeding colonies.

The three auklet species are extremely abundant breeders in the eastern Bering Sea, with estimated populations of 6 million (least auklet), 2 million (crested auklet) and around 0.5 million (parakeet auklet). All are long-lived and reproduce slowly, but data on reproduction are difficult to gather because many nest deep in crevices. Most individuals of all species concentrate near their breeding colonies from May to September, but mostly move out of the Bering Sea in winter. Least and crested auklets dive to moderate depths to prey on zooplankton. Parakeet auklets feed at varying depths and on a greater variety of prey than do the other two species.

This first-year monitoring program includes studies of three major topics--population estimates, productivity estimates, and food habits. Based on the results of our studies and on information collected by others, we have made recommendations for monitoring strategies.

Population Studies

The objectives of our population studies were (1) to determine if seabird population size had changed on the Pribilofs and at Cape Peirce since previous studies, and (2) to estimate seabird population size

The population studies focused on a few key seabird species, and included two main strategies--visual counts of seabirds on plots studied in previous years, and intensive sampling of portions of plots using time-lapse photography.

Our research was focused on four areas: the documentation of diurnal trends in abundance, seasonal trends in abundance, among-year trends in abundance and analysis of methods to improve population estimators.

Most species of seabirds exhibited distinct diurnal cycles in attendance that were not in phase with each other. These cycles were pronounced early in the season but diminished as incubation got underway. In general, plot censuses should be conducted during the mid-incubation period, when numbers of birds are most stable and counts may be made over a broad segment of the day.

The influence of seasonal trends (variation in attendance over the course of the breeding season) in counts of seabirds may be very important in assessing among-year trends in population size. When a large seasonal component of variation exists (as was found for several species) several replicate counts are necessary to distinguish among-year from within-year components of variability. Unfortunately our baseline from the Pribilofs is limited to single counts sampled over a broad time period (UP to one month) thus preventing the elucidation of unambiguous among-year components of populaton changes.

For many species the counts on the Pribilofs in 1984 were lower than counts made in 1976 or 1982, and usually much lower thanin 1976. These changes were more pronounced on St. George than on St. Paul. The most convincing evidence for a substantial decrease in population trend was for red-faced cormorant, on both islands. For other species (1) apparent changes in abundance were not significantly different among years (common murre and red-legged kittiwake), or (2) there were significant changes in abundance but counts in 1984 indicate recovery relative to 1982 (northern fulmar), or (3) different trends occurred on the two islands (black-legged kittiwake and thick-billed murre), suggesting that seasonal changes (sample dates) might be responsible for the significant test statistics.

We found that the method of stratification originated by Hickey and Craighead (1977) is useful in improving population estimates based on changes in occurrence or density of some species among strata. To increase precision, our population estimation analyses describe maximum likelihood estimators that optimally fit the seabird data to mathematical distributions of known properties. An important investment of time in future studies would be to accurately determine the area of study plots and the area of the cliffs (proportionof the total cliff area) occupied by birds to improve extrapolation procedures.

Our cluster counting and maximum likelihood estimator procedures always improved our estimates (increased the precision and reduced the confidence intervals) of population size over methods previously used, i.e., mean density/area estimators (Hickey and Craighead 1977, Craighead and Oppenheim 1982). Our ability to estimate populations ranged from very good for thick-billed murres (± 10%) to poor for red-faced cormorant (± 100%).

In summary we feel a more critical examination of the seabird monitoring strategy be undertaken before the MMS program becomes firmly established. A monitoring program demands that studies be comparable among years; however an uncritical philosophy of repeating prior baseline studies (often designed with different research foci) may preclude meeting current objectives. We recommend that emphasis be placed on determining the most effective means of monitoring trends. To achieve this, improvement in plot selection, sampling intensity (spatial and temporal) and analytical procedures all need to be addressed. A lower, albeit important, research priority should be to improve the technique for estimating actual population size.

Productivity Studies

The term ‘productivity", in this study, is the mean number of chicks per nest (or site, in the case of murres) still alive in study plots at the termination of field investigations. All complete nest platforms were considered kittiwake nests; all sites on cliffs where murre eggs were seen were considered murre nests. Productivity estimates, when compared with those of past years, showed that productivity has been low for the past few years, including 1984, for most species.

Estimates of black-legged kittiwake productivity were very low in 1984 on St. George (0.14) and St. Paul (0.06) islands and at Cape Peirce (less than 0.01). Likelihood Ratio Tests indicated that 1984 was among the poorest of years measured for black-legged kittiwake productivity and reproductive success in the southern Bering Sea, Comparisons over recent years at other colonies in the Bering Sea indicate that black-legged kittiwake productivity has been depressed for three years at many important colonies (St. George, St. Paul, Cape Peirce, St. Matthew and possibly St. Lawrence).

Red-legged kittiwake productivity was very low on St. George and St. Paul islands in 1984 (0.13 and 0.09). Likelihood Ratio Tests indicate that on St. George Island, where about 80% of the world population nests, productivity has been low for at least the last five years when data were obtained.

Estimates of productivity of thick-billed murres in 1984 were much higher on St. George Island (0.31) than on St. Paul (0.03); it has been speculated that human disturbance at St. Paul may have the effect of depressing seabird productivity. Productivity of thick-billed murres was markedly higher in 1984 on St. George than Craighead and Oppenheim recorded in 1982.

Maximum estimates of productivity of common murres at Cape Peirce in 1984 were only 0.05, lower than recorded in 1976 and 1981. During the studies in 1984 and 1976, common ravens preyed. heavily on eggs of common murres and black-legged kittiwakes at Cape Peirce. During years when productivity is depressed (when breeding birds may be stressed, as in 1984), ravens may be more effective predators of eggs and chicks.

There were no significant differences in productivity among different elevational strata or among different plots for any key species of seabird studied in 1984 on the Pribilof Islands or at Cape Peirce.

Sufficient time should be budgeted in seabird colony studiesso that productivity (mortality) of eggs and chicks can be tracked through the entire breeding season (until surviving chicks are large). Studies that end early run the risk of inaccurately estimating productivity.

Analysis of time-lapse photography shows great promise as a tool for documenting trends in colony attendance, which may be related to reproductive status. Detailed computer analyses of time-lapse photography may help determine the number of breeding murres (especially common murres) on crowded ledges where eggs and chicks (breeding pairs or active sites) often are difficult or impossible to detect by customary visual methods.

Feeding Studies

Food habits studies of 10 seabird species at the Pribilof Islands , showed that some specialized in fish and others ate predominantly pelagic invertebrates. In 5 species (northern fulmar, both kittiwakes, parakeet auklet, tufted puffin) fish comprised greater than 80%.of wet weight diet.

In three other species (common murre, thick-billed murre, horned puffin) fish comprised 25-70% of diet wet weight, with the remainder being primarily crustaceans (in murres) or squid (in horned puffins). In the remaining two species (least and crested auklets), fish comprised less than 2% of diet wet weight, and crustaceans comprised greater than 94%.

Differences in the diets of birds grouped by age, time during the breeding season, or island (St. George or St. Paul) were found in 3 of the 4 species studied in detail. Only in least auklets was the diet similar between months and islands. Hence, if the diets of seabirds are tobe useful at all in monitoring studies, It is important to control collections for various attributes of the birds' ages, collection locations and times of sampling.

Wet weight measurements of food samples were more rapid, more precise and more consistent than were volumetric measurements, Wet weights are recommended as the preferred method of measuring the amounts of food eaten by seabirds. Although no statistical evaluation was made, non-parametric statistical methods probably are more appropriate for analyzing differences in the amount of food eaten than are parametric methods.

Monitoring Strategies

The objectives of a seabird monitoring program are to measure trend in populations and to determine if observed changes in trend are development-related. Potential items to be monitored include population numbers, productivity, and seabird diet.

Past research at some colonies has demonstrated that small to moderate changes in numbers and annual production of seabirds at colonies can be documented. Causes of change have been more difficult to determine, though changes in food availability, resulting from such things as fishing by man, large-scale shifts in ocean circulation or climatic changes, have been implicated. There is no indication from the literature that any activities related to OCS development, except for oil spills, have caused population changes to seabirds.

Based on an analysis of available literature and an evaluation of results from this program, a combination of two general approaches seems desirable for monitoring studies--(1) repeated measures of population numbers over time at selected colonies to determine population trends, and (2) experiments at sites of OCS activity to determine whether the activities affect annual productivity. Trend measurements alone cannot isolate causes of change, and results of experiments at sites of OCS activities cannot, without trend measurements, be readily translated into regional population-level effects. It doesnot appear that food habits studies would contribute a great deal to determining whether bird population numbers change or to establishing whether OCS activities caused any changes. However, catastrophic diet changes have been linked to major population changes in some species of seabirds. If diets of seabirds are not monitored systematically in similar situations in the Bering Sea, similar changes could be attributed arbitrarily to OCS activities.

For measuring regional trends in population numbers over time, monitoring should focus on species that are abundant, widespread, and easily sampled and that have several years of historical data at the colonies to be monitored. Species that are endemic to the area also are of particular interest. At least one species from each major foraging type (e.g., benthic, surface, nearshore, offshore) should be included if possible. In the Bering Sea, the five most suitable species are, in approximate order of suitability: red-legged kittiwake, black-legged kittiwake, thick-billed murre, least auklet, and red-faced cormorant. Colonies that would be most suitable as trend monitoring sites, based on the number and diversity of seabird species present, ease of study, and amount of historical data available, are those on the Pribilof Islands, St. Lawrence Island, Bluff, St. Matthew/Hall islands, and Cape Peirce/Shaiak Island. Other colonies are considered less suitable.

The primary variable of interest for trend monitoring is population numbers, and several considerations apply. Two measurements are desirable: (1) the number of birds in attendance and (2) the number of nests or breeding birds. Distributional characteristics of most seabirds in colonies suggest that the best enumeration techniques involve stratifying cliff faces on which birds occur, counting of birds on sample plots, and accounting for clustering of birds in statistical treatment of data and deriving maximum likelihood estimators that optimally fit the seabird data to mathematical distributions of known properties. Patterns of temporal variability in bird attendance at colonies suggest that at least ten replicate counts should be made. Counts should be designed (e.g., collapsible into simpler forms) so that data collected can be readily compared with data from previous studies.

For determining whether OCS activities contribute to seabird population changes, site-specific studies of the effects of selected activities on productivity are recommended. Studies with spatial controls should be designed around specific activities that occur near seabird colonies or feeding areas. The measured effects of these activities on colony productivity should be translated into potential long-term effects on regional population numbers so that correlations may be made with results of the trend monitoring studies (see above). Unfortunately, the activity most likely to affect population numbers is probably an accidental oil spill, effects of which would be difficult to experimentally evaluate because locations of spills are not predictable. The most that can be hoped for in such a case would be to quantify oil-caused mortality to the extent possible and attempt to relate mortality level to observations at trend monitoring stations (e.g., at colonies).

Productivity data collected on test and control sites should be amenable to rigorous statistical tests for differences among locations and years. Passive methods for determining productivity (e.g., observations from a distance) are recommended to prevent reduced productivity as a consequence of the research activity. Automatically-controlled camera systems to regularly photograph sample plots offer promise in both population and productivity studies.

CHAPTER I

INTRODUCTION AND BACKGROUND*

By

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● Johnson, S.R. and D.M. Troy. 1985. Chapter I. Introduction and Background. Pages 1 to 33. <u>In</u>: S.R. Johnson (Ed.). Population Estimation, Productivity, and Food Habits of Nesting Seabirds at Cape Peirce and the Pribilof Islands, Bering Sea, Alaska. Report by LGL Ecological Research Associates, Inc. to Minerals Management Service, Anchorage, Alaska. 330 p.

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INTRODUCTION

The United States Department of the Interior (USDI), Minerals Management Service (MMS), contracted LGL Ecological Research Associates Inc. (LGL) to design and implement a seabird monitoring program at two colonies in the Alaska Bering Sea--the Pribilof Islands and Cape Peirce (Fig. 1). MMS wishes to monitor seabird breeding colonies because seabirds are highly visible, major components of marine ecosystems, and because they may be vulnerable to Outer Continental Shelf (OCS) development activity. Further, many of the seabirds occurring in the Bering Sea are protected by treaties between the U.S.A., Japan, Canada, and the U.S.S.R. to conservation of migratory birds and their environment. These treaties prohibit the disturbance of nesting colonies and directs the contracting parties to undertake measures necessary to protect the environment of migratory birds and to prevent and abate the pollution or detrimental alteration of that environment.

The seabird monitoring program constitutes efforts by the U.S.A. to better understand what environmental factors influence seabird abundance and productivity and to determine if seabirds are affected by OCS oil and gas activity scheduled to occur soon in the Bering Sea.

Objectives

The purpose of the work conducted during the summer of 1984 was to measure selected population characteristics of nesting seabird colonies at Cape Peirce (exclusive of Shaiak Island) and on the Pribilof Islands. The studies in 1984 are part of a long-term monitoring program, and as such, include a re-census of colonies that have been censused before.

Specific objectives were to

(1) develop statistically valid measures of the number of birds and the chick productivity for each major species in the Cape Peirce and Pribilof Islands colonies,

(2) develop estimates of kinds and amounts of foods consumed by the major species in the Pribilof Island colony,

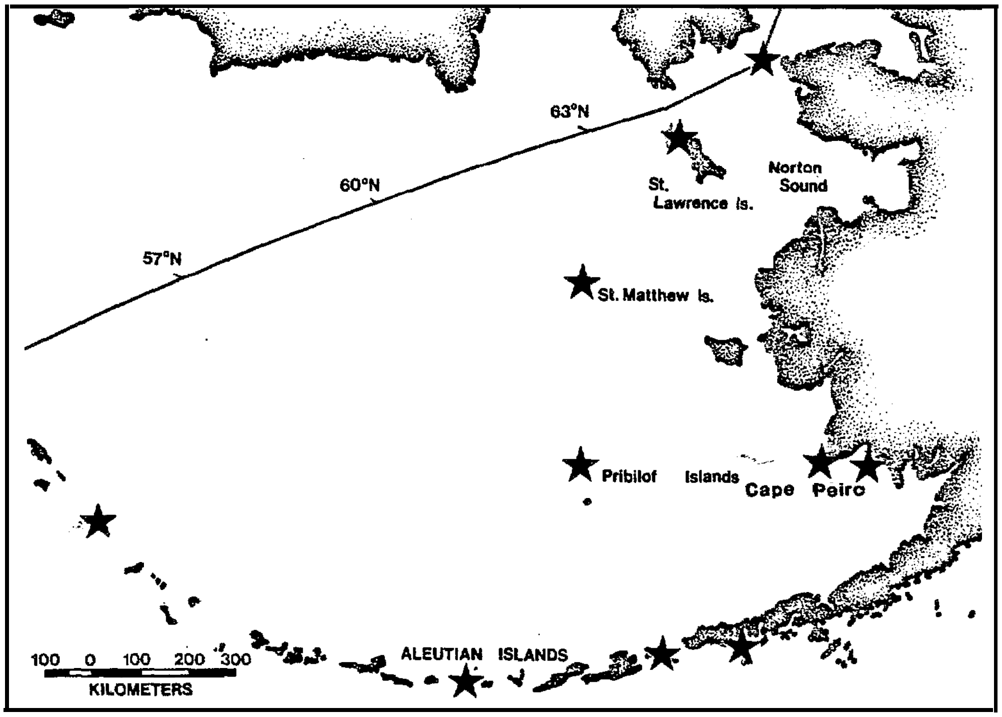

Figure 1. Major breeding concentrations of seabirds in the Bering Sea (greater than 500,000 birds) (after Sowls et al. 1978, Nysewander et al. 1982).

(3) compare the results of the study with those of previous studies of the colonies,

(4) discuss the biological significance of population trends in the colonies, and

(5) develop strategies for future monitoring efforts for the colonies.

Sites for Study

The sites of interest are in the southern Bering Sea. Cape Peirce is on the mainland, whereas the Pribilof Islands are remote oceanic islands close to the shelf break (Fig. 2).

Dick and Dick (1971) and Petersen and Sigman (1977) describe the Cape Peirce area in detail, especially climatic and physiographic features. Hickey and Craighead (1977) describe the physiography and climatic features of the Pribilofs.

Aside from sporadic hunting and fishing activities near the entrance to Nanvak Bay, and the activities of biologists there, little human use is made of the Cape Peirce ares- The nearest permanent residents are at the Air Force Radar Stationat Cape Newenham, about 10 km W of Cape Peirce. The nearest village is Goodnews Bay, about 25 km N of Cape Peirce.

Two villages are located on the Pribilof Islands; the largest is on St. Paul, where an airport and extensive system of roads and trails provide access to most of the island. The smaller village and airport and less extensive system of roads onSt. George somewhat limits access to seabird cliffs over most of this island.

All four islands in the Pribilof group--St. Paul, St. George, Otter, and Walrus islands--support seabirds; however, only the first two have large breeding populations and have been the subjects of intensive study. Cape Peirce has more than one colony--Cape Peirce proper and nearby Shaiak Island.

The species present in the four colonies and their estimated population sizes are listed in Table 1 (Sowls et al.. 1978). Several major differences are evident between the species compositions of the two areas. At the Cape Peirce colonies, two species--common murre and black-legged kittiwake--account for most of the birds. The tufted puffin and glaucous-

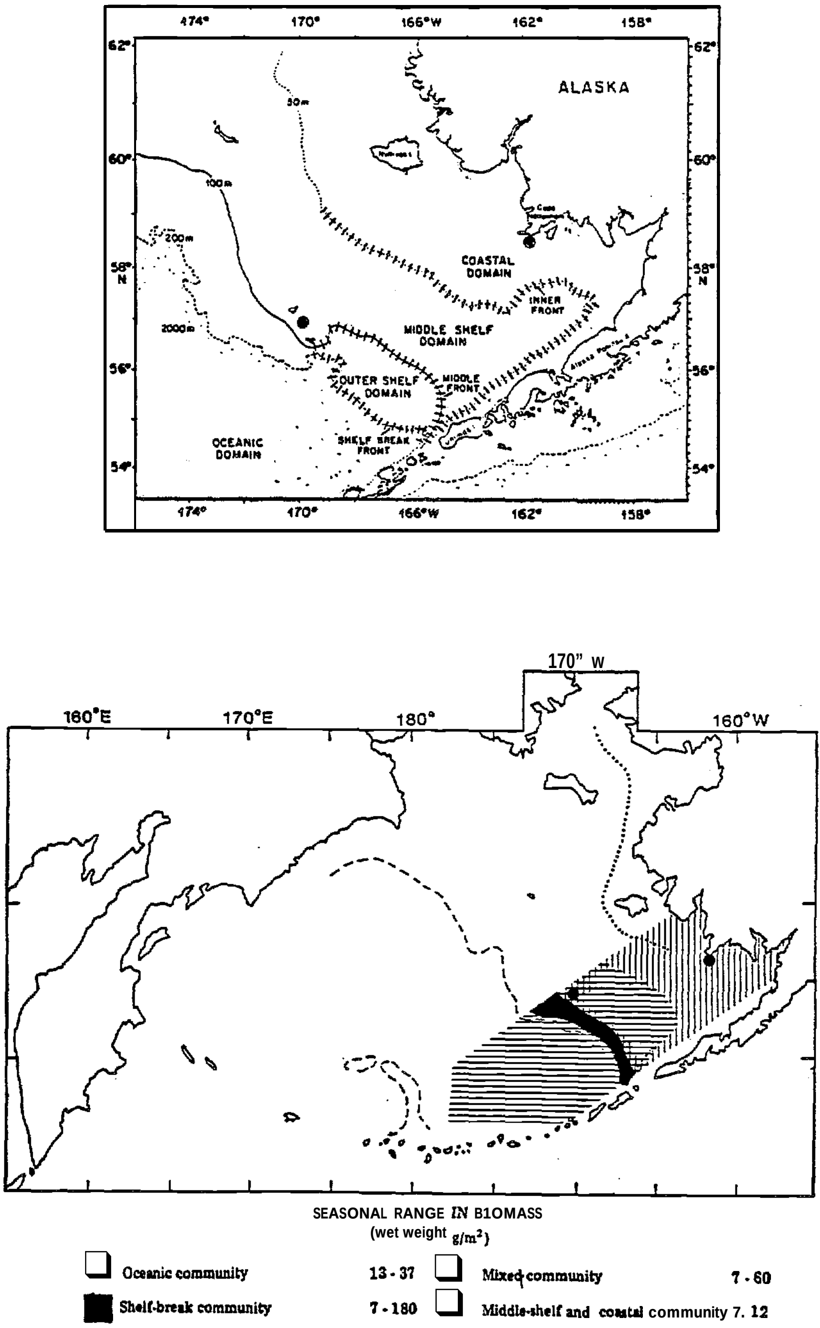

Figure 2. (Top) Approximate locations of domains and fronts over the southeast Bering Sea shelf (after Kinder and Schumacher 1981). (Bottom) Diagrammatic representations of seasonal and spatial variations in wet weight biomass of zooplankton and micronecton in the southeast Bering Sea (from Cooney 1981). Dots indicate the locations of Cape Peirce (on the mainland) and the Pribilof Islands (near the shelf break front).

Table 1. Population estimates (birds) of seabirds in study areas (from Sowls et al. 1978).

	Pribilof Islands		Cape Peirce	
	St. George	St. Paul	Cape Peirce	Shaiak Island
Northern fulmar	70,000	700		
Red-faced cormorant	5000	2500	15	
Double-crested cormorant				600
Pelagic cormorant			700	100
Glaucous-winged gull	x		20	500
Black-legged kittiwake	72,000	31,:00	200,000	20,000
Red-legged kittiwake	220,000	2200		
Common murre	190,000	39,000	500,000	50,000
Thick-billed murre	1,500,000	110,000		
Pigeon guillemot			300	X
Parakeet auklet	150,000	34,000	100	X
Crested auklet	28,000	6000		
Least auklet	250,000	23,000		
Horned puffin	28,000	4400	900	x
Tufted puffin	6000	1000	100	80,000
TOTAL	2,519,000	253,800	702,187	115,800

winged gull are also very common but are restricted primarily to Shaiak Island.

In contrast, the Pribilof Islands support a much more diverse assemblage of species. Eleven species may be considered very common--northern fulmar, red-faced cormorant, black-legged kittiwake, red-legged kittiwake, common murre, thick-billed murre, parakeet auklet, crested auklet, least auklet, horned puffin, and tufted puffin. In all cases much larger populations exist on St. George Island than on St. Paul Island. But, except for northern fulmar, each species is numerous on both islands.

BACKGROUND

Previous Studies in the Areas of Interest

Several studies of seabirds have been conducted at each study site prior to 1984; these are summarized in Table 2. At the Pribilof Islands, the data for productivity are the most comprehensive, but good data for food habits are also available for several years. At Cape Peirce, population estimates form the most extensive data sets, followed by productivity estimates.

Two important points need to be made regarding these earlier studies. First, there is tremendous variability in the scope and spatial and temporal extent of the investigations. Some studies concentrated on only a few of the species present, others on most species. For example, some studies in the Pribilof Islands examined both major islands, others only one. Similarly, at Cape Peirce, studies are divided between Shaiak Island, Cape Peirce proper, and both. Some studies lasted single days, others for entire summers. Fortunately, to maximize the compatibility among studies, most recent investigations in the same areas focused on the same study plots that were used by earlier investigators.

The second important considerations that results of many of the studies (Table 2) remain unpublished. Our preliminary inquiries indicated that most unpublished studies were available; in this report we have used summaries of the most intensive unpublished productivity research (e.g., D.S. Lloyd, Univ. of Alaska, 1980-81, both study areas).

Table 2. Seabird studies conducted at the Pribilof Islands and Cape Peirce.

	Pribilof Islands				Cape Peirce			
Year	**Source**	Population **Estimation**	**Productivity**	**Food**	**Source**	Population **Estimation**	**Productivity**	**Food**
1970					Dick and Dick 1971	non-systematic	limited	limited
1973					Divoky unpubl. Dick unpubl.	rough census 1 day 7	 ?	
1975	Hunt et al. 1978		yes	yes				
1976	Hickey and Craighead 1977	study plots			Petersen and and Sigman 1977	study plots	yes	
1977	Hunt et al. 1978		yes	yes	Petersen unpubl.		(1 day)	?
1978	Hunt et al. 1981		yes					
1979	Hunt et al. 1982		yes					
1980	Lloyd unpubl.		RLKI					
1981	Lloyd unpubl. Roby unpubl.	study plots	yes least auklet		Lloyd unpubl.	study plots	yes	limited
1982	Craighead and Oppenheim 1982 Roby unpubl.	study plots	 least auklet					

Biology of Key Species

Analysis of previous studies suggests that 11 species are common in the study area (including both sites). Summaries of the biology of the most common species (those emphasized in this study) are Presented below.

Kittiwakes

Kittiwakes are small, pelagic gulls. Two species occur in the Bering Sea--the black-legged kittiwake (*Rissa tridactyla*) and the red-legged kittiwake (*R. brevirostris*). Black-1egged kittiwakes are circumpolar in distribution and are numerous in the eastern Bering Sea, where a minimum breeding population is estimated at 750,000 (Sowls et–al. 1978). Population indices derived from aerial and shipboard censuses indicate the presence of 1-3 million black-legged kittiwakes in summer and 3-4.5 million in fall over the eastern Bering Sea (Gould et al. 1982). Red-legged kittiwakes are endemic to the Bering Sea. They are known to breed only at Buldir and the Bogoslof Island group in the Aleutians, in the Commander Islands, and in the Pribilof Islands. About 88% of the estimated world population of about 250,000 birds breeds at the latter site.

Black-legged Kittiwake. The breeding distribution of black-legged kittiwakes in the Bering Sea is depicted in Figure 3. Black-1egged kittiwakes typically nest on ledges on vertical faces of cliffs, although they may nest on gradual slopes if ground predators are absent. They lay clutches of one to two (rarely three) eggs (Hunt et al. 1981c) in the Bering Sea.

At Buldir Island from 1974-76, peak laying of black-legged kittiwakes occurred between 14-24 June, peak hatching occurred from 11-21 July, peak fledging was from 7-25 August and departure took Place between 15-30 August (G.V. Byrd, USFWS and R.H. Day, Univ. Alaska; unpublished data). At the Pribilof Islands from 1975-79, mean date of clutch initiation was about 1 July, mean date of hatching was about 24 July, and mean date of fledging was about 11 September; the period of residency extended from mid-April to mid-October (Hunt et al. 1981b). Nesting at the northern colonies may be delayed in cold years due to ice cover on the seas and

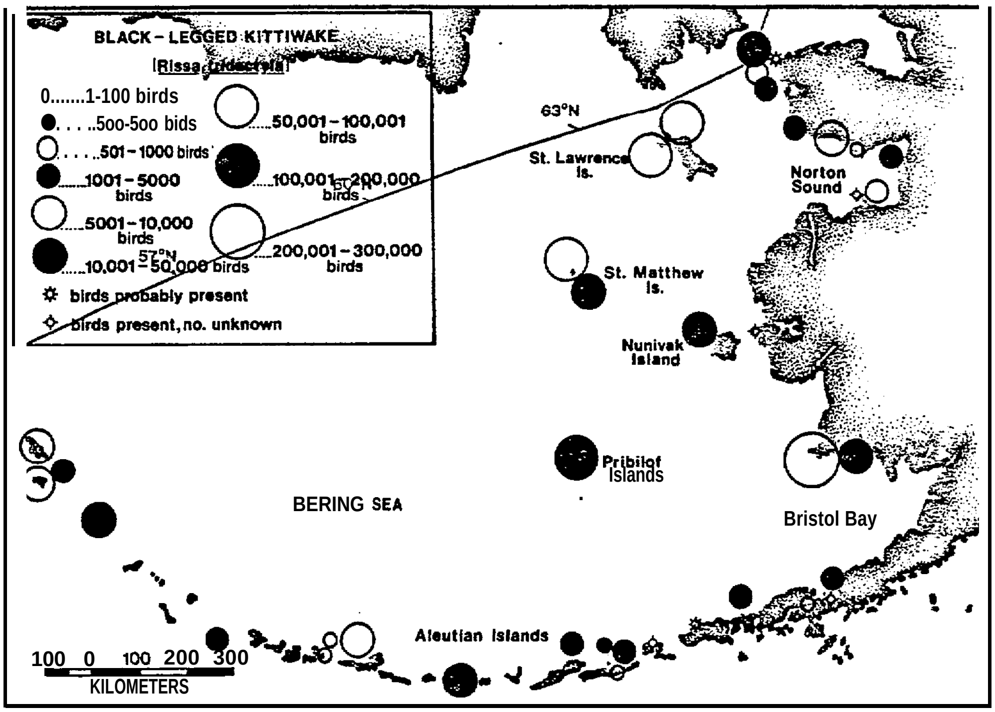

Figure 3. Breeding distribution of black-legged kittiwakes in the Bering Sea (from A.L. Sowls et al. 1978, AINWR 1981, D.R. Nysewander et al. 1982, F.H. Fay pers. comm.).

snow cover on nest sites (D. G. Roseneau, LGL Alaska Research Associates, Inc. , pers. comm.).

Black-1 egged kittiwakes vary considerably in reproductive success, both among years and among sites. Reasons for the high annual variability in kittiwake reproductive success are not fully understood. Weather is presumed to play a part, either as a long-term mediator of prey production, as an influence on phenology of prey availability in a given year, or in interfering with foraging efficiency of the birds during key periods in the reproductive cycle. At present there are insufficient data to test various hypotheses.

In Britain, black-legged kittiwakes first breed at three to five years of age (Coulson 1966). At onset of breeding, life expectancy is 5.4 years for males and 7.1 years for females (Coulson and Wooler 1976). These estimates may not be valid for the Pacific population.

Non-breeding birds in pelagic habitats are widely dispersed. In the southeastern sector of the Bering Sea, Hunt et al. (1981c) described a tendency for higher densities between the 100-m isobath and deeper waters of the shelf break, and for lower densities between the 50- and 100-III isobaths.

In winter, most of the breeding population leaves the Bering Sea, though some spend the winter northof the Aleutians, on shelf break and oceanic waters north to the Pribilofs (Shuntov 1972). Observations along the ice-front indicate that kittiwakes are not particularly abundant there relative to their abundance in areas south of the ice pack (Divoky 1981). Gould et al. (1982) described kittiwakes as virtually absent from shallow waters of Bristol Bay in winter, but present in ‘fair numbers" over shelf break and oceanic waters.

The feeding method of kittiwakes is primarily dipping; however, surface-seizing and occasionally shallow pursuit-diving is employed (Hunt et al. 1981a). Fish are the primary prey, but crustaceans (euphausiids, amphipods) and cephalopods are also consumed. In the Pribilof Islands, the most important prey reportedly has been walleye pollock, but other fish such as capelin, sand lance, and myctophids also are preyed upon; Hunt et al. (1981a) noted an increase in the proportion of fish (especially pollock) taken as the breeding season progressed and a corresponding decrease in use of crustaceans. In other regions, sand lance and capelin predominate over pollock as principal prey items, and in the northern Bering, arctic cod is also important (Drury et al. 1981). In the Bering Strait and Seward Peninsula region, kittiwakes may prey heavily on crustaceans in July of some years (Hunt et al. 1981a). The presence of sand lance (and presumably capelin) seems to be important to high reproductive success (Murphy et al. 1980).

Red-legged Kittiwake. The breeding distribution of the red-legged kittiwake in the Bering Sea is depicted in Figure 4. Red-legged kittiwakes nest on cliff ledges (Hunt et al. 1981c). Single-egg clutches are the rule, although two-egg clutches have been reported (Hunt et al. 1981b) .

Red-legged kittiwakes arrive at the Pribilof Islands in early to late April and most leave in September (Hunt et al. 1981d). At Buldir Island, 1974-76, the peak laying period was 20 June to2 July; peak hatching was 21-30 July; peak fledging was 20 August to 10 September; and departure occurred 10-25 September (G.V. Byrd, USFWS and R.H. Day, Univ. Alaska; unpublished data). On St. George Island, 1976-78, mean date of clutch initiation was 4-7 July; mean date of hatch was 31 July to 10 August; and mean date of fledging was 10-18 September.

On the Pribilof Islands, chicks fledged per nest attempt ranged from 0.3-0.6, except during 1978 when this value fell to 0.10-0.13. Fledging success for hatched chicks was high, averaging 70-87% (Hunt et al. 1981a). On St. George Island in 1981, productivity fell below 0.10 chicks per nest attempt, and many pairs did not build nests (D.S. Lloyd, unpub. data). Reasons for breeding failures of this magnitude are not known. Hunt et al. (1981b) thought poor breeding success in 1978 resulted from bad weather that interfered with feeding, but this reasoning may be insufficient to explain the 1981 breeding failure (R.H. Day, Univ. Alaska, pers. comm. 1982).

In summer, red-legged kittiwakes are concentrated over the shelf break west and south of the Pribilofs. Few are sighted in water shallower than 100 m and very few are recorded north of 590N or east of 165°W (Hunt et al. 1981d).

Little is known of the winter distribution of this species. Shuntov (1972) stated that many, if not most, red-legged kittiwakes leave the

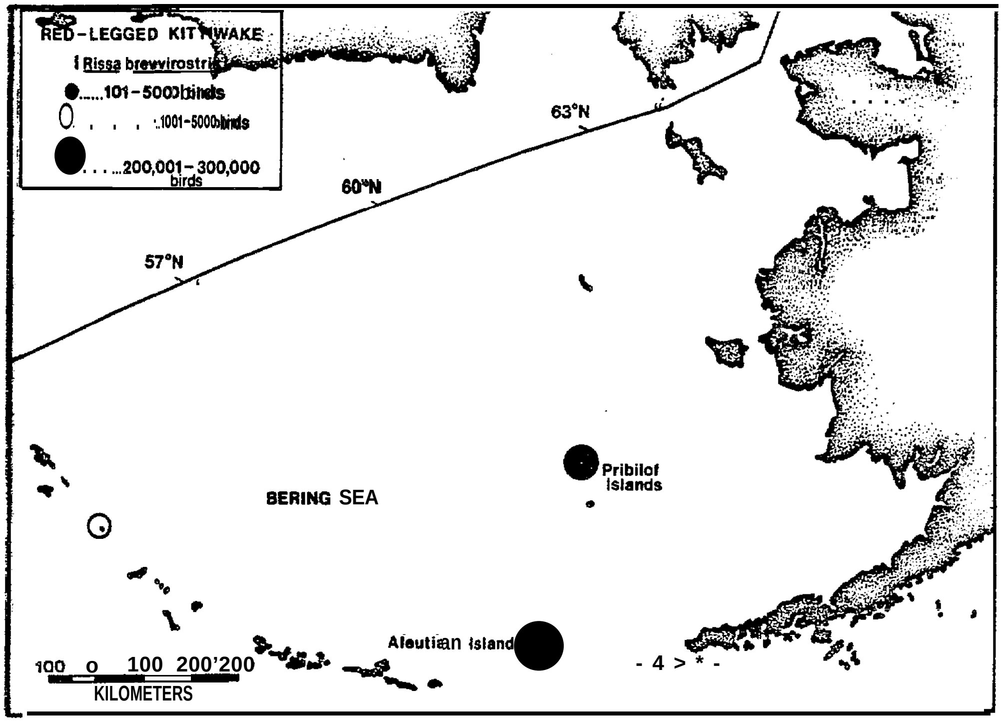

Figure 4. Breeding distribution of red-legged kittiwakes in the Bering Sea"(from A.L. Sowls et al. 1978).

Bering Sea. Records from the Gulf of Alaska in fall and winter (Kessel and Gibson 1978) support the hypothesis that dispersal out of the Bering Sea occurs before winter.

Feeding is by dipping or surface-seizing (Ashmole 1971). Hunt et al. (1981a) found myctophids (lantern fish) to bean important food item at the Pribilof Islands; walleye pollock were also taken at the Pribilofs. Cephalopods were the most important prey item other than fish. Huntet al. (1981a) noted a trend towards increased use of fish from June to September. In the Aleutians, red-legged kittiwakes were found to feed primarily on fish and crustaceans, and secondarily on cephalopods (Day 1980).

Murres

Two species of murre, thick-billed (*Uria lomvia*) and common (*U. aalge*), occur in the Bering Sea; both are widely distributed in the North Pacific and the North Atlantic. The eastern Bering Sea reportedly supports a minimum of 5.3 million breeding murres (Sowls et al. 1978) (Fig. 5).

Because the two species are similar in appearance, many observers have not distinguished between them in pelagic censuses; however, the relative abundance of the two murres at their breeding colonies is better known. Common murres predominate at the mainland coastal colonies of the Bering Sea such as Cape Peirce, whereas thick-billed murres predominate in the Aleutian, Pribilof, and other offshore islands and in the northern Bering Sea (Roseneau and Springer 1982). They are often found nesting in mixed colonies. Life histories of the two species are similar in many respects; unless indicated otherwise, "murre" in the following accounts refers to both species.

Murres lay a single eggon the bare rock of cliffs. Common murres tend to use broad ledges and flat areas, whereas thick-billed murres tend to use narrower ledges on steep cliffs.

In the southern Bering Sea, murres begin to aggregate on waters near the colonies in late March and April (Hunt et al. 1981b). Laying begins from early June (Cape Peirce) to late June, and peaks from mid- to late June. Peak hatching in the Pribilof Islands occurs from late July to mid-

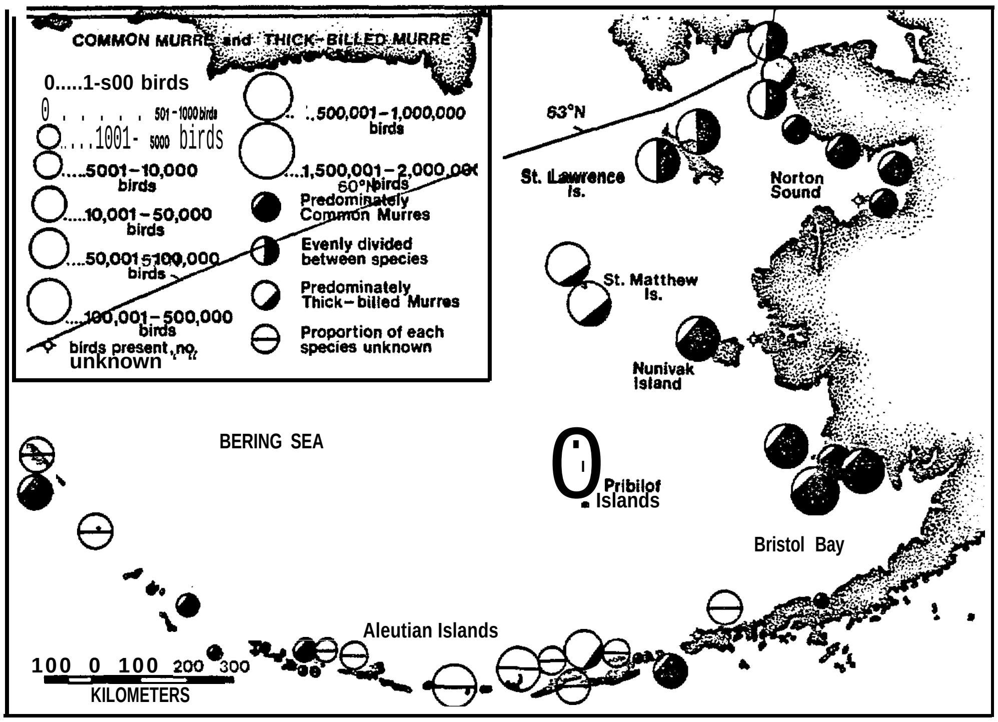

Figure 5. Breeding distribution of common and thick-billed murres in the Bering Sea (from A.L. Sowls et al. 1978, AINWR 1981, D.R. Nysewander et al. 1982, F.H. Fay, Univ. Alaska, pers. comm. 1982).

August, and peak fledging occurs from mid-August to early September (Hunt et al.' 1981 b). Breeding phenology is generally later in northern areas such as St. Lawrence Island and Norton Sound than in the Pribilof Islands. But among-site differences in timing of breeding activities are sometimes obscured by large interannual differences, such as a 2.5 week difference between peak laying in 1977 and 1978 at Bluff in Norton Sound (Drury et al. 1981).

Young murres 'leap" from their natal cliffs at about three weeks of age and glide to the sea. They remain in the water for an additional three weeks or more before they are capable of sustained flight (Tuck 1960). Adults accompany the chicks at sea at this time; here the adults undergo molt and are incapable of flight for about two weeks (Roseneau and Springer 1982).

Murres probably do not breed until their fifth year "(Birkhead and Hudson 1977). Average life expectancy for adult common murres in Wales was estimated to be 11 years, and adult survivorship was 91.5% (Birkhead and Hudson 1977). Estimates of reproductive success of murres from various locations in the Bering Sea have ranged from 0.3-0.7 young fledged per egg laid (Hunt et al. 1981c).

At the Pribilof Islands, relatively high densities of murres are found near the breeding colonies (Fig. 6) (Hunt et al. 1981b) and along a hydrographic front located 55-60 km from the Pribilof Islands (Kinder et al. 1983). It is not known what proportion of non-breeding murres are associated with the colonies in summer, although peak numbers in both early and late summer may represent periods when birds prospecting for nest sites (including sub-adults) are present at the colonies (Tuck 1960).

Murres are distributed in fall over shelf waters from the Gulf of Anadyr to Bristol Bay. They may remain in northerly areas of the Bering Sea until forced south by advancing ice (Shuntov 1972). Thick-billed murres are known to winter in leads and polynyas north of the ice-front (Roseneau and Springer 1982), and both species have been recorded along the ice-front; murre densities to 1000/km^2 at the front are common, and concentrations of 10,000/km^2 and a total count of 25,000 individuals in one flock have been recorded (Divoky 1981). As the ice-front advances southward, murres tend to concentrate in the southeastern Bering Sea, where extensive shelf areas remain ice-free (Roseneau and Springer 1982);

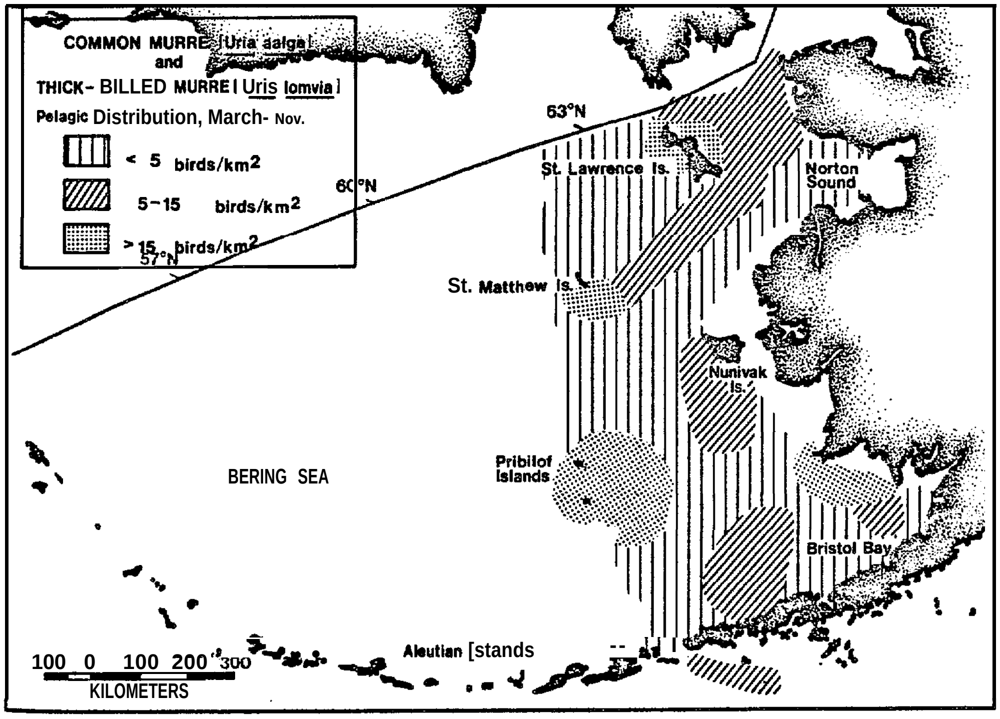

Figure 6. Pelagic distribution of common and thick-billed murres in the Bering Sea, March-November (after G.L. Hunt et al. 1981a, G.L. Hunt et al. 1981c).

numbers appear to increase in the eastern Aleutians and **Unimak** Pass during the fall (Shuntov 1972).

Murres feed by diving and may attain depths of 110-130 m (**Forsell** and Gould 1980). Fish are the principal prey, but invertebrates are often an important constituent of the diet. Common **murres** tend to feed within a few km of shore in water 50 m or less in depth, whereas thick-billed **murres** may feed tens of kilometers to sea in deep water (**Roseneau** and Springer 1982). Thick-billed **murres** also take a greater variety of prey (with agreater proportion of invertebrates in the diet) than do common **murres.**

Common **murres** are dependent on nearshore mid-water fishes, whereas thick-billed **murres** use **demersal** fishes. Common **murres** in the Bering Sea feed on a variety of fish including cod, sand lance, **capelin** and **pricklebacks (Stichaeidae);** the latter is used principally as food for the chicks. Thick-billed **murres** frequently prey on all of the above fish (except **pricklebacks)** and also take **sculpins,** which occur near the sea bottom (**Roseneau** and Springer 1982). Invertebrates consumed by both species **include,** in approximate order of importance, shrimps, **amphipods, euphausiids,** cephalopods and **polychaetes** (**Roseneau** and Springer 1982). There is considerable regional variability in diet; **murres** on the **Pribilof** Islands take walleye **pollock** extensively, whereas **murres** in Norton Sound are dependent on sand lance and arctic cod (Hunt et al. 1981a).

Cormorants

Figure 7 depicts distribution and relative abundance of the three cormorant species found in the eastern Bering Sea. The red-faced cormorant (Phalocrocorax urile) is mostly confined to the Aleutian Islands and the Alaska Peninsula. Its breeding range extends from the Commander Islands through the Aleutian Islands, north to the **Pribilof** Islands (**Sowls** et al. 1978) and east along the Gulf of Alaska coast to Prince William Sound, where the population appears tobe increasing (**Kessel** and Gibson 1978). About 160,000 pelagic (Phalocrocorax pelagicus) and red-faced cormorants are estimated to occur in the eastern Bering Sea. The relative proportions of the two species have not been determined for several colonies. Only red-faced cormorants breed on the **Pribilof** Islands

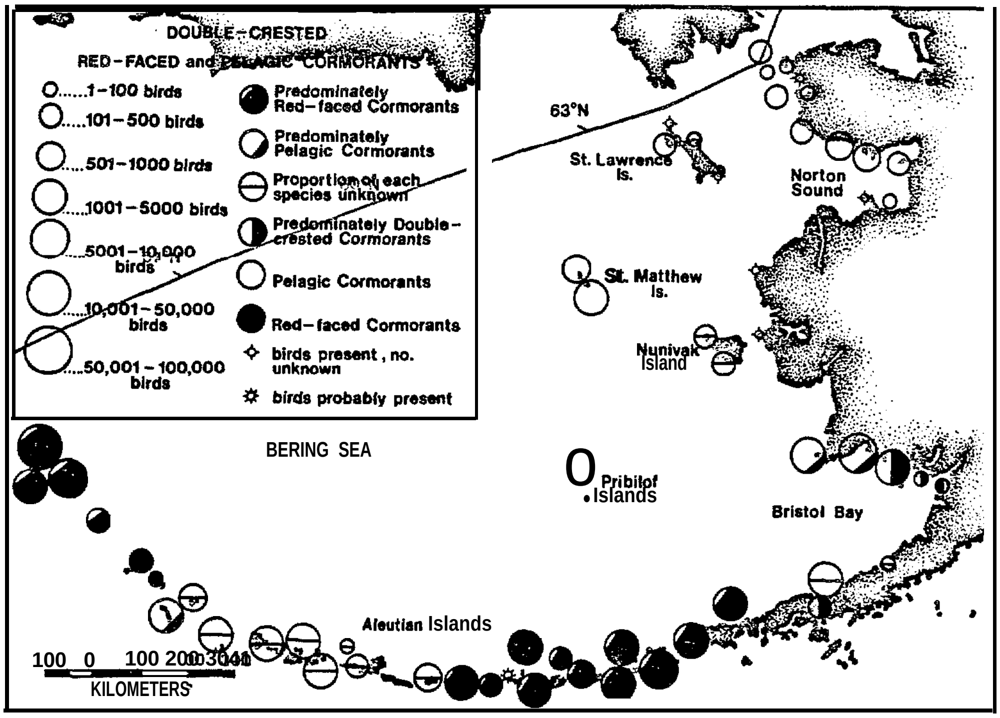

Figure 7. Breeding distribution of double-crested, red-faced, and pelagic cormorants in the Bering Sea (from A.L. Sowls et al. 1978, AINWR 1981, D.R. Nysewander et al. 1982).

although pelagic cormorants were reported from the area earlier in the century. Both pelagic and double-crested (*Phalocrocorax auritas*) cormorants are relatively common at the Cape Peirce colonies (the former at the Cape, the latter on Shaiak Island) and red-faced cormorants are scarce.

In the Pribilof Islands, the nests of red-faced cormorants are scattered on the lower portions of cliffs (Hunt et al. 1981b). Hunt et al. (1981c) recorded clutch sizes of two to three at several locations on St. Paul Island. Broods of one to four were recorded in the western Aleutians in 1974 (Trapp 1975).

AtSt. Paul Island from 1975-78, the mean date of clutch initiation ranged from 13-30 May, the mean date of hatch ranged from 21 June to 5 July, and the mean date of fledging ranged from 5-24 August. Breeding phenology at Buldir Island, 1974-76, was similar to that recorded at St. Paul. Red-faced cormorants are year-round residents at the Pribilof Islands (Hunt et al. 1981b) and probably throughout most of their breeding range.

On the Pribilof Islands, the average number of young fledged per nest attempt was 1.25; young fledged per successful nest (fledging at least one young) was 2.0. The primary cause of egg and chick loss was desertion by the parents; reasons for nest desertion were unknown (Hunt et al. 1981b). Nests left unattended by adults were heavily preyed upon by foxes on the Pribilof Islands (Hunt 1978). Survivorship trends and age at first breeding are not known, but the related double-crested cormorant generally breeds at three years (Palmer 1%2).

Nesting cormorants feed near shore in shallow water, seldom more than a few km from their breeding colonies. Their feeding method is pursuit-diving (Ashmole 1971). Fish, mostly sculpins, are the primary prey, but decapods (shrimp and crab) and amphipods are also eaten (Hunt et al. 1981 a).

Auklets

Parakeet (*Cyclorrynchus psittacula*), crested (*Aethia cristatella*), and least (*A. pusilla*) auklets are common seabirds of the eastern Bering Sea. The least auklet is the most abundant, with an estimated population of six million in the eastern Bering Sea. The crested auklet is often found in association with the least auklet in breeding colonies, but is less abundant, with an estimated two million occurring in the eastern Bering Sea. There are on the order of 300,000-600,000 parakeet auklets in the eastern Bering Sea (Sowls et al. 1978).

All three species are similar in many aspects of their behavior, food habits and natural history. They all forage on crustacean zooplankton and nest in crevices on talus slopes or rocky shorelines, often in mixed species colonies. Because of these similarities, the natural histories of these three species will be described together.

The breeding distributions of the least, crested and parakeet auklets in the eastern Bering Sea are depicted in Figures 8 and 9. All three species lay single-egg clutches and are believed to first breed at three years of age (Scaly and Bedard 1973).

Least and crested auklets nest in crevices in talus formations (either coastal slopes or up to 1 km inland), among boulders on beaches, in cavities in cliffs, or (in the Aleutians] in lava rubble (Sealy 1968). Searing (1977) found greater numbers of least auklets in areas of steep slopes, angular rocks and deep talus, whereas numbers of crested auklets were highest on slopes that faced the sea and had larger boulders. Scaly (1968) and Knudtson and Byrd (1982) found that the talus slopes occupied by crested auklets on St. Lawrence and Buldir islands tended to have larger boulders and crevice openings than those occupied by least auklets.

On St. Lawrence Island, parakeet auklets are largely scarp-face nesters (not talus nesters like the _Aethia_ auklets), and when they do nest in talus, it is primarily in grassy areas or turf-covered slopes (Bedard 1969a). On the Pribilof and Aleutian islands, parakeet auklets nest beneath large boulders or cavities in cliffs (Scaly 1968).

Phonological data for all three species at St. Lawrence Island and Buldir Island are presented in Table 3. The extent of snow cover on the nesting grounds is thought to influence the timing of breeding (Sealy 1975).

Because nests are often deep in crevices, it is difficult to gather data on reproductive success for these species. Scaly and Bedard (1973) calculated the reproductive success of parakeet auklets at St. Lawrence Island to be 0.52 young fledged per nest (n = 31). Hatching success was

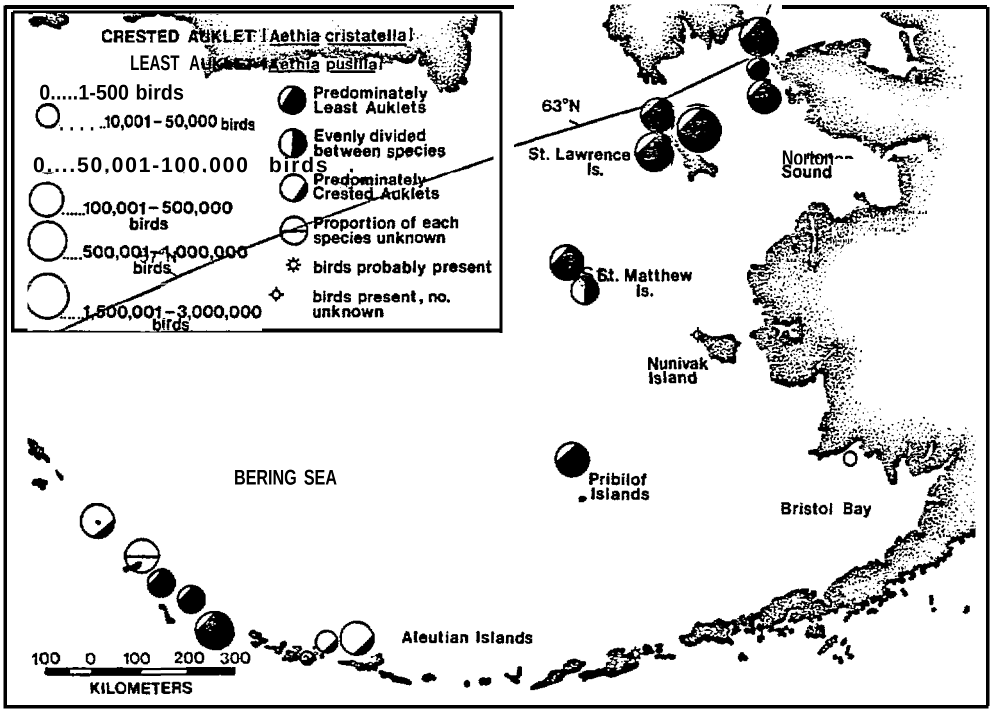

Figure 8. Breeding distribution of crested and least auklets in the Bering Sea (from A.L. Sowls et al. 1978, AINWR 1981, R.H. Day, Univ. Alaska, pers. comm. 1982, G.F. Searing 1977, F.H. Fay, Univ. Alaska, pers. comm. 1982).

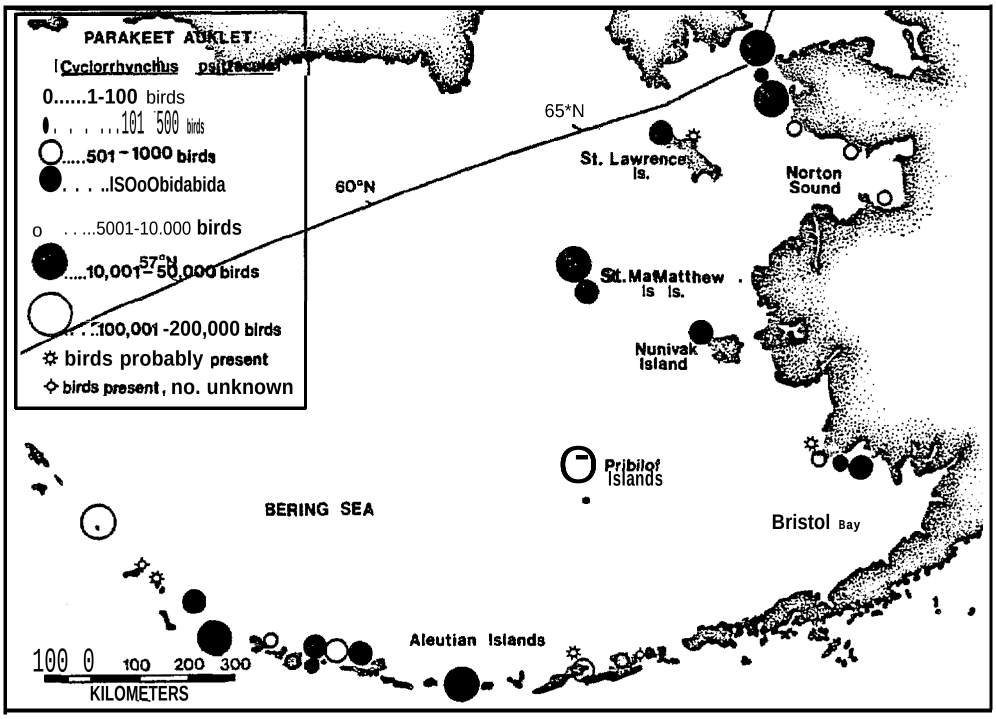

Figure 9. Breeding distribution of parakeet auklets in the Bering Sea (from A.L. Sowls et al. 1978, AINWR 1981, R.H. Day, Univ. Alaska, pers. comm. 1982, D.R. Nysewander et al. 1982, F.H. Fay, Univ. Alaska, pers. comm. 1982).

Table 3. Phenology of arrival and nesting on St. Lawrence and Buldir islands for three species of auklets occurring in the Bering Sea.

	Arrival Offshore	Arrival On Cliffs	Peak Laying	Peak Hatching	Peak Fledging
Least auklet					
St. Lawrence[1]	10 - 15 May	20 - 29 May	06 Jun - 02 Jul	22 Jul - 01 Aug	20 Aug - 01 Sep
Buldir[2,4]	Late April?	15 - 18 May	28 May - 06 Jun	30 Jun - 09 Jul	29 Jul - 12 Aug
Crested Auklet					
St. Lawrence[1]	13 - 18 May	18 - 29 May	24 Jun - 03 Jul	29 Jul - 11 Aug	03 Sep - 09 Sep
Buldir[2,4]	Late April?	15 - 18 May	28 May - 05 Jun	05 Jul - 12 Jul	29 Jul - 15 Aug
Parakeet auklet					
St. Lawrence[1,3]	04 - 13 May	19 - 24 May	21 Jun - 25 Jun	26 Jul - 30 Jul	29 Aug - 07 Sep
Buldir[2,4]	Late April?	15 - 18 May	02 Jun - 11 Jun	03 Jul - 15 Jul	29 Jul - 15 Aug

[1] Searing 1977.

[2] G.V. Byrd, USFWS and R.H. Day, Univ. Alaska, unpublished data.

[3] Sealy and Bedard 1973.

[4] Knudtson and Byrd 1982.

68% and fledging success (n = 21) was 76$. Based on a small sample size (n = 16) of least auklets, Searing (1977) estimated young fledged per nest with eggs to be 0.34. On Buldir Island the same parameter for crested auklets was 0.43 (n = 9) and for least auklets 0.43 (n = 14) (Knudtson and Byrd 1982). At St. Lawrence Island in 1981 (D. G. Roseneau, pers. comm. 1982)$ seven of thirteen nests with newly hatched young of known fate survived to fledging weight; if this survival (54%) is taken as equivalent to fledging success, then the estimate is close to SearingSs (1977) value of 56% fledging success for least auklets. At Buldir Island, all chick mortality occurred within the first week of hatch (Knudtson and Byrd 1982). Young are able to fly quite well upon leaving the nesting crevices. They are able to dive almost immediately and appear to be independent of the adults. However, strong onshore winds can cause sea-going chicks to be blown back onto land, resulting in some mortality (Scaly 1968).

From May to September, auklets are concentrated near their breeding colonies. At the Pribilof Islands, Hunt et al. (1981a) found that crested and least auklets usually foraged within 5 to 10 km of shore, whereas parakeet auklets were observed foraging ‘several tens of kilometers from the colonies. At St. Lawrence Island$ the auklets from colonies at Northwest Cape and Southwest Cape often feed in an area 30-50 km (or more) north of Gambell; birds from Southwest Cape must travel at least 70 km to reach this feeding area (D.G. Roseneau, pers. comm. 1982).

Data are insufficient to describe the winter distribution of auklets. Shuntov (1972) stated that most small auklets leave the Bering Sea in fall, wintering along the Aleutian chain and in the open North Pacific. The water surrounding Kodiak Island is a known wintering area for crested auklets (Gould et al. 1982). All three species occur around the Pribilof Islands in winter (Scaly 1968), but in small numbers. Large concentrations of least auklets have been seen in spring along the ice edge north and east of the Pribilof Islands (Gould et al. 1982), and all three species raft in dense flocks in leads near St. Lawrence Island during the spring (Bedard 1967).

The auklets feed by diving (Ashmole 1971). Least and crested auklets specialize in preying on zooplankton at moderate depths (Hunt et al. 1981a). At the Pribilof Islands, least auklets prey primarily on calanoid copepods, with amphipods comprising a relatively minor portion of the diet. Crested auklets take mostly euphausiids, with secondary reliance on amphipods (Hunt et al. 1981d). Searing (1977) and Bedard (1969b) arrived at similar conclusions with respect to food habitsof least auklets; however, Searing's results indicated that crested auklets were almost completely dependent on calanoids. These auklets tend to maintain a more varied diet in early summer, but both species depend on their respective favored prey during the chick-rearing period.

Parakeet auklets at both St. Lawrence Island and the Pribilof Islands are more diverse than least and crested auklets in their feeding habits. At the Pribilof Islands they fed on euphausiids, fish larvae, polychaetes and amphipods. Fish are less important in the diet at St. Lawrence Island than they are at the Pribilof Islands (Hunt et al. 1981a).

The Bering Sea distribution of parakeet auklets differs from that of the _Aethia_ auklets in that parakeet auklets are found in a greater number of locations (particularly in coastal waters along the mainland) but in lower densities. Several authors have suggested that this distributional difference is a reflection of differences in food dependencies--the parakeet auklet depends on a more varied and widely distributed food supply, which includes epibenthic invertebrates, than do the _Aethia_ auklets, which prey on patchily abundant zooplankton species (Bedard 1969b, Hunt et al. 1981d).

SUMMARY

The U.S. Minerals Management Service (MMS) desires to carry out a program to monitor populations of seabirds in the Bering Sea, and to determine if any population changes that occur are caused by OCS petroleum development operations. It is desired that studies in the first year of this program investigate seabird abundance, productivity and diet; compare new findings with findings of previous studies; discuss the significance of population trends observed; and develop strategies for future monitoring.

MMS has selected the seabird colonies at Cape Peirce on the Alaska mainland and at the Pribilof Islands for the initial investigations. Several studies have been conducted at each location in the past, but the results of past studies are frequently not suitable for making inter-study comparisons.

Seabirds of 11 species are common in the colonies of interests, if both sites are included. The Pribilof Island colonies support a more diverse species assemblage than does Cape Peirce. The species Potentially amenable to monitoring studies include ‘black-legged and red-legged kittiwakes; thick-billed and common murres; red-faced, pelagic and double-crested cormorants; and parakeet, crested and least auklets.

Black-legged kittiwakes number from 1-4 million in the eastern Bering Sea in summer and fall. They nest abundantly at both Cape Peirce and the Pribilofs, varying greatly in reproductive success from year to year. Non-breeders are widely dispersed in the Bering Sea in summer; most move south in winter. They feed mainly on fish at or near the surface.

Red-legged kittiwakes nest abundantly (88% of the world population of 250,000) at the Pribilofs, but not at all at Cape Peirce. Their breeding success is highly variable annually. Feeding birds in summer concentrate south and west of the Pribilofs; most move south in winter. They feed mainly on fish at or near the surface.

About 5.3 million murres breed in the eastern Bering Sea; of the two species, common murres predominate at Cape Peirce and thick-billed murres predominate on the Pribilofs. Murres are long-lived, slow-reproducing birds with less annual variability in breeding success than the kittiwakes. In summer most concentrate to feed near the colonies; most also winter in the Bering Sea. Both species eat mainly fish; common murres depend largely on nearshore mid-water fishes and thick-billed murres use demersal fishes in deeper waters.

Of the cormorant species, the red-faced cormorant is the only one nesting at the Pribilofs, and the pelagic cormorant is dominant at Cape Peirce. Red-faced cormorants are year-round residents at the Pribilofs. All the cormorant species feed largely on fish, which they catch by diving in waters near their breeding colonies.

The three auklet species are extremely abundant breeders in the eastern Bering Sea, with estimated populations of 6 million (least auklet), 2 million (crested auklet) and around 0.5 million (parakeet auklet). All are long-lived and reproduce slowly, but data on reproduction are difficult to gather because many nest deep in crevices.

Most individuals of **all** species concentrate near their breeding colonies from May-to September, but move out of the Bering Sea in winter. Least and crested auklets dive to moderate depths to prey on zooplankton. Parakeet auklets feed at varying depths and on a greater variety of prey than do the other two species.

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CHAPTER II

POPULATION STUDIES*

By

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INTRODUCTION

The objective of a population monitoring program is to document population levels over time. The experimental design of a monitoring program should be such that it minimizes (1) the sampling effort required and (2) the magnitude of change (or difference) among populations required to detect changes. One of our goals in this study was to use a variety of techniques for sampling and analyzing seabird populations at colonies in order to explore possible improvements in seabird population monitoring strategies. Limits on our experimentation were established by. the need to maintain comparability of our results with those of prior investigations at the study colonies.

The principal parameters of concern in this monitoring study are population size and trend, i.e., (1) how many individuals are present, and (2) is the population growing, stable, or shrinking? Although closely related, size and trend are distinct parameters that should be estimated independently. In the context of a monitoring program *per se* the estimation of trend, or change over time, is of greatest interest. Measurement of trend in populations does not necessarily require knowledge of the actual population size, and may be considerably easier to estimate. However, knowledge of population size as well as absolute estimates of the magnitude of change (as opposed to trend information only) may both be Of considerable value to resource managers.

In this report, we describe the procedures and results of population monitoring studies conducted in seabird colonies at Cape Peirce and the Pribilof Islands. The objectives of these studies were to

(1) document trends in seabird populations,
(2) estimate seabird population sizes, and
(3) improve methodologies for deriving estimates necessary for the first two objectives.

Sample Design Considerations

Trend in the sizes of the populations of seabird species breeding at a colony is-the usual measurement of interest when monitoring the health of the populations. Rapid changes in population sizes of adults and subadults might occur because of catastrophic events such as oil spills in areas where birds congregate on the water. Monitoring of bird numbers should be able to detect large changes caused by such events.

Though catastrophic changes in colony size can be detected fairly easily, slower, steady changes often are more difficult to detect. Such changes may result if environmental perturbations affect productivity or survival rates of a population. Many seabirds are long-lived and it may take many years for changes in the productivity of populations to cause appreciable changes in colony size. Because of the need to detect these more subtle changes, it is important that estimates of population size be as statistically precise as possible.

Hickey and Craighead (1977), the most detailed seabird population estimation study available for the Pribilofs, estimated the 95% confidence interval for the common seabirds at the colonies to be ± 50% of their population estimates. Craighead and Oppenheim (1982) revised this precision to ± 36%. Unless the precision of these estimates can be improved significantly, it will not be possible to show that any but catastrophic changes in colony size have occurred.

Many methods have been described for estimating population sizes of seabirds to monitor for population changes. Some attempts have been made to standardize census techniques (e.g., Birkhead and Nettleship 1980, Harris et al. 1983, Nettleship 1976); however, most field investigators adopt their own methods, perhaps because of variations among studies in logistics support, time constraints, population parameters of interest, or differences among investigators in their appreciation for the statistical limitations of the various approaches. Thus, in terms of designing a monitoring study one must look very carefully at historical (existing) studies to determine the utility of these data in tracking the parameters of interest.

One of the major confounding factors in attempts to estimate population sizes at colonies is the variability in colony attendance that occurs independently of variations in size of nesting populations. Reported causes of this variability include seasonal trends and diurnal cycles in attendance, tidal cycles, and weather-induced variations (Slator 1979, Harris et al. 1983, Gaston and Nettleship 1982). Large, unexplained, short-term changes in attendance (e. g., large differences in counts between days at the same site) have been observed to occur, without apparent cause. It is important to recognize this variability, because its occurrence invalidates many attempts to test for changes in size of breeding populations.

To test for differences among samples, or in a sampled population over time, it is necessary that the among-sample variability be much larger than the measurement error associated with each sample (i.e., the precision of the measurement being taken). If a point-in-time count is being used to represent the number of birds occupying a cliff face for a particular year, then this error term includes errors in counting (probably trivial) and temporal variability in seabird attendance over the portion of breeding season when the population of interest is assumed to be present. The largest measurement errors are caused by the. variability, in bird attendance at study plots. In many studies this error is ignored. This is acceptable only if the magnitude of this error is known to be small. Unfortunately, we know that attendance patterns of seabirds at breeding colonies is quite variable, and that corrective measures, such as standarization of time of day and season when the count is made, cannot completely eliminate or reduce this component of variability to an acceptable level.

Several replicates of counts of birds on study plots are required to assess the magnitude of measurement error. Such replication has rarely been a component of Alaskan seabird population studies. An alternative approach for dealing with measurement error is to use a very large number of sample plots, assuming that errors will not all tend to be in the same direction over a significant number of plots. This approach may require a large number of study plots in order to detect small population changes--a requirement unavailable at a great many colonies (e.g., access problems may limit the number of plots that can be sampled). Further, the assumption that errors will tend in the same direction may not be valid.

Field Methods

Terminology

The primary sample unit for the population study is the sample plot. Plots are defined regions of cliffs within which seabirds were enumerated. Our study plot is equivalent to the "ledge" of Hickey and Craighead(1977) and the 'colony" of Petersen and Sigman (1977). Plot boundaries were delimited on photographs by the original investigators. These photographs were loaned to us to aid in locating the same sample units. usually plots were unambiguously defined in that a discrete area of cliff was selected for counting birds. In most cases the count area was surrounded by uninhabited or uninhabitable areas so that decisions as to inclusion of individual birds were unnecessary. Plots were selected based on their accessibility and the availability of reasonable vantage points. These units cannot be considered as random samples, although we have to assume they are representative of the colonies they sample.

Plots were frequently divided into subplots. Our subplots correspond to divisions of plots used by some previous investigators and could be used in more detailed analyses of changes in distribution of birds within plots.

Within each plot (or subplot) birds were counted by 'clusters"(= aggregation counting). Clusters are defined as aggregations of birds separated from all other conspecifics by at least two bird lengths or an individual of another species.

Two units larger than plots--colony and strata--were recognized. The colony encompasses all study plots and other portions of cliffs occupied by seabirds at a study location. For this study the colonies are Cape Peirce, St."George Island, and St. Paul Island. The two Pribilof Island colonies were partitioned into strata based on cliff height using the method described by Hickey and Craighead (1976). h total of five strata were defined as follows:

Stratum 1	0- 200 ft	o-61 m
Stratum 2	200- 400 ft	61-122 m
Stratum 3	400- 600 ft	122-183 m

Stratum 4	600- 800 ft	183-244 m
Stratum 5	800-1000 ft	>244 m

Plots within these colonies were assigned to strata for the purpose of population estimation. All five strata occur on St. George Island; only Strata 1 and 2 occur on St. Paul. Only stratum 1 occurs at Cape Peirce.

Counts of seabirds were made at study plots used during previous investigations at the Pribilof Islands and Cape Peirce. The approximate locations of study plots are shown in Figures 1 and 2. The dates of sampling are summarized in Appendix 1. Counts were made at approximately the same time of day as during previous studies (afternoon-evening); allowances were made for changes in time zones used in setting "local time".

During each census of a study plot, birds were counted by clusters. The result of a census was a frequency distribution of the number of occurrences of each cluster size. This technique provided both a count of the total number of birds present, and an index of their aggregation. When possible, for each cluster the number of nests with eggs, chicks, and/or birds in incubation postures (kittiwakes) were recorded. Platforms without eggs, chicks, or ‘incubating" birds were not enumerated.

We attempted to sample each plot two to five times. Because the census periods were spread over a considerable period of time (e.g. eight weeks on St. George Island) all visits may not be considered replicates because attendance patterns of several species varied over the course of the study (e.g., auklets fledged before the study finished).

Time-lapse cameras were used to obtain a more detailed record of attendance patterns over the course of the study (Appendix 2 describes equipment and sample locations). Two cameras were used at Cape Peirce and four to six on St. George Island. These cameras photographed portions of the seabird colonies once per hour. Later, the film was developed and photographic images were projected onto a digitizing platten and the location of each bird was recorded for each hour record. Additional information recorded from these photos included the presence of eggs, chicks, and nests (kittiwakes). Most of this film has been archived at LGL Ecological Research Associates, Inc. (address on front cover). Detailed analysis of three camera locations--DUH at Cape Peirce; High

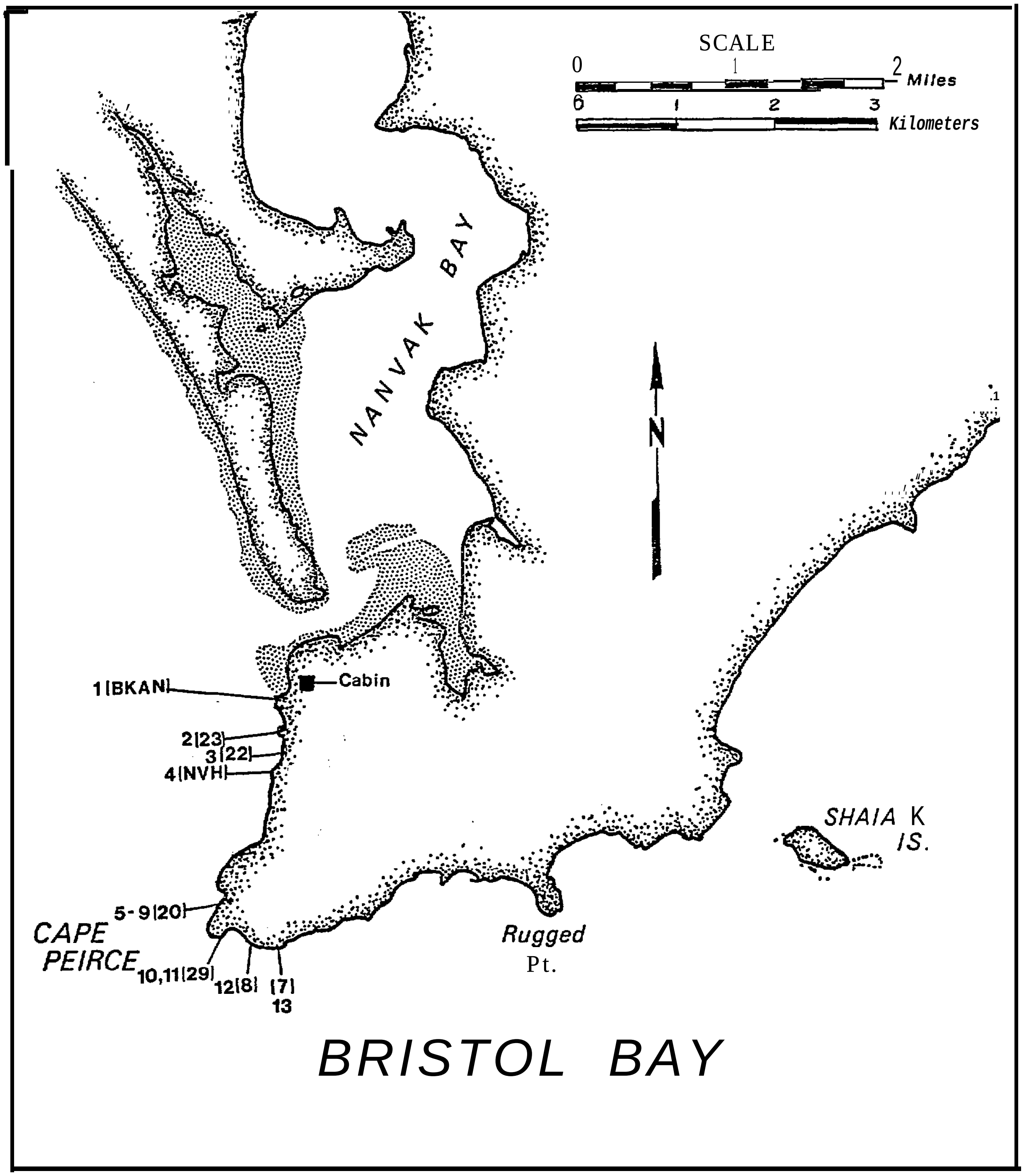


Figure 1. Locations of study plots at Cape Peirce, Alaska. Our designations 1-13 correspond to plot identifiers used in tables. Plot identifiers in parentheses are designators used by previous investigators--numbers by Petersen and Sigman (1977), alpha values by D. Lloyd (unpublished).

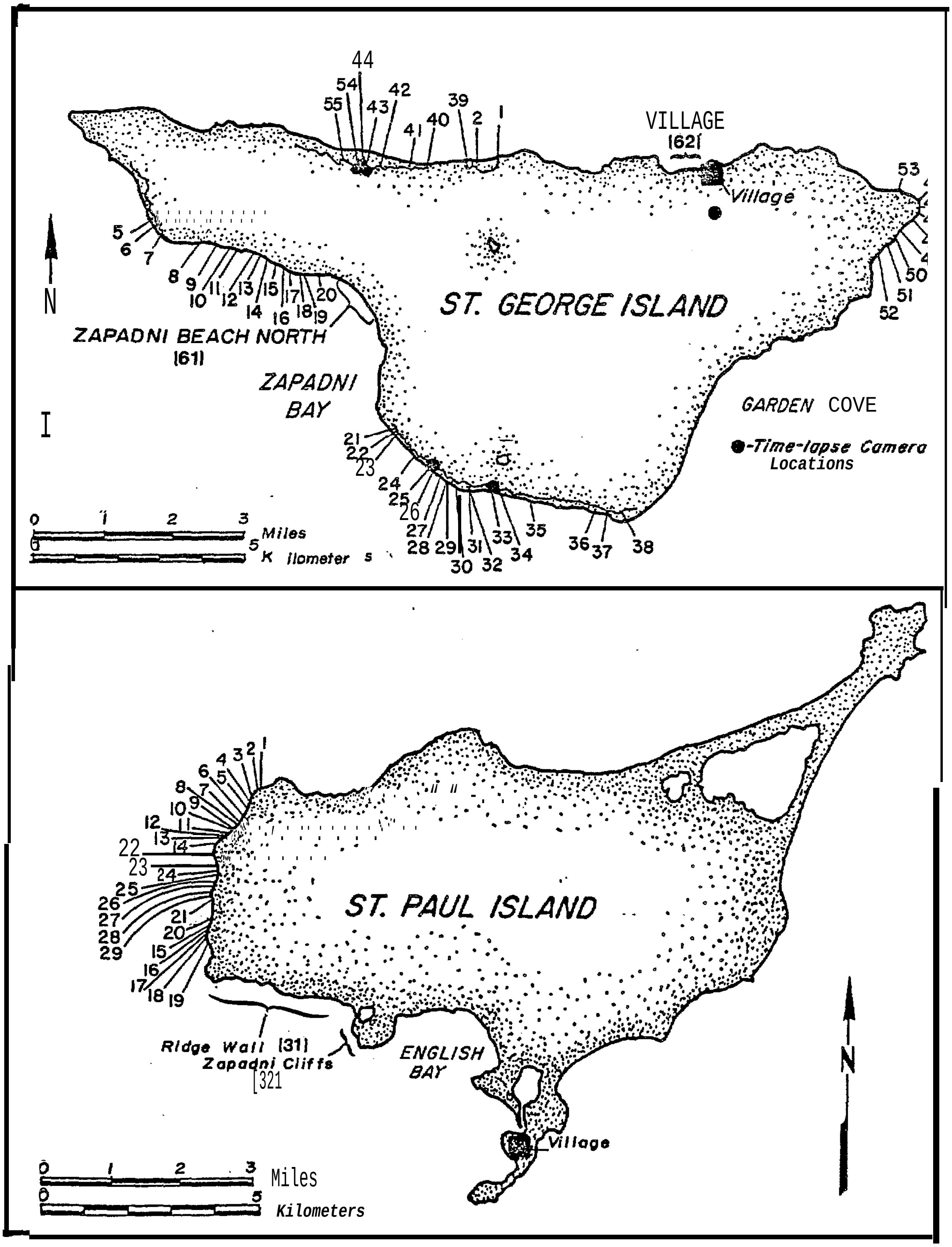


Figure 2. Study plot locations used for population' estimates on the Pribilof Islands. Numbers in parentheses are our number equivalents for plots with word names.

Bluff 1 and 2, and Zapadni at St. George Island--are described in this report.

The population studies comprised four independent series of investigations. These were (1) the assessment of diurnal trends in attendance, (2) seasonal trends in abundance, (3) among-year trends in abundance, and (4) estimation of population size. Methods, results and preliminary discussions of these topics are addressed separately in the following pages. This is followed by a concluding discussion and summary.

ASSESSMENT OF POPULATION TRENDS

Diurnal Patterns in Colony Attendance

Methods

Diurnal patterns in seabird attendance were studied using two methods. At Cape Peirce a 24-hour watch (counts at I-hr intervals) was made at several nesting plots on 7 June. The most complete documentation was obtained by analysis of the time-lapse camera record. Two types of analyses of the time-lapse data were done. Counts of each species were enumerated by hour. Correlations of counts ateach hour were made with counts 1 through 36 hours later (autocorrelation) to determine if there was any periodicity in the occurrence of seabirds on the cliffs. A diurnal or 24-hour cycle is revealed in this type of analysis by high correlation at 24-hour lags, i.e., high or low counts are at 24-hour intervals. Counts were also compiled as to the actual hour of the day to produce hourly abundance summaries for each hour of the day. These summaries were of mean ± 2 standard errors of the number of birds recorded in the study area. These summaries reveal the timing of peak attendance and the variability of counts at the same time each day. The photo record for each sample location was segmented into periods roughly corresponding to each roll of film (4-10 days). The two types of analyses described above were done for each period. Analysis by period had two functions; first it allowed us to investigate whether diurnal cycles persisted throughout the breeding season. Second, changing film often resulted in a slight change in photo boundaries and potentially the number of birds visible for counting. By analyzing each roll separately this potential bias was eliminated.

Analysis was restricted to those periods where the photo record was complete enough so that a reasonable summary was possible. In locations where fog or other factors resulted in an intermittent record, some periods could not be meaningfully analyzed. If a good hourly summary was available, the hourly counts were analyzed using Kruskal-Wallis non-parametric 'ANOVA' to determine if significant differences existed among counts of each hour.

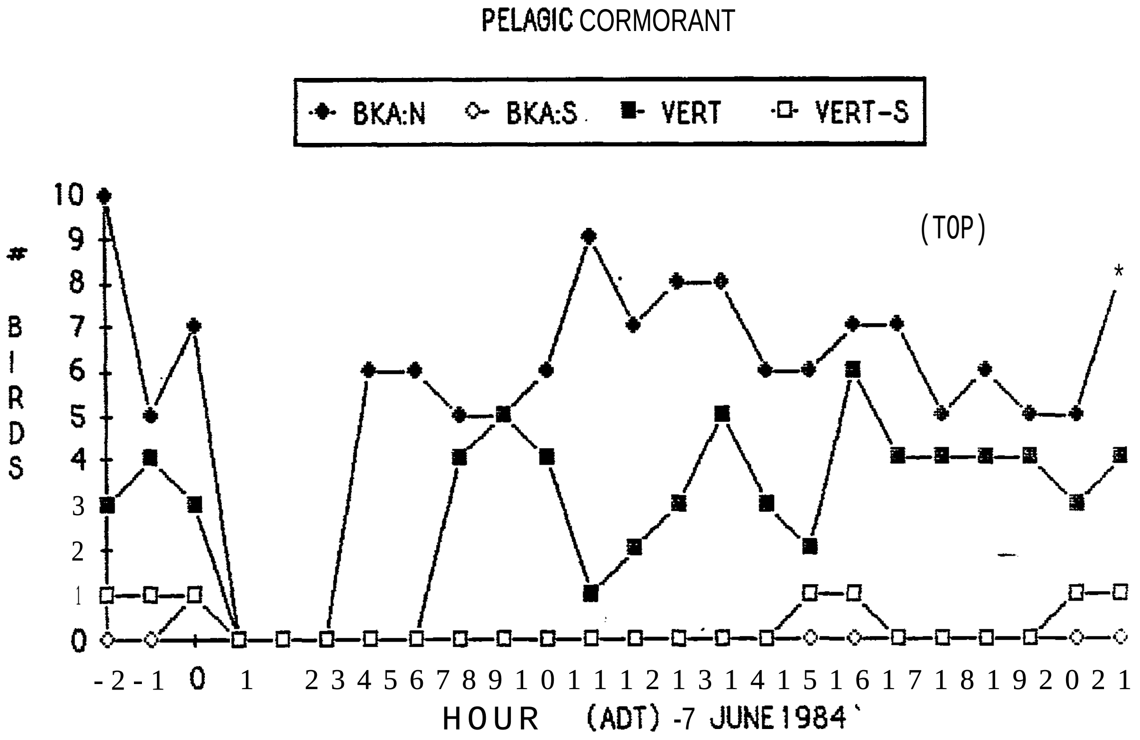
Results

Cape Peirce.

Pelagic cormorant--Pelagic cormorants occurred on four plots where 24-hour watches were conducted at Cape Peirce. At two locations, BKAS and VERT-S, occurrence was limited to sporadic appearance of only one bird. The remaining plots, BKAN and VERT, had 4-10 cormorants regularly present.

Attendance counts are shown in Figure 3. Qualitative evaluation of these patterns revealed no diurnal attendance schedule for cormorants. They were present at all times (i.e., when light was sufficient to permit censuring), and although no regular attendance trend was apparent, the hour to hour variability was substantial.

Black-legged kittiwake--Black-legged kittiwakes were present on five of the plots monitored hourly for 24 hours on 6-7 June at Cape Peirce. Plots of their attendance patterns are illustrated in Figure 3. Black-legged kittiwake numbers were quite stable during most of the day. Between 0600 and 2300, counts showed relatively little variability and no consistent or cyclical trends were evident. Although no counts were possible between 0100 and 0400, the counts immediately before and after this period indicate that most kittiwakes were absent during the dark hours, at least at this early breeding season date (pre-incubation for many birds).



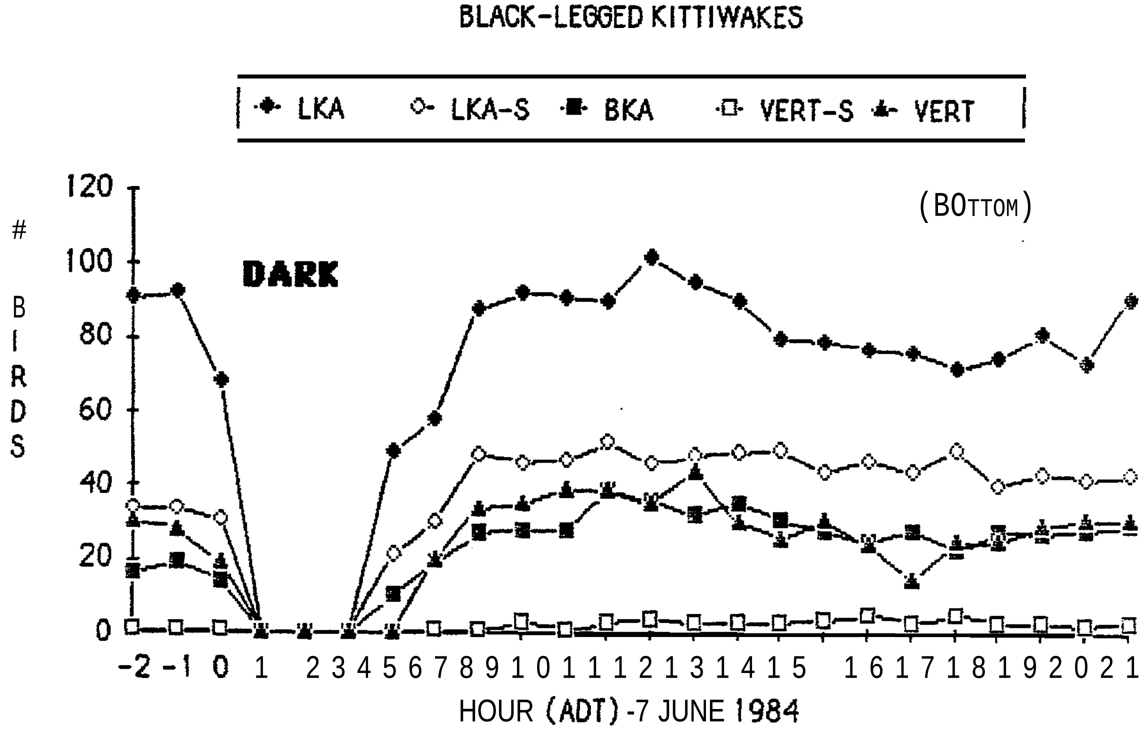


Figure 3. Diurnal attendance of pelagic cormorants at four population plots, Cape Peirce, Alaska (TOP) ; and black-legged kittiwake at five population plots, Cape Peirce, Alaska (BOTTOM).

Common murre--Common murre attendance was studied for 24 continuous hours on three plots at Cape Peirce. Common murres were present on the plots for only a portion of the daylight hours (Fig. 4). First arrival occurred between 0500-0600 and the last departures occurred between 1600-1900 hours. During the portion of the day that the murres were on the plots, two types of attendance patterns could be discerned. The plots with small numbers of attending birds (< 40) had relatively stable numbers of birds between 0600 and 1500 hours. The single plot with numerous murres (VERT) exhibited marked fluctuations in attendance with no obvious pattern (Fig. 4).

A detailed analysis of common murre attendance was provided from the time-lapse study at DUH plot. Trends in attendance patterns were analyzed for two periods: 7-16 June (Period 1), and 10-17 July (Period 3). Correlegrams for each period are shown in Figure 5. The variability in attendance for each hour within these periods is summarized in Figure 6.

The correlegrams show a pronounced 24 hour cycle early in the season ((7-16 June, Period 1) but that this is absent a month later. The hourly count summaries show a similar seasonal shift. In June a regular cycle is evident with low counts of common murres in the early morning and a peak attendance around noon. Testing for differences in median count among hours yielded a highly significant statistic ($p<0.001$). In July the mean counts were relatively uniform throughout the day (not significantly different), however, no counts were possible very early in the morning (00-03) because of darkness.

An interesting feature of these graphs is that the variability of counts at each hour is inversely related to the mean count; i.e., the lower the count the higher the variability. This trend is opposite to the more common pattern of increasing variances with larger means.

In terms of censusing murres, the implication of the results are that some standardization of count times would be required for studies done early in the season, but timing restrictions could be relaxed by mid-season. A suitable period for early season counts, based on similar mean counts and small, overlapping confidence intervals, would be 12:00-18:00.

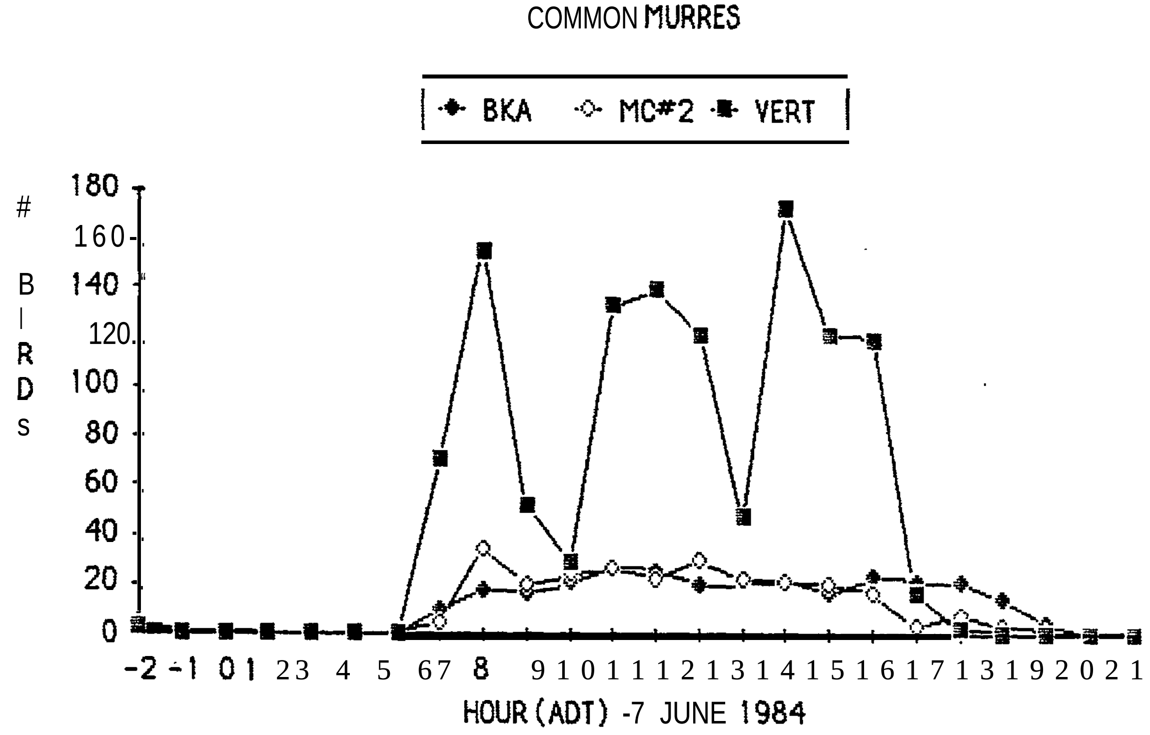


Figure 4. Diurnal attendance of common murres on three population plots at Cape Peirce, Alaska, 1984.

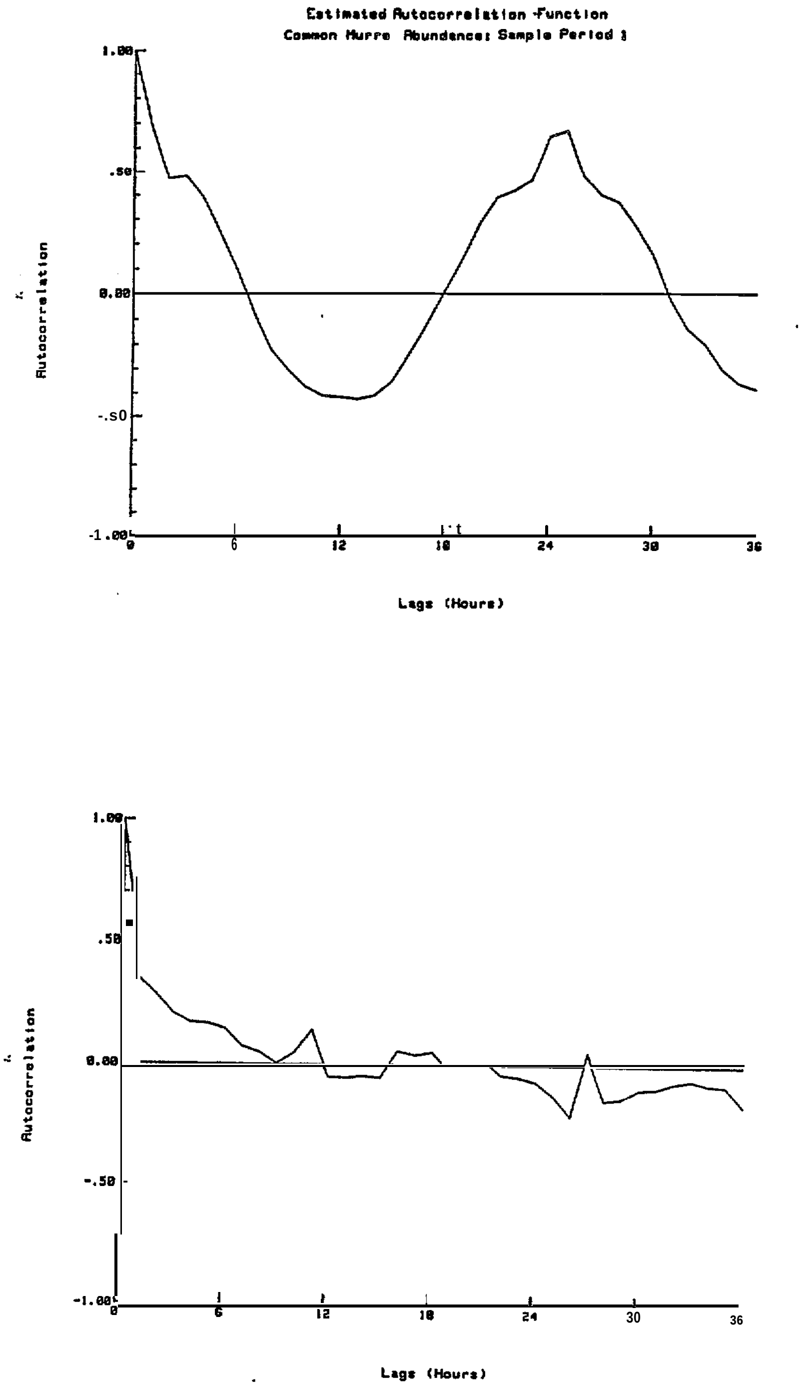


Figure 5. Correlegrams of common murre attendance at Cape Peirce (DUH). -

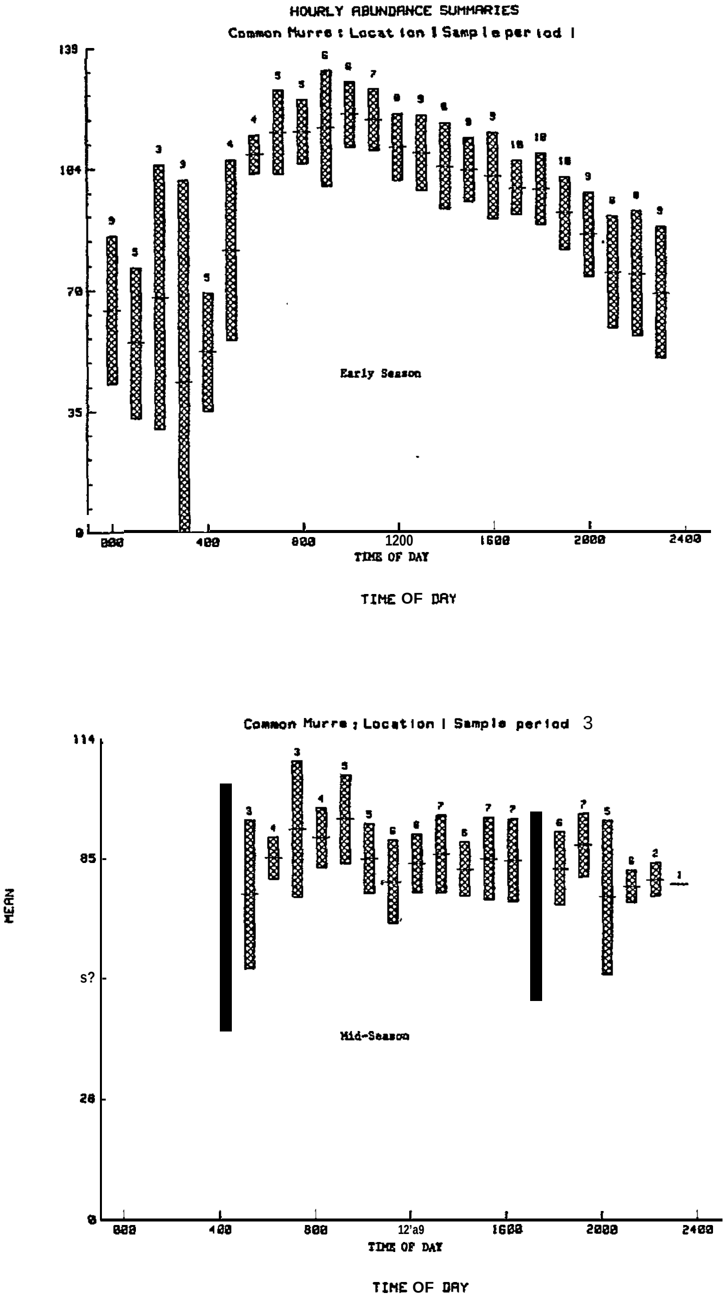


Figure 6. Hourly abundance summaries for common murres at Cape Peirce (means ±2 se.; sample size above se. bar).

Horned puffin--Horned puffin attendance at study plots at Cape Peirce during the 24-hour counts is shown in Figure 7. Horned puffins occurred in such low numbers that few generalizations can be made. This species was recorded only during afternoon and evening.

St. George Island (Pribilof Islands). Our investigation of diurnal patterns of seabird attendance on the Pribilof Islands were made using time-lapse cameras at two locations on St. George Island: High Bluff and Zapadni (population plot #25).

Northern fulmar--Northern fulmars were present in low numbers on one of the camera plots, Zapadni. Autocorrelation analyses were done for three sample periods and the resultant correlegrams are shown in Figure 8. In the first period (23-27 June) fulmar counts were positively correlated at all lag intervals indicating that the number of birds present was relatively constant and noncyclical.

This is confirmed by the actual counts-by-hour data shown in Figure 9. Note that the number of fulmars present averaged about two birds. Therefore, few inferences should be made from these data. Autocorrelation analyses of sample Periods 2 and 4 resulted in no evidence of a diurnal pattern (period 2) and perhaps a weak cycle during Period 4.

The count data (Fig. 9) show similar trends. During Periods 1-3 the mean hourly counts are either relatively constant (1 and 2) or erratic (3). However, during Period 4 the counts trend in an upward direction for 0900 through 2000 then start downward for 2 hours. Unfortunately fog and darkness precluded coverage during the remainder of the day.

Analysis for among-hour similarities in median abundance for Periods 1 and 2 resulted in failure to reject the hypotheses of similar counts during all hours (Kruskal Wallis Test, Period 1, H=5.05, df=13, p=0.97; period2, H=11.92, df=10, p=0.29).

Red-legged kittiwake--Red-legged kittiwake cliff attendance was monitored by the High Bluff camera. Unfortunately persistent fog greatly reduced the number of usable frames resulting from this effort. The results are therefore largely qualitative. None of the correlegrams (Fig. 10) indicate the presence of a diurnal pattern; however, early morning

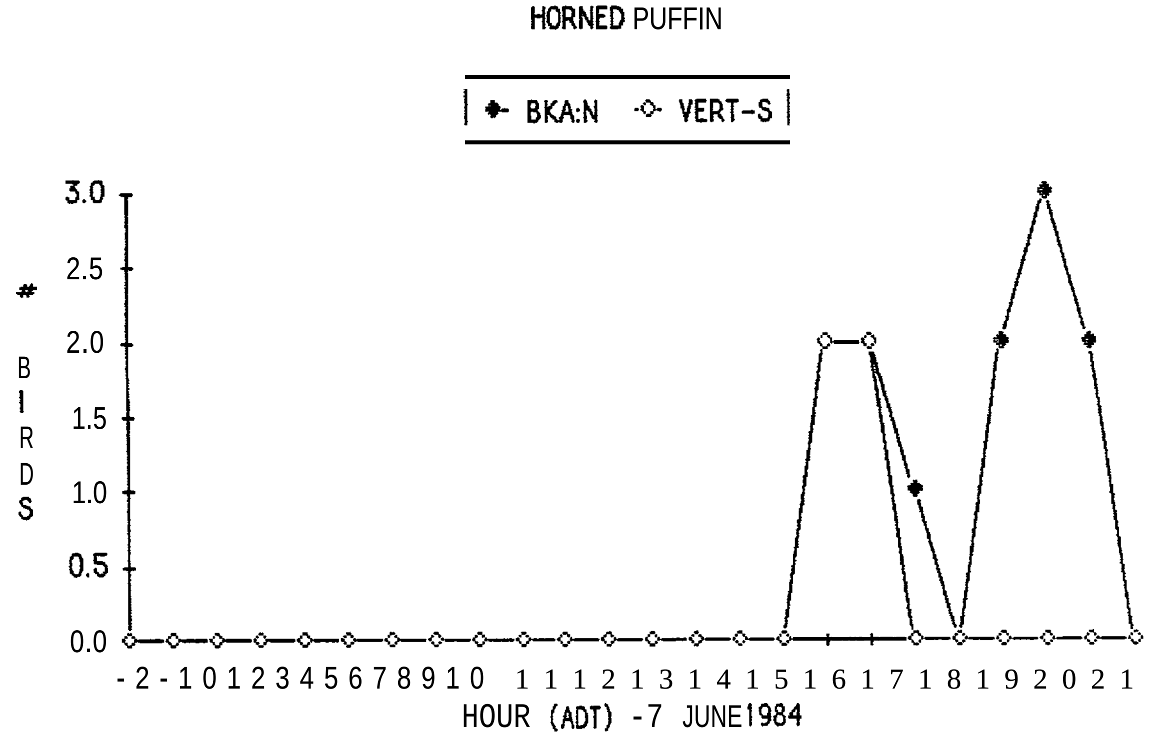


Figure 7. Diurnal attendance of horned puffins at two study plots at Cape Peirce, Alaska.

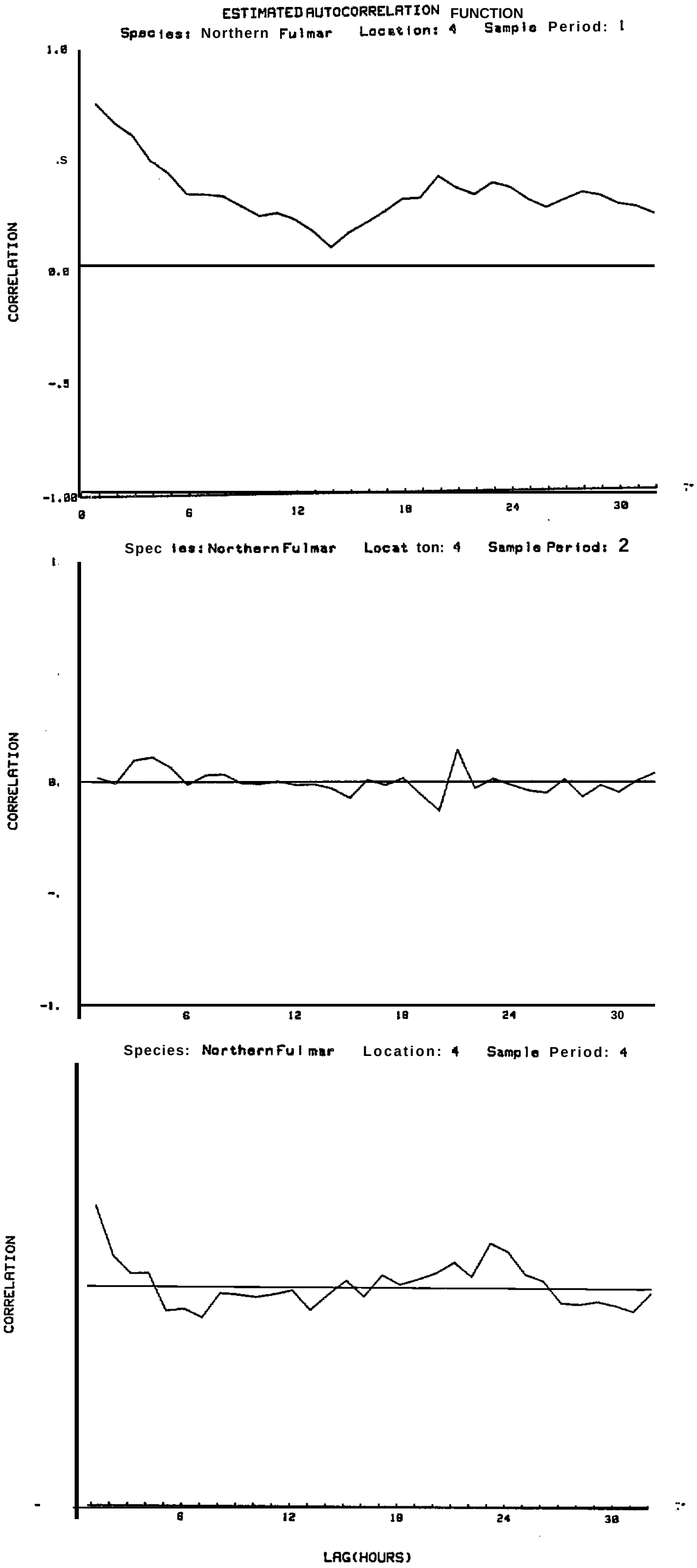


Figure 8. Correlegrams of northern fulmars on St. George Island.

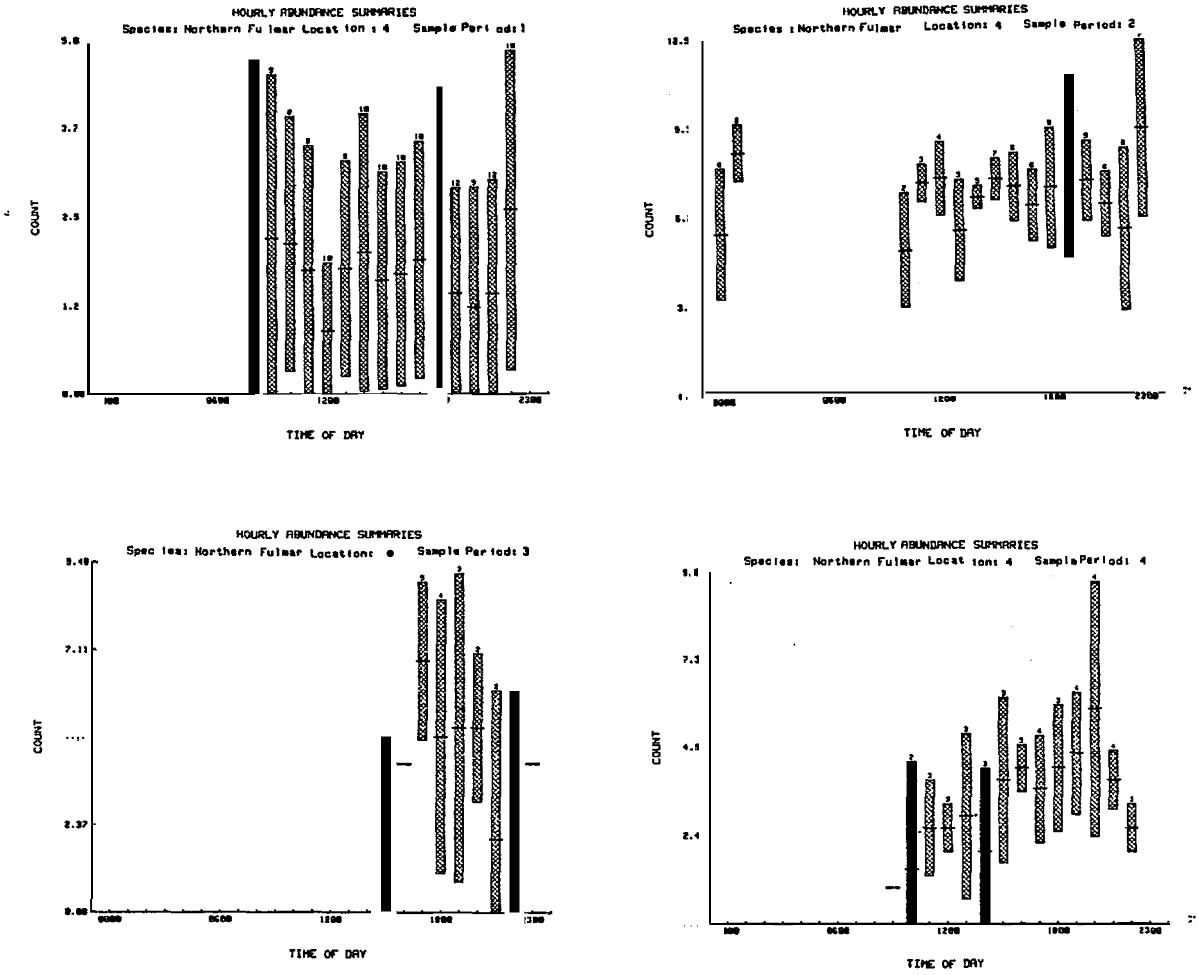


Figure 9. Hourly abundance summaries for northern fulmars on St. George . Island (means ±2s. e.; sample size above se. bar).

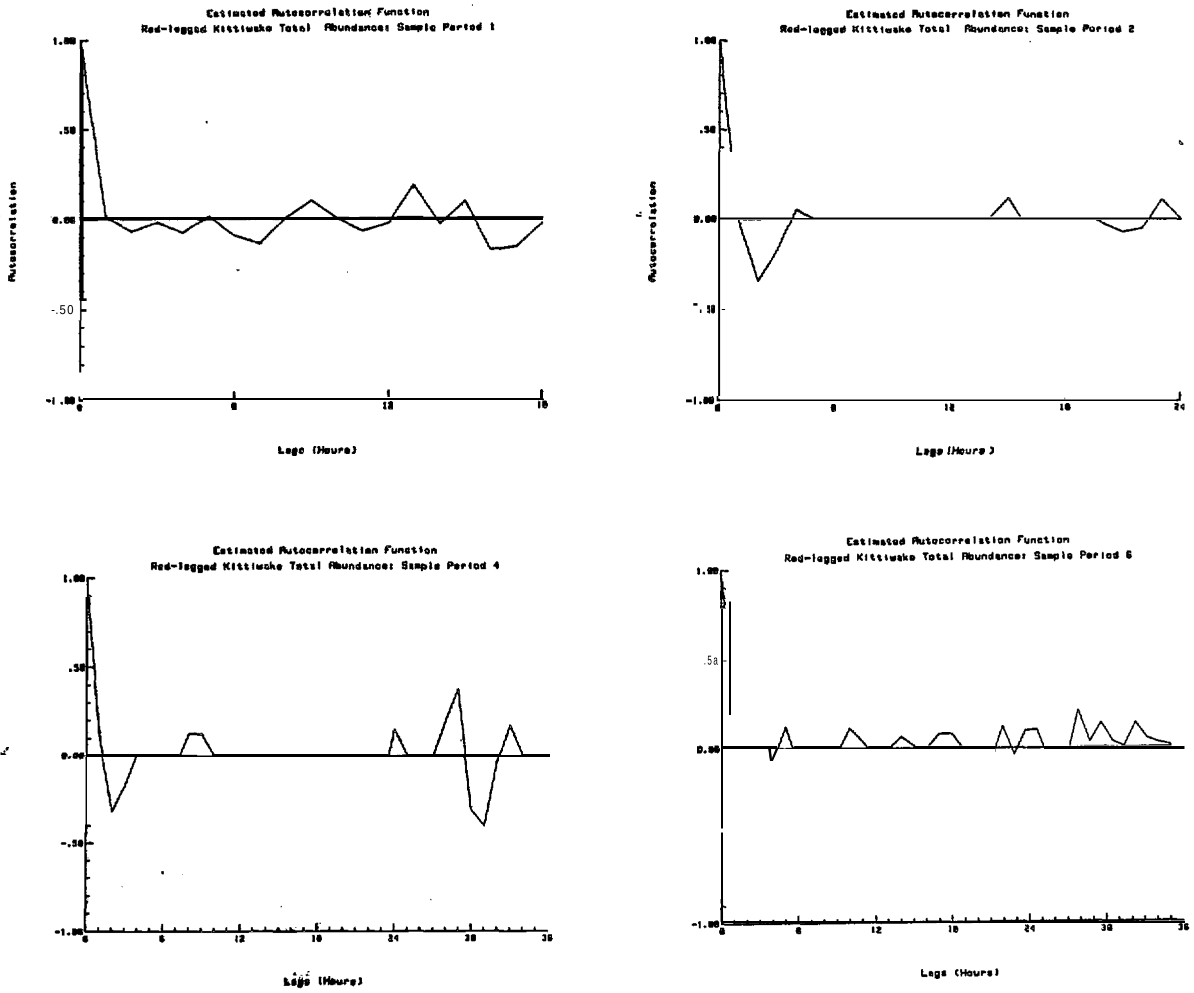


Figure 10. Correlegrams for red-legged kittiwakes on St. George Island.

data were limited. The hourly count summaries for the first and last periods suggest that morning counts may be low relative to those late in the day (Fig. 11).

Thick-billed murre--Thick-billed murres were present at both St. George camera locations, however, the record available for High Bluff is very poor (intermittent coverage due to fog) in comparison to Zapadni and only the latter is presented here. The autocorrelation analyses (Fig. 12) show that in period one (late June) a diurnal attendance cycle occurred, but that this was quite weak by period 2 (early July) and absent during Period 4 (mid-July).

The hourly attendance summaries (Fig. 13) also show the diminution of cyclical trends in attendance. Peak attendance of thick-billed murres appear to occur in early morning (at or before 0700). Counts diminished thereafter until approximately noon when they leveled out for the remainder of the day.

Parakeet a --Parakeet auklets were present at the Zapadni camera location. Autocorrelations for the first two sample periods are shown in Figure 14. During Period 1 some periodicity was definitely present. A 24-hour correlation is evident but some shorter period trends may also be present. Periodic trends were less pronounced during the second time period but slight indication of a 24-hour trend is still present.

The hourly count summaries (Fig. 15) show that peak numbers of parakeet auklets were present in mid-afternoon (1400-1600). The indistinct autocorrelations were probably because of the high variability in counts at most hours.

Crested auklet--Crested auklets were present at Zapadni but in such low numbers (maximum of four in the photographic record) that detailed analysis of attendance patterns is unwarranted. They exhibited a tendency toward a 24-hour cycle with peak numbers (or most regular occurrence) in mid-afternoon.

Least auklet--Diurnal periodicity in least auklet colony attendance was studied using two methods. Time-lapse techniques were used at Zapadni

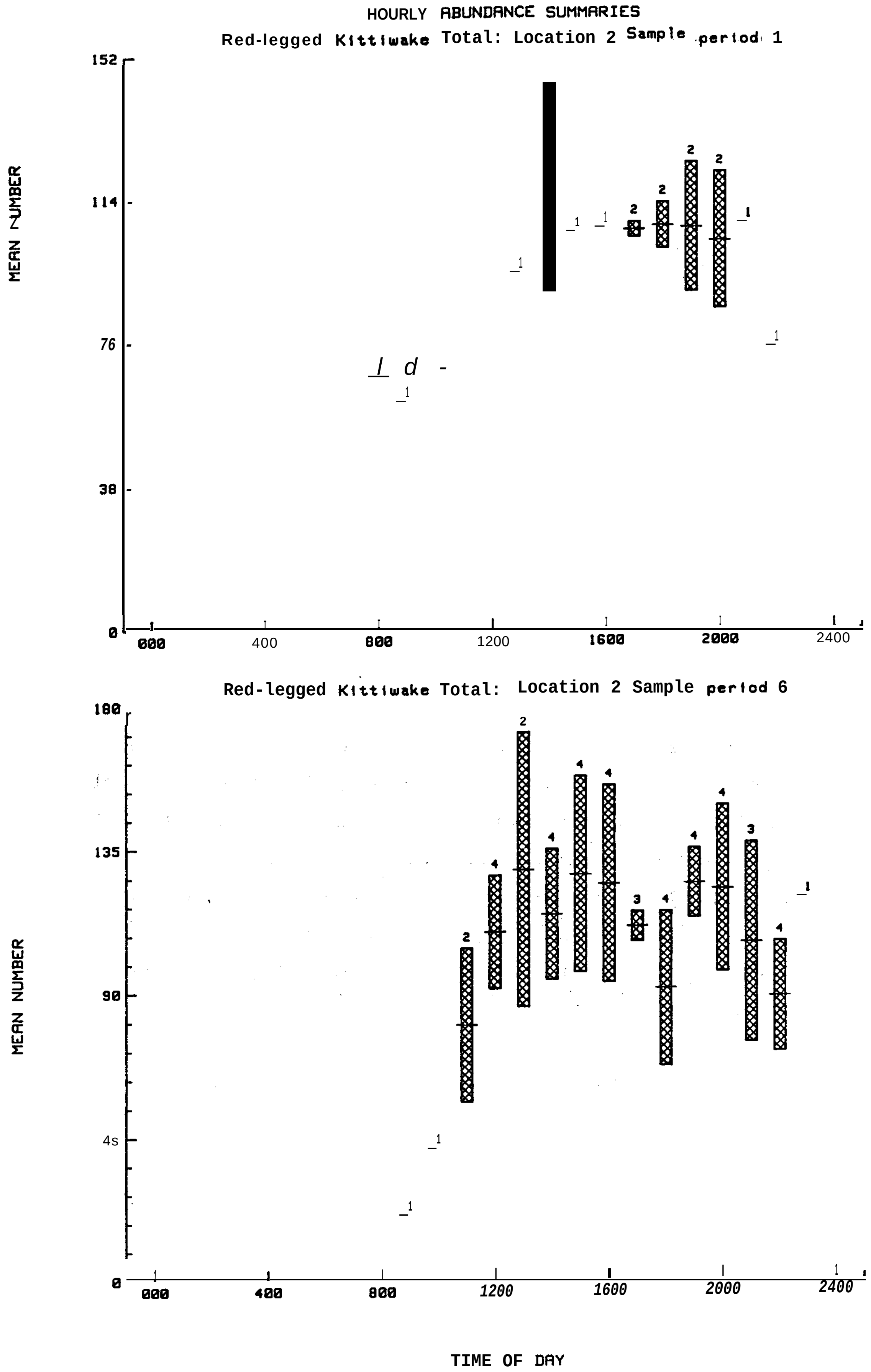


Figure 11. Hourly count summaries for red-legged kittiwakes on St. George Island (mean ± 2 se.; sample size above se. bar).

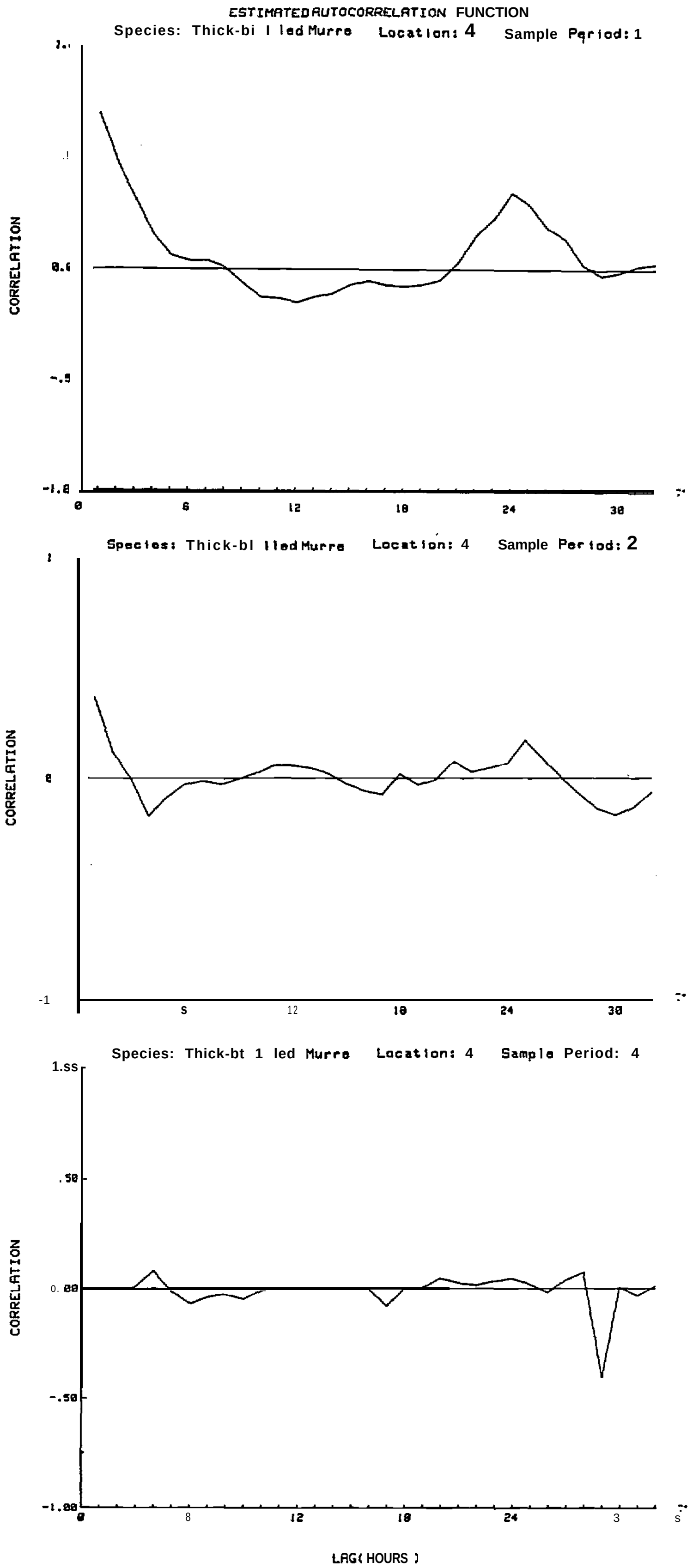


Figure 12. Correlegrams for thick-billed murres on St. George Island.

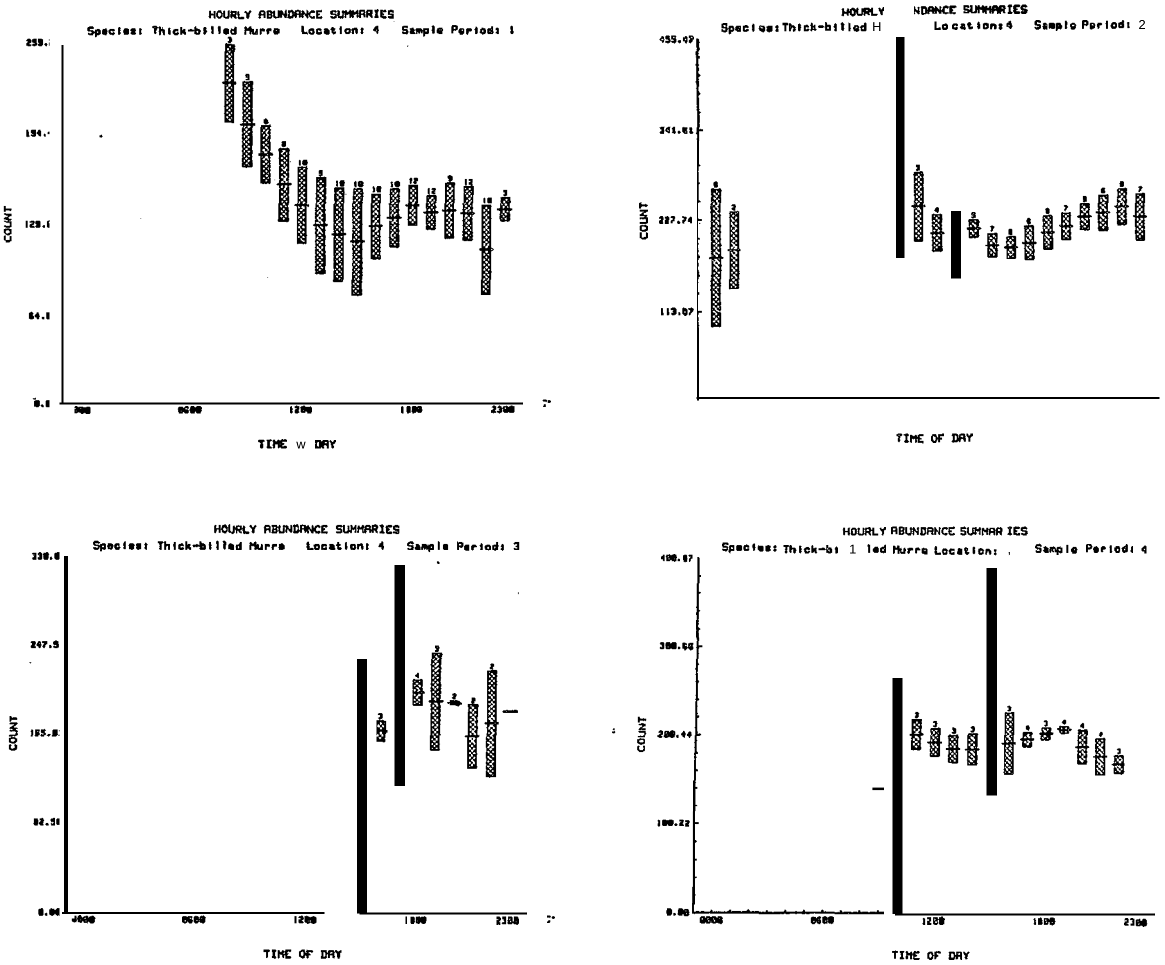


Figure 13. Hourly count summaries of thick-billed murres on St. George Island (mean i- 2 se.; sample size above the se. bar).

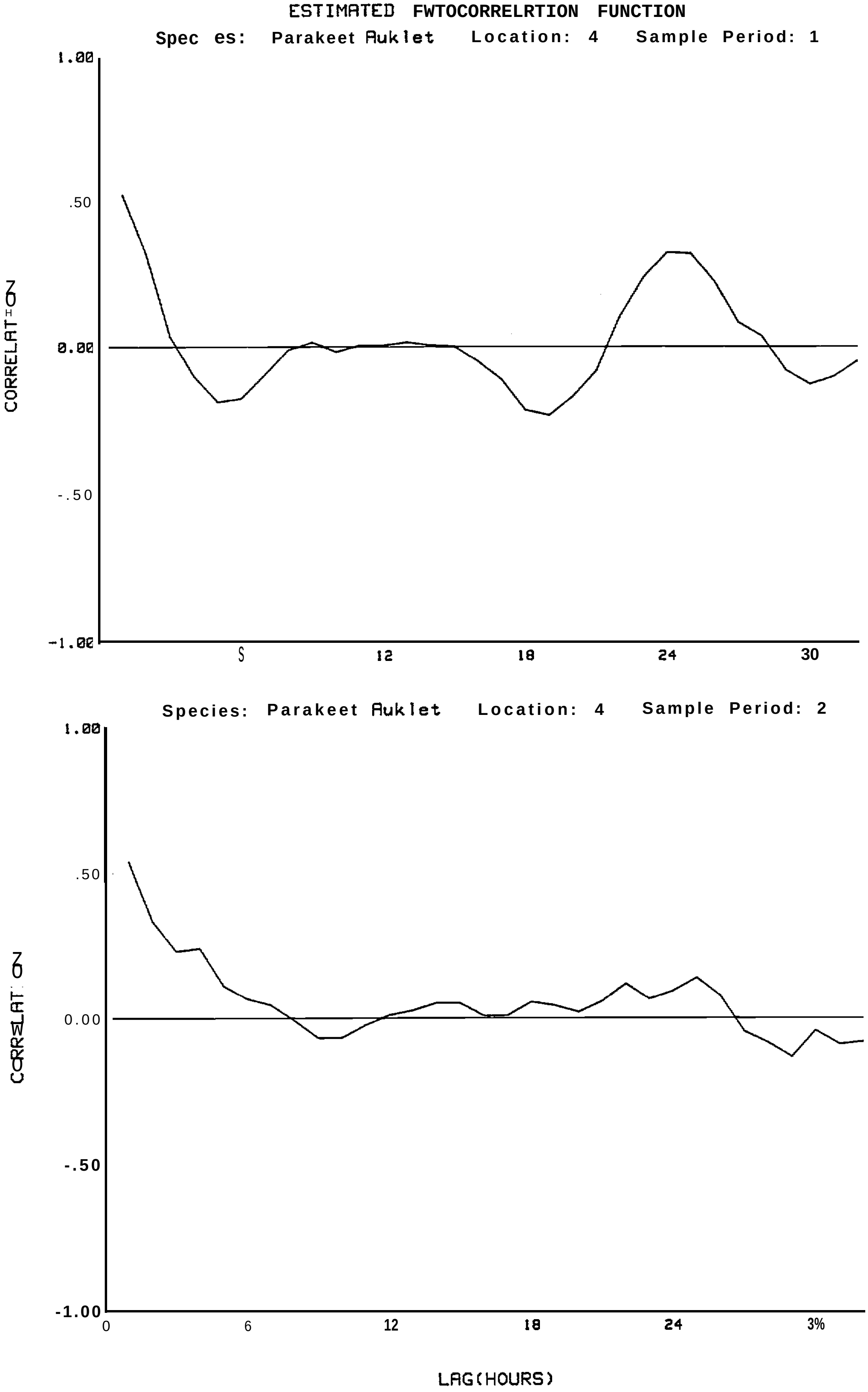


Figure 14. Correlegrams for parakeet auklets on St. George Island.

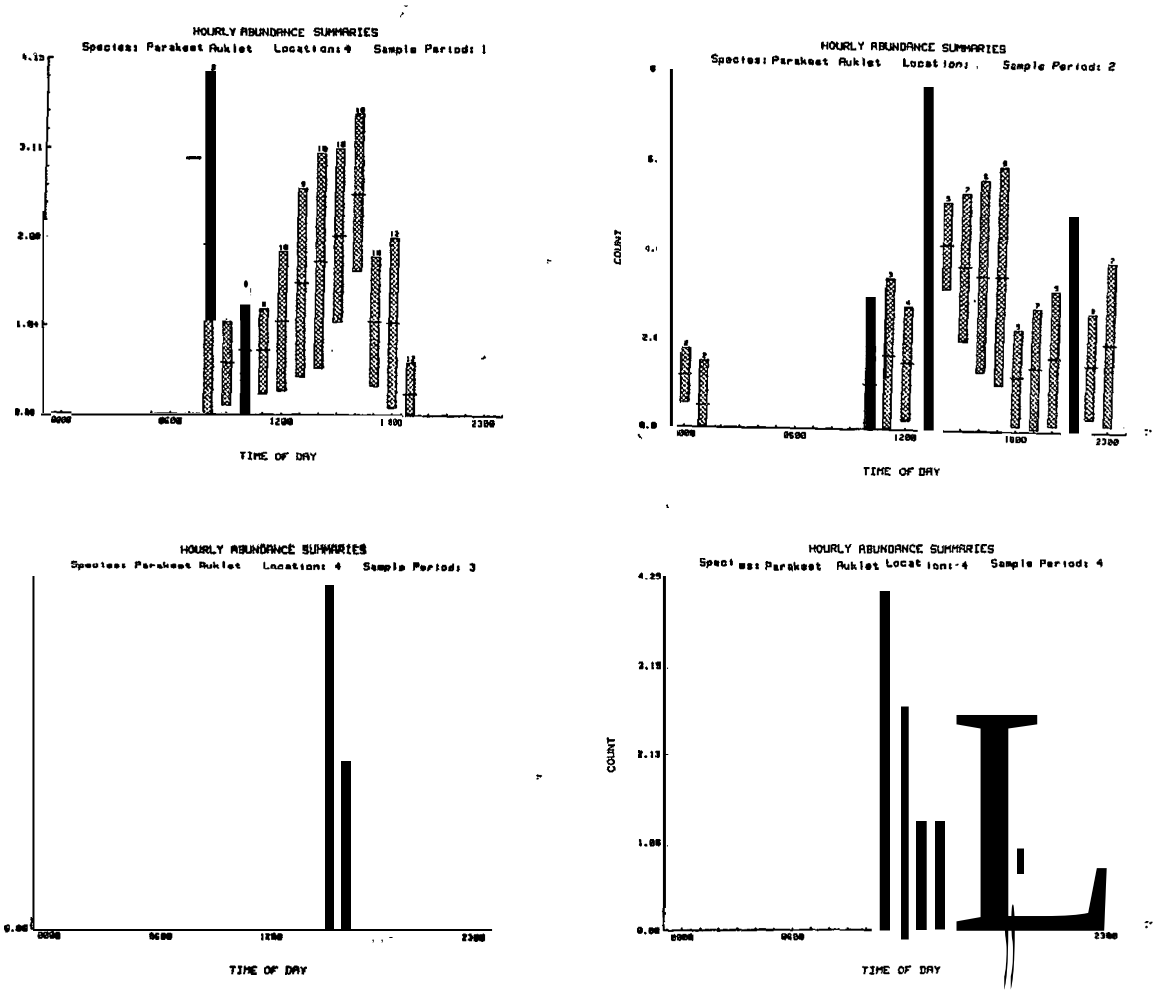


Figure 15. Hourly count summaries for parakeet auklets on St. George Island (mean+2 se.; sample size above se. bar).

where least auklets were of rare but regular occurrence. An independent survey, albeit only for one day, was made of auklets associated with the Ulaikaia Ridge colony.

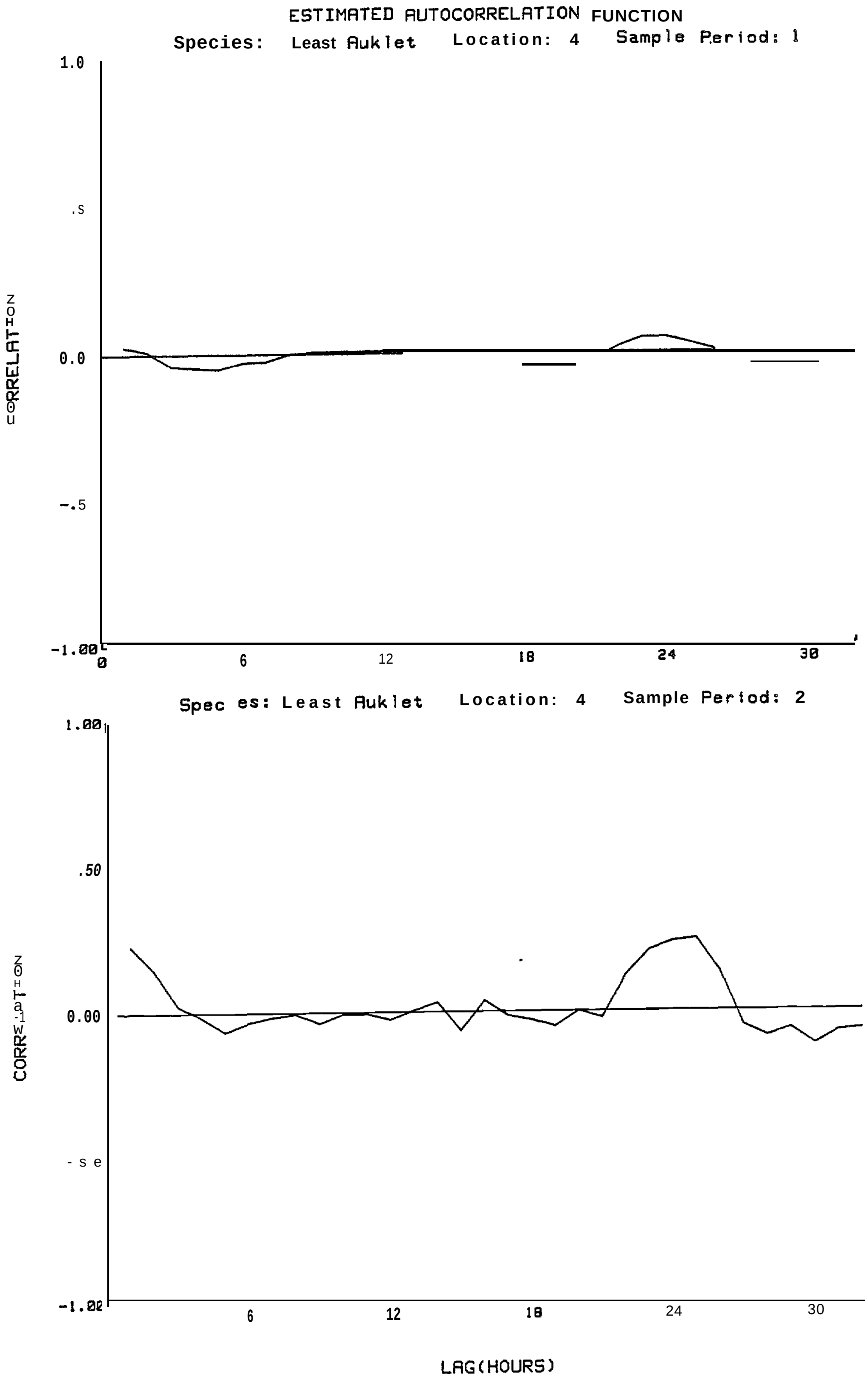
Results of autocorrelation analyses of attendance Pattern at Zapadni are shown in Figure 16 for sample Periods 1 and 2. During Period 1 very little evidence of any patterns could be found; however, a24 hour pattern was evident in Period 2. The hourly count summaries in Figure 17 reveal that least auklets peaked in abundance during the afternoon (similar to the other auklets) but that the counts were quite variable.

Flights of least auklets passing over the St. George Airstrip enroute to the Ulaikaia colony were observedon7 July between 1050 and 0030 (8 July). Flock sizes were estimated and tallied for every 10-min interval in this time range. The census point varied in space during the course of the day as the flight corridor of the auklets shifted. Results of the counts are illustrated in Figure 18. The distribution of the counts was bimodal with abroad peak during mid-day, a late evening minimum, anda sharp peak prior to nightfall.

The results of our counts are compared with thoseof Craighead and Oppenheim (1982) in Figure 18. The 1982 counts were made approximately three weeks later in the summer (31 July) than our counts. The two sets of counts are quite similar in pattern, although the 1984 distribution appears to be more peaked and to have a slight phase-shift towards earlier times of day.

Horned puffin--Correlegrams of horned puffin attendance at Zapadni for Periods 1 and 2 are shown in Figure 19. During both these periods horned puffins appear to have had a diurnal (24 hr) period in their attendance patterns. The hourly count summaries (Fig. 20) show that counts of puffins on the cliffs increased throughout the day, peaking just before dark.

Tufted puffin--Tufted puffin were regularly recorded at Zapadni but rarely more than three birds. Only in Period 1 was the species present before noon, thereafter birds were seen until dark in all periods. The paucity of observations does not warrant more detailed analyses.



ESTIMATED AUTOCORRELATION FUNCTION

Species: Least Auklet Location: 4 Sample Period: 1

Spec es: Least Auklet Location: 4 Sample Period: 2

Figure 16. Correlegrams for least auklets on St. George Island.

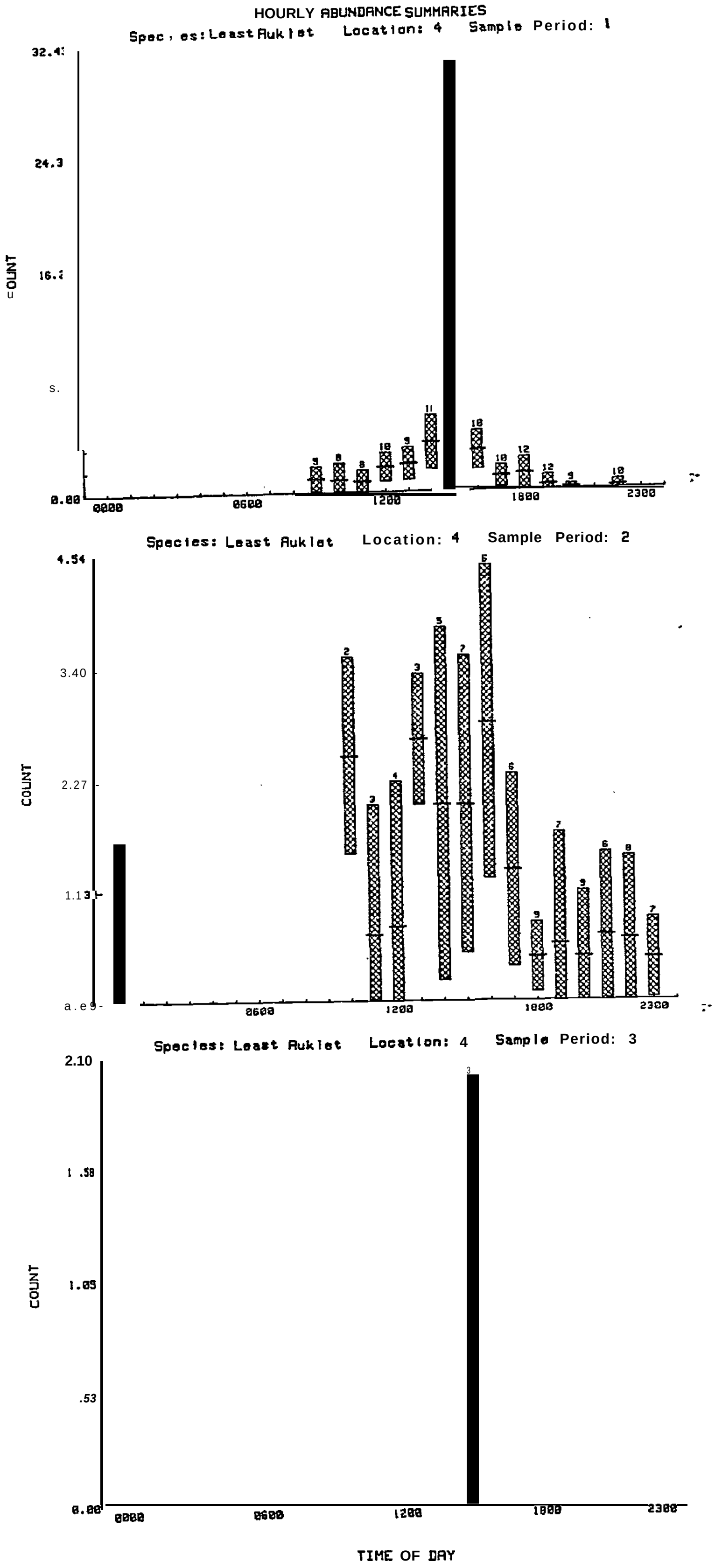


Figure 17. Hourly count summaries for least auklets on St. George Island (mean ± 2 se.; sample size above se. bar).

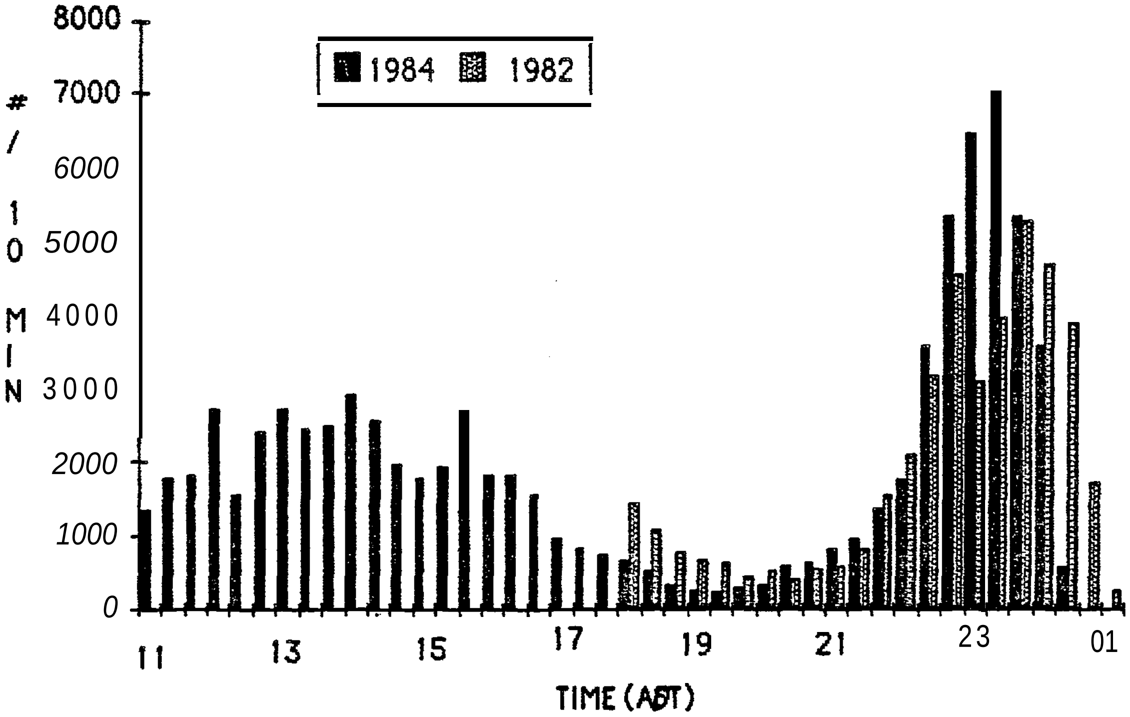


Figure 18. "A comparison of 10-minute counts of least auklets flying into the Ulaikaia Ridge colony, St. George Island, Alaska, 1982 and 1984.

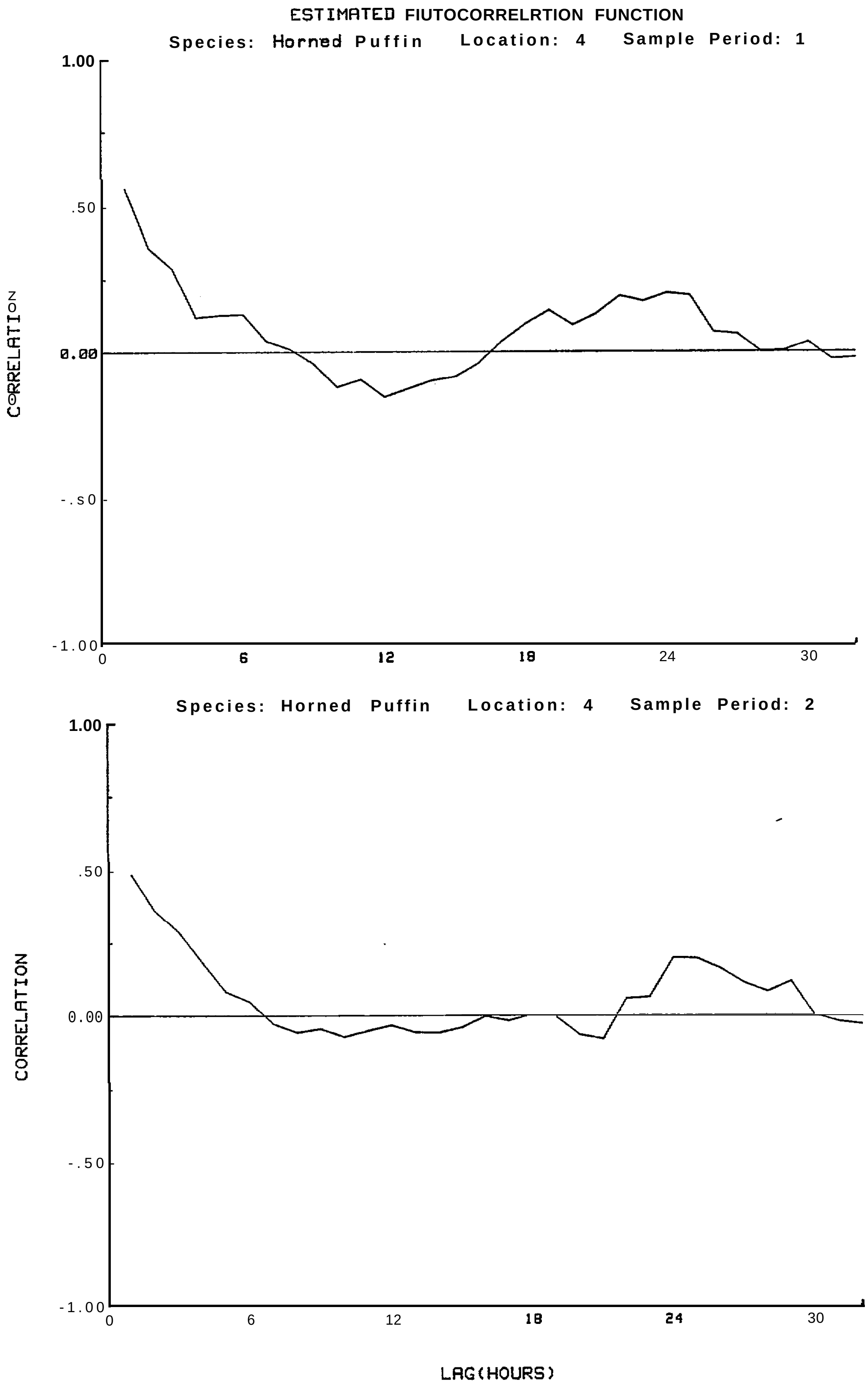


Figure 19. Correlegrams for horned puffins on St. George Island.

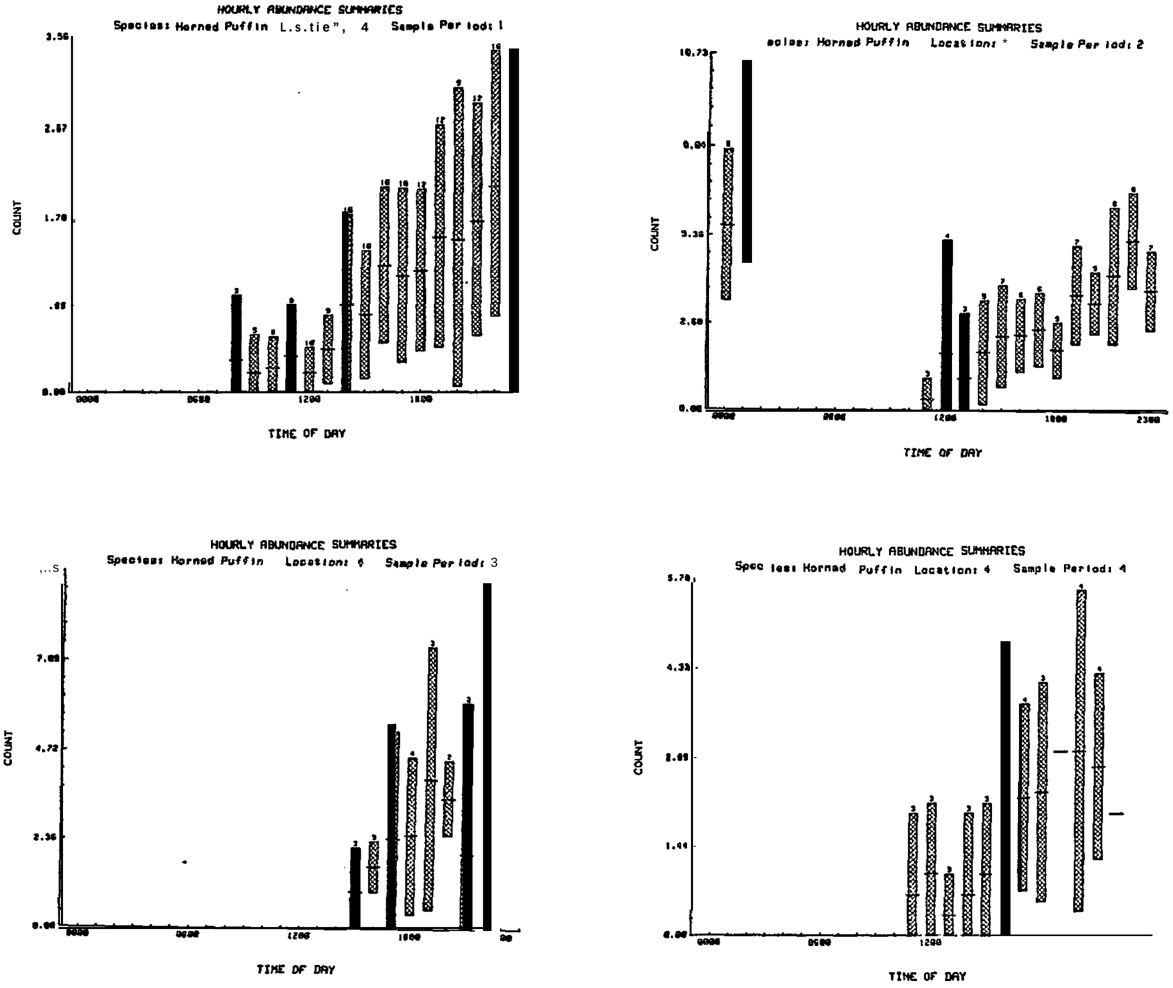


Figure 20. Hourly count summaries for horned puffins at Zapadni on St. George Island (mean_+ 2 se.; sample size above s.e. bar).

Discussion

As a final summary of trends in diurnal attendance patterns, two sets of cross-correlation analyses were completed, one each for Periods 1 and 2 at Zapadni-St. George Island. These correlations are similar to the autocorrelations except that counts of species A are compared to counts of species B (at various time lags) rather than to itself. The purpose of the analyses is to document phase shifts in attendance patterns among species, or alternatively, which species have similar attendance patterns. The results are shown in Figures 21 and 22.

A high correlation at lag 0 represents species that have similar attendance patterns. This attribute is shared by few species; the three auklets have similar patterns but none of the remaining species do.

The species of greatest concern to our sampling program are the non-cavity, cliff-nesting species, i.e., those birds whose appearance on cliffs is most closely indicative of breeding birds. Two of these species were present in sufficient numbers at Zapadni for analysis and comparisons namely thick-billed murres and northern fulmars. During Period 1, these two species were about 8-12 hours out of phase in the attendance patterns; however, in Period 2 no pattern was discernible. This parallels the general loss of diurnal cycles mentioned earlier.

The topic of diurnal patterns in seabird attendance patterns is of great importance to population studies because the existence of periodic patterns in attendance can greatly affect the number of birds present on study plots and influence analyses by producing spurious trends or obscuring actual population changes.

The analyses presented above document the level of occurrence and persistence of cycles for many species. Certainly these data could be analyzed in much greater detail to explore additional facets of seabird biology; however, the following generalities relevant to monitoring population trends can be made:

(1) Most species have pronounced diurnal cycles early in the breeding season.

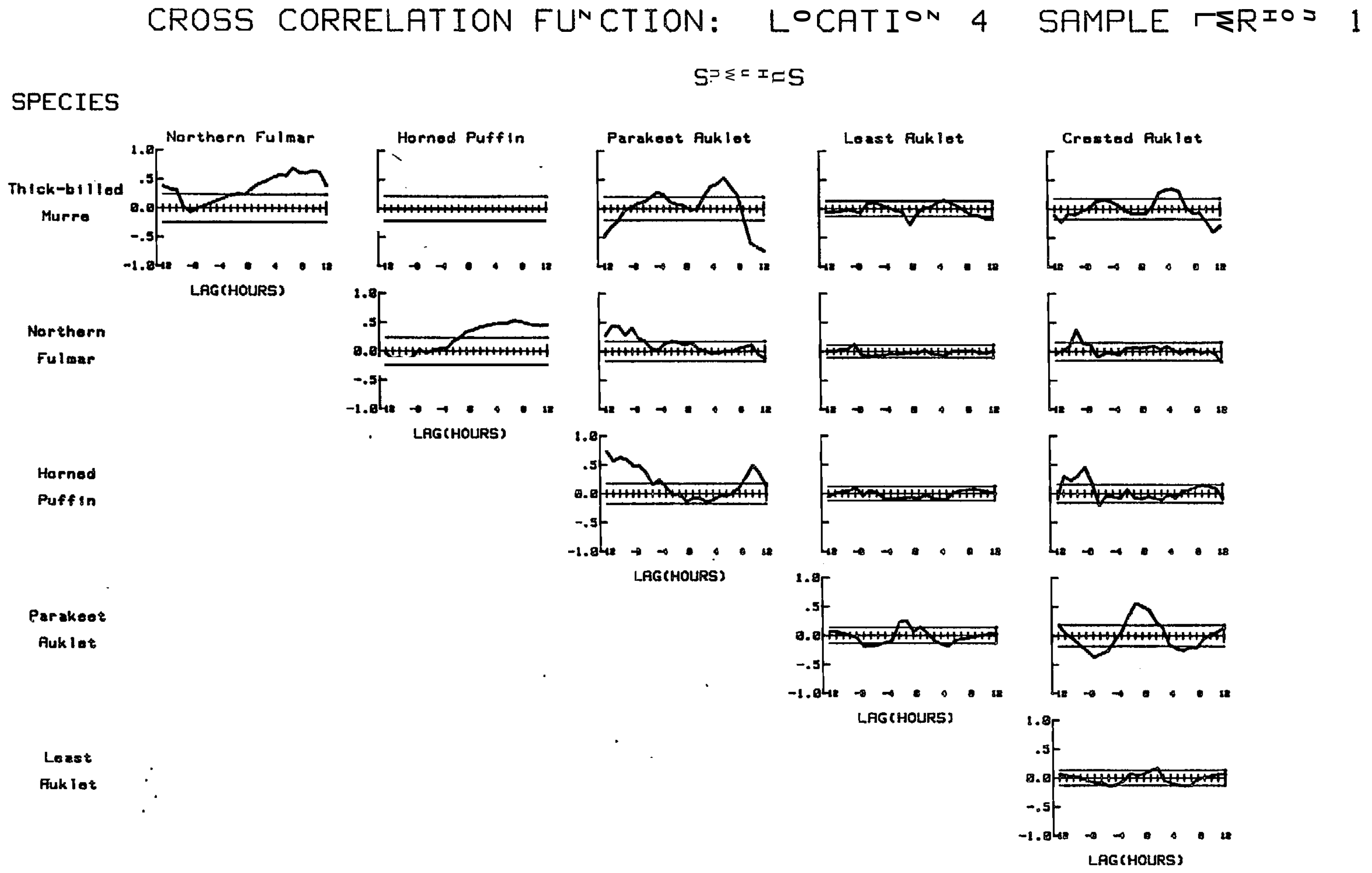


Figure 21. Cross correlations among seabirds at Zapadni on St. George Island during Period 1 (late June).

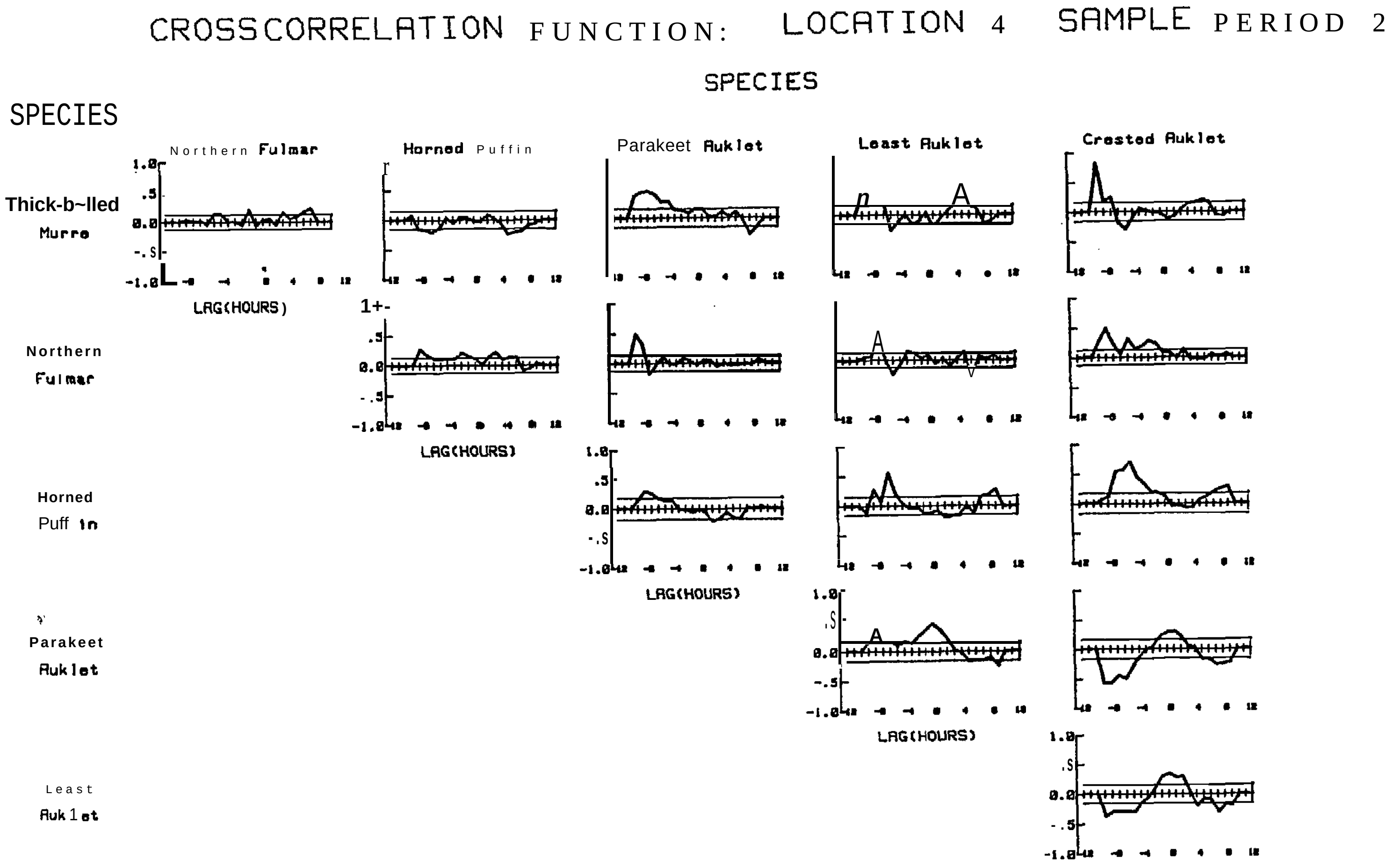


Figure 22. Cross correlations among seabirds at Zapadni on St. George Island during Period 2 (early July).

(2) For most species (all the non-cavity, cliff-nesting species studied], these diurnal trends quickly diminish so that during the middle portion of the nesting season (most of incubation) diurnal patterns are minor during most of the day.

(3) Diurnal patterns are nonsynchronized among most species. This necessitates that if the time of counts are to be standardized the selection should be based on a species-specific criterion.

Variation in Attendance Patterns Among Sample Periods - Seasonal Trends in Abundance

Methods

Countsof birds on the study plots were compared over the breeding season to look for relationships between the date of census (intervals of three days to one week) and the abundance of birds on the plots. Some differences would be expected, for example, least auklets started fledging in late July, consequently the number of auklets present in the colony would be expected to correspondingly decline through August. In cases where no differences in counts among sample periods were found, it would be legitimate to treat censuses as replicate counts for among-year comparisons.

There were five sample periods at St. George and Cape Peirce and, two on St. Paul (Table 1). The five periods on St. George and the two periods on St. Paul represent relatively discrete blocks of time, and testing for among-period differences was required in order to determine which periods represent replicates and which are influenced by seasonal variations in attendance patterns. The five periods at Cape Peirce comprise two discrete blocks of dates (June and July) with three and two replicates each.

In summarizing the study plot counts, the following points should be considered. On St. George and St. Paul islands, coverage of most plots was intermittent, i.e., very few plots were sampled during all sample periods. In particular, plots in the higher strata (3-5) were irregularly

Table 1. Summary of sample periods for seabird population plot censuses.

St. George Island		
	Period 1	24 - 29 June
	Period 2	2 - 11 July
	Period 3	22 July
	Period 4	28 - 31 July
	Period 5	11- 15 August
St. Paul Island		
	Period 1	13- 16 July
	Period 2	4-8 August
Cape Peirce		
	Period 1	9- 13 June
	Period 2	14- 16 June
	Period 3	17- 19 June
	Period 4	10 - 12 July
	Period 5	13- 15 July

censused because of fog. The results of all counts are given in Appendices (Appendix 3 - Cape Peirce, Appendix 4 . St. George, and Appendix 6 - St. Paul). For the purpose of these analyses a reduced matrix of the most complete plot-by-period coverage was used to ensure a standard sample area when testing for among-period differences in abundance (Friedman test). An example of the reduced plot matrix is shown for thick-billed murre in Table 2. If significant differences among sample periods were found, then multiple comparisons using the Bonferroni procedure (overall of 0.05) were used to help isolate periods of greatest deviation. The Cape Peirce results were complete and no special considerations are necessary.

Results

Cape Peirce.

Pelagic cormorant--Counts of pelagic cormorants on the Cape Peirce study plots are shown in Appendix 3. These counts exhibit a moderate amount of variability among periods, and show a small decrease in numbers in July (Periods 4 and 5) relative to June (Periods 1-3). These differences are not significant (Friedman $T=9.48$, $df=4$, $p>0.05$). A considerable amount of within-month (among-replicate) variability is evident as well.

Glaucous-winged gull--Occurrences of glaucous-winged gulls on study plots at Cape Peirce are summarized in Appendix 3. Glaucous-winged gulls were infrequent throughout the breeding season and were essentially absent until mid-June.

Black-legged kittiwake--A very marked trend is apparent for counts for Cape Peirce (Appendix 3). These counts show a very substantial (>76%) decrease in numbers of black-legged kittiwakes over Periods 1-4 with a slight recovery in Period 5. Periods 1-3 were within a 10-day interval in mid-June; during this interval kittiwake abundance decreased by approximately a third. Counts among periods vary quite significantly (Friedman $T=26.54$, $df=4$, $p< 0.001$). This marked temporal variability in

Table 2. Trends in the seasonal abundance of thick-billed murres recorded during plot censuses on St. George Island, Alaska.

STRATUM- 1				
PLOT	**PERIOD 1**	PERIOD 2	**PERIOD** 4	PERIOD 5
8	220	186	210	23'3
9	259	308	227	370
10	340	286	314	373
11	62	82	105	97
12	123	34	151	179
13	96	98	125	111
14	87	162	120	130
15	88	107	111	124
16	143	Ill	107	131
17	124	102	119	118
18	54	82	68	91
19	132	98	111	131
20	27	44	31	44
24	192	461	504	342
46	193	158	241	268
47	140	93	117	99
48	184	148	296	291
49	17	6	8	9
51	77	40	79	80
52	67	61	80	61
53	74	93	111	127
61	175	395	288	480
62	49	64	137	136
Subtotal	2923	3274	3660	4031
STRATUM- 2				
21	22	94	73	84
22	45	121	120	156
23	85	246	205	246
24	330	646	463	830
25	215	496	534	539
Subtotal	697	1603	1395	1855
TOTAL	3620	4877	5055	5886

attendance indicates considerable dynamics in kittiwake attendance and may preclude the use of counts made even only a few days apart as replicates.

Common murre--Counts from Cape Peirce appear in Appendix 3. The counts of common murres differ significantly among sample periods (Friedman T=12.24, df=4, $p < 0.025$). The July counts (Periods 4 and 5) appear to be considerably (20%) less than those for June (Periods 1-3).

Pigeon guillemot--This species was encountered infrequently at Cape Peirce. The only record of guillemots on the study plots was of two birds on Plot 3 during sample Period 5.

Horned puffin--Among-period variability was extreme in counts from Cape Peirce (Appendix 3) although plots contained very few birds. Significant among-period variability was not detected using the Friedman Test (T=6.31, df=4, $p > 0.01$).

Tufted puffin--Tufted puffins occurred too infrequently on study plots at Cape Peirce to assess seasonal patterns in attendance. The count data by plot appear in Appendix 3.

St. George Island (Pribilof Islands).

Northern fulmar--Counts of northern fulmars on all plots during all census periods on St. George Island are summarized in Appendix 4. This species was recorded in all strata except Stratum 4. Analysis of these data suggest that fulmar numbers varied significantly over the course of the summer (Friedman T=33.12, df=3, $p < 0.001$). Multiple comparisons (Bonferroni procedure) reveal that counts are relatively stable during late June and July (Periods 1-4) but that substantially increased numbers are present in August. Counts in Stratum 2 appeared to be more stable than those in Stratum 1.

Red-faced cormorant--Results of all counts of red-faced cormorants on St. George Island can be found in Appendix 4 (nest data are summarized in Appendix 5). This species was recorded in only the two lowest strata.

The count data show that red-faced cormorants were rather sparsely distributed on our study plots. The Friedman analysis did not reject the hypothesis of similar attendance during all sample periods ($T=2.49$, $df=3$, $p>0.5$).

Black-legged kittiwake--All counts of black-legged kittiwakes on study plots at St. George Island are shown in Appendix 4 (nest data are summarized in Appendix 5). This species occurred in plots in all strata. These counts demonstrate considerable variability. The early July count (Period 2) was markedly lower than those of late June (Period 1). Counts in Period 4 (late July) were approximately double those of early July and numbers increased somewhat again by mid-August. The small sample of Plots censused during Period 3 (see Appendix 4) show that black-legged kittiwake numbers were intermediate between those counted in Periods 2 and 4. The number of birds on Plots 45-53 increased steadily for Periods 2-5 in the following sequence: 137, 195, 250, 279. Thus it appears that kittiwake numbers were relatively high in late June, dropped markedly in early July, then increased during the remainder of the study. These interpretations are based largely on results from Stratum 1. The few counts for Stratum 2 do not show this pattern as clearly.

The Friedman analyses confirm the qualitative observation made above (counts differed significantly among periods, $T=20.78$, $df=3$, $p<0.001$). Multiple comparisons identified Periods 1 and 2; and 1, 4, and 5 as relatively homogeneous groups.

Red-legged kittiwake--A complete summary of counts of red-legged kittiwakes on St. George Island study plots is provided in Appendix 4 (nest data are summarized in Appendix 5). This species was found in all five strata. Note that plots in Strata 3, 4, and 5 where this species reaches its peak abundance, are not included in the Friedman analyses because none of these plots could be sampled during the initial portion of the breeding season. Red-legged kittiwakes appear to have increased steadily each sample period. However, this trend was not significant (Friedman $T=4.8o$, $df=3$, $p>0.1$).

Common murre--A complete record of counts of common murres on St. George Island study plots is provided in Appendix 4. Common murres were recorded on plots in all strata except Stratum 3. These data show that the number of common murres in attendance at the study plots increased steadily during the summer and more than doubled between June and August. Friedman analysis of these results support the observation that counts vary significantly over sample periods (T=9.72, df=3, p<0.025). However, the Bonferroni multiple comparisons did not segregate any subgroups of homogeneous periods.

Thick-billed murre--A complete summary of counts of thick-billed murres recorded on study plots on St. George Island is provided in Appendix 4. This species was found in all five strata. These data show that thick-billed murres increased in abundance with each sample period. August (Period 5) counts averaged approximately 50% greater than the initial late June counts (Period 1). The Friedman results confirm the heterogeneity in counts among sample periods (T=18.30, df=3, p<0.001). Multiple comparisons segregate two subgroups, low counts during Periods 1-4 and high counts in Periods 4 and 5 (note that period 4 was intermediate and could be classified with either group).

Parakeet auklet--A complete record of parakeet auklets counted during plot censuses on St. George is provided as Appendix 4. Two prominent features are evident in the trends in seasonal abundance of this species. First, the marked increase in auklet numbers between Periods 1 and 2; this is an artifact of our sample schedule. Almost all of the difference is due to a single plot (61), which was sampled in the evening during Period 1 after most auklets had departed. Second, auklet numbers dropped markedly during the second half of the study; they were virtually absent by August.

The significance of these observations were verified by the Friedman analyses which indicate among-period variability (T=27.78, df=3, p<0.001). Three overlapping subgroups of periods were identified using multiple comparisons. Low counts during late season (Periods 4 and 5), high counts during early season (Periods 1 and 2). These two groups were bridged by a nonsignificant difference between the two intermediate counts of Periods 1 and 4.

Crested auklet--A complete record of counts of crested auklets on St. George Island is provided in Appendix 4. The crested auklet was the least common of all the regularly occurring seabirds on the Pribilof study plots. The only generality that can be made is that very few crested auklets appeared in August. However, differences between sample periods cannot be statistically verified (Friedman $T=4.84$, $df=3$, $p>0.1$). Trends between Periods 1 and 2 are inconclusive. This species appeared to be most numerous in Stratum 1 in Period 1, and in Stratum 2 during Period 2. As with parakeet auklets the sampling design is likely inappropriate for crested auklets.

Least auklet--A complete record of least auklet counts on St. George Island study plots is provided in Appendix 4. The same limitations that were described for the other two auklets apply to the interpretation of these results. The main conclusion is that least auklets were essentially absent from the study plots by August. Friedman analysis documented the among-period heterogeneity ($T=22.34$, $df=3$, $p<0.01$). No periods particularly different from the others were segregated by the multiple comparisons.

Horned puffin--Counts of horned puffins on study plots on St. George Island are summarized in Appendix 4. Meaningful interpretation of puffin attendance data suffers from many of the same limitations as interpretation of auklet data, thus appropriate conclusions are difficult to make. On St. George Island, total counts of horned puffins appeared to vary greatly, but not in an obvious pattern. Friedman analysis did not reject the hypothesis of equal attendance during all sample periods ($T=4.79$, $df=3$, $P> 0.1$).

Tufted puffin--A complete record of tufted puffin counts on St. George Island study plots is provided in Appendix 4. Analysis of these data using the Friedman Test resulted in a significant test statistic ($T=9.52$, $df=3$, $p<0.025$) but no clear pattern was evident.

St. Paul Island (Pribilof Islands). A few plots were censused in only one of the two sample periods. These are Plot 4 (Period 1 only), Plot 8 (Period 2 only), and Plot 32 (Period 2 only - Zapadni). These plots and Plot 6 (which partially overlaps Plot 5) are not included in the subtotals or totals calculated for the sample periods (Appendix 5) nor are they used in the Friedman analyses. Friedman analysis of two groups (treatments) is equivalent to a Wilcoxin paired-sample test.

Northern fulmar--Counts for St. Paul Island are shown in Appendix 6.', These counts also illustrate the late summer increase in numbers of birds on the study plots, with August counts (period 2) being approximately double the July (Period 1) counts Counts during the two sample periods were significantly different (T=4.03, df=1, p<0.05). Trends appear to be similar in both strata.

Red-faced cormorant--The results for St. Paul Island are shown in Appendix 6 (nest data are summarized in Appendix 7). Again, the number of birds censused was quite small. The overall trend appears to be opposite that found on St. George with the August counts lower than July. The difference between sample periods are not significant (T=0.53, df=1, p>0.25). Note that this is a consequence of trends in Stratum 2 only. It is apparent that our study plots do not represent the core of the cormorant breeding areas, at least on St. Paul Island. Plot 32 (Zapadni), which was censused only in Period 2 and hence not included in the totals, contained almost three times more cormorants than all the other plots combined. Any inferences concerning trends in cormorant numbers based on these scant data are tenuous at best.

Black-legged kittiwake--Counts by period of black-legged kittiwakes are shown in Appendix 6 (nest data are summarized in Appendix 7). Study plot attendance by this species in August was significantly higher than in July (T=22.57, df=1, p<0.001).

Red-legged kittiwake--Counts of red-legged kittiwakes are summarized in Appendix 6 (nest data are summarized in Appendix 7). The total counts suggest an increase in abundance in August relative to July; however, the trend is not significant (T=3.33, df=1, p>0.05).

Common murre--The seasonal use dates for St. Paul (Appendix 6) point to an increase in the number of attendees during the course of the summer. The difference is not of sufficient magnitude to result in a significant test statistic (T=1.20, df=1, p>0.25).

Thick-billed murre--Counts on study plots by sample period of thick-billed murres on St. Paul Island are summarized in Appendix 6. Counts in August were significantly higher than those in July (T=9.63, df=1, p<0.005).

Parakeet --Counts of parakeet auklets on St. Paul Island study plots are summarized in Appendix 6. Although total counts dropped from July to August the difference was not significant (T=0.53, df=1, p>0.25).

Crested auklet--Crested auklets were found on only one plot on St. Paul Island. On Plot 31, 21 birds were found on the July count but only one was found in August.

Least auklet--Counts of least auklets on St. Paul Island study plots are summarized in Appendix 6. These species exhibited a precipitous decrease in abundance between the July and August sample periods (T=4.0, df=1, p<0.05).

Horned puffin--Counts of horned puffins on St. Paul are summarized in Appendix 6. On this island the August counts averaged higher than the July counts. This difference was not significant (T=2.00, df=1, p>0.1).

Tufted puffin--Tufted puffin were too rare on St. Paul Island (occurred on only-3 plots) to warrant analyses.

Discussion

Seasonal trends in bird abundance (attendance) is important in designing seabird monitoring programs. If the sizes of populations attending colonies change rapidly over the course of the breeding season, it may be difficult to take sufficient samples or to standardize census times so that meaningful interpretations of among-year trends can be made. The sampling problems introduced by seasonal variations in attendance are similar to those resulting from diurnal variations. It must be determined to what extent seasonal variation reduces the reliability of year-to-year population estimates.

The results described thus far suggest that there is pronounced seasonal variation in colony attendance for many of the key study species. This type of variability has been previously documented, e.g., in thick-billed murres (Gaston and Nettleship 1981) and fulmars (Hatch 1979). The magnitude of this variability and its implications for monitoring often are underestimated or ignored. For example, past censuses at the Pribilofs have encompassed much of July, and our results indicate that, from the beginning to end of this period, black-legged kittiwake attendance might double. Thus, if among-year sampling schedules were offset by even two weeks, the data on population levels of black-legged kittiwakes could not legitimately be compared. The large decline in black-legged kittiwake attendance found at Cape Peirce over a 10-day period in June provides a further illustration of this point.

We cannot adequately characterize seasonal variability because of the infrequency of our sampling. Our intent was to include replicates in our study to measure short-term, random variability in attendance. Our results seem to indicate that our "replicates", in fact, document directional variations? i.e., one-way, short-term trends in attendance. Separating these two components of variation may not be possible without much more intensive sampling.

To help elucidate the relative importance of these two contributing factors, the counts for each species during sample periods from all study areas are plotted in Figures 23 to 27. Each point on each figure represents the total count of birds (during that sampling period) on all of the plots where birds were consistently recorded during all sampling

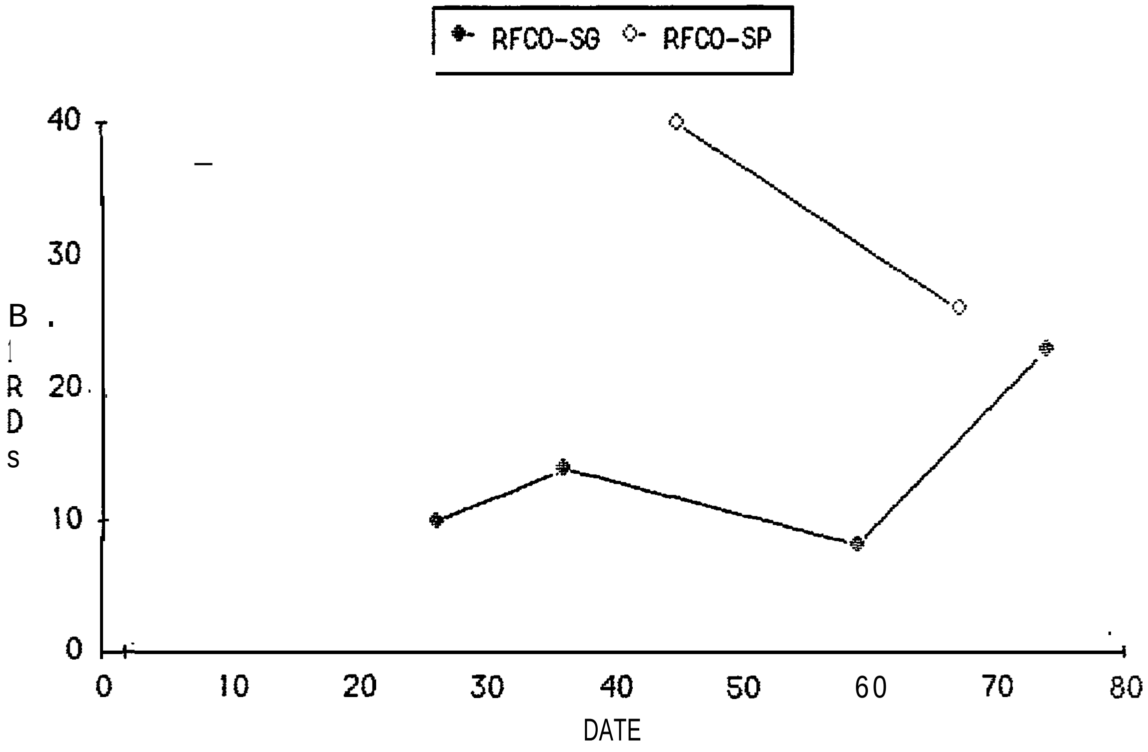


Figure 23. Counts of red-faced cormorants on St. George Island (SG) and St. Paul (SP) islands during different sampling periods in 1984.

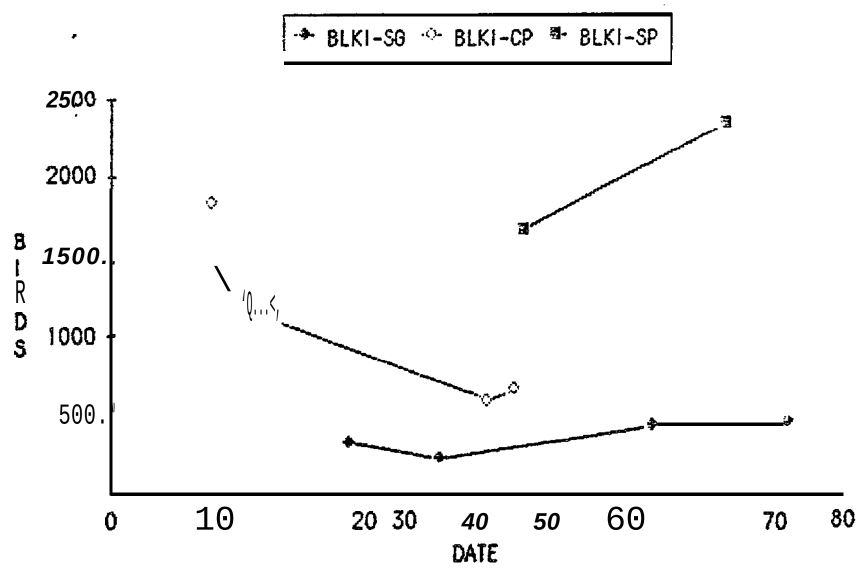


Figure 24. Counts of black-legged kittiwakes on St. George (SG) and St. Paul (SP) islands during different sampling periods in 1984.

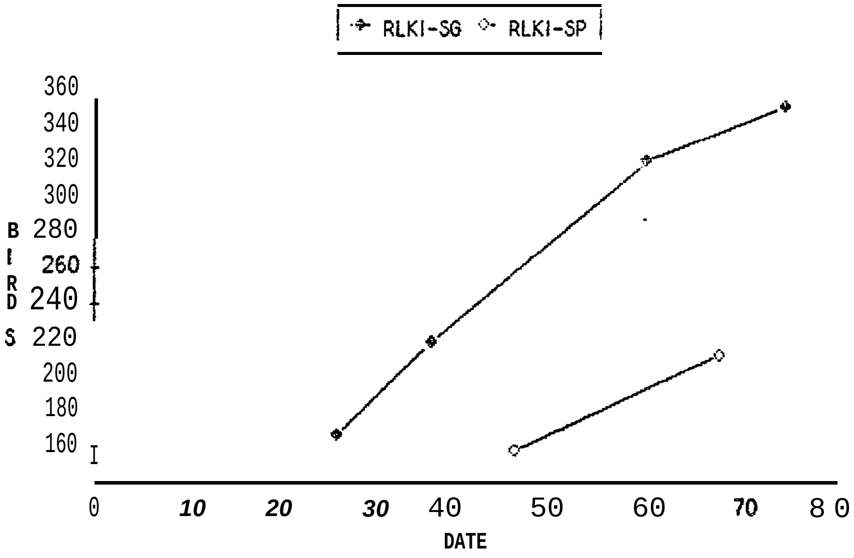


Figure 25. Counts of red-legged kittiwakes on St. George (SG) and St. Paul (SP) islands during different sampling periods in 1984.

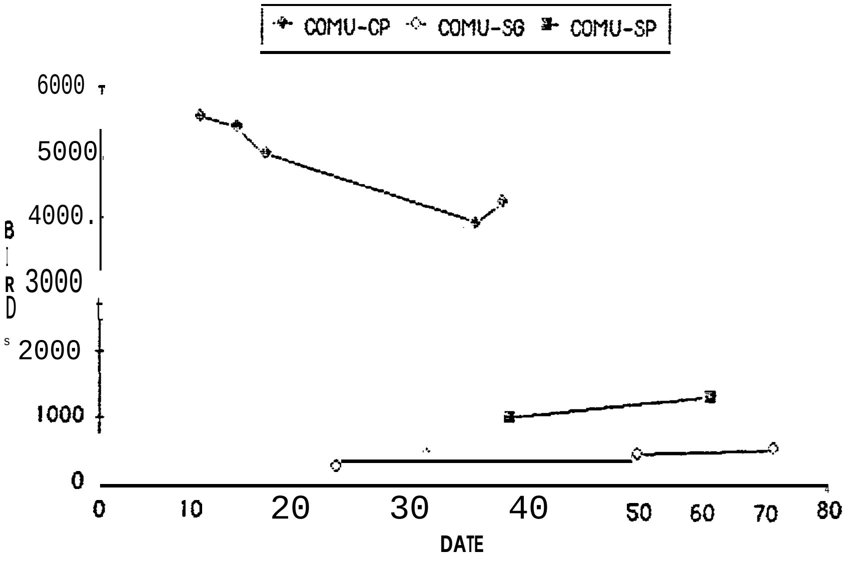


Figure 26. Counts of common murres at Cape Peirce (CP), St. George (SG) and St. Paul (SP) islands during different sampling periods in 1984.

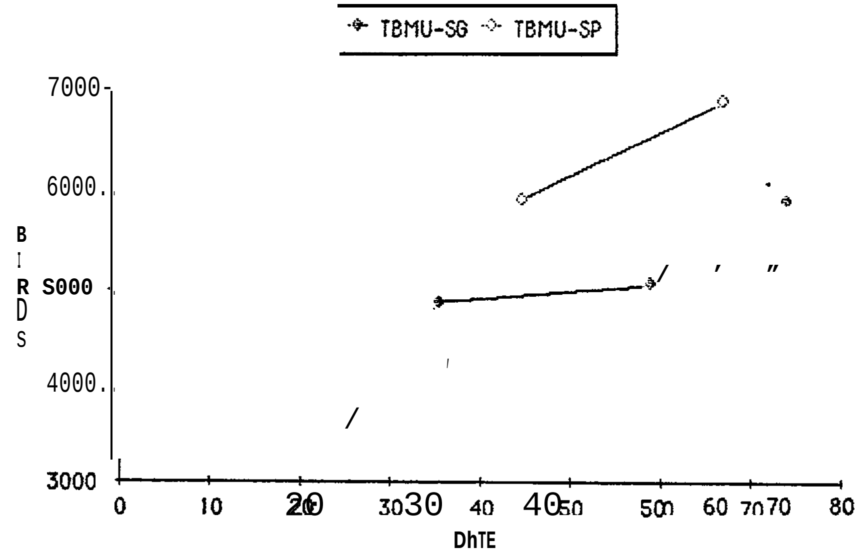


Figure 27. Counts of thick-billed murres on St. George (SG) and St. Paul (SP) islands during different sampling periods in 1984.

periods. The purpose of this exercise was to see if trend sat all three areas were coincident. Dates have been assigned a numerical value; 1 is 1 June and 80 is 19 August. The numerical value corresponding to the beginning date of the sampling period at each study location is given below. See Table 1 for the range of dates corresponding to each sampling period.

	St. George Island	St . Paul Island	Cape Peirce
Period 1	26	45	11
Period 2	36	67	15
Period 3	52		18
Period 4	59		41
Period 5	74		44

Seasonal trends are shown for red-faced cormorants (Fig. 23), black-legged kittiwakes (Fig. 24), red-legged kittiwakes (Fig. 25), common murres (Fig. 26), and thick-billed murres (Fig. 27). The trends from the censuses of each species from all study areas are similar wherever they overlap in time. This indicates that the trends in fact document regular temporal attendance patterns by the seabirds.

The data also suggest that these trends may be independent of breeding phenology. For example, breeding phenology at Cape Peirce is 2-3 weeks ahead of that at the Pribilofs, and such close concordance in trends between these locations (such as for black-legged kittiwake) would not be expected if they were caused by changes in the phases of breeding. For the present, we conclude that seasonal variation in attendance patterns can be large, perhaps obscuring among-year trends in plot counts.

Among-year Trends

Methods

As an index to changes in total population we compared counts made over years on the same set of study plots. In the case of the Pribilof Islands our estimate of attendance was derived by averaging counts we made during periods that sampling had occurred in previous years. The dates of censuses used for among-year comparisons at the Pribilif colonies are as follows:

St. George Island
1976: 9 July - 3 August
1982: 23 July - 3 August
1984: 9 - 31 July (Periods 2-4)

St. Paul Island
1976: 17 - 21 July
1982: 18 - 20 July
1984: 13 - 26 July (Period 1)

The analysis of plot counts made in various years in the study colonies is a straightforward mathematical exercise and the results are reported in the following pages. The interpretation of these results are not so straightforward As was documented in the preceding pages, there are many components of variability that may obscure trends or create spurious ones. The problem with diurnal cycles is lessened because the data analyzed below are restricted to July censuses when diurnal patterns were minimal or absent and most counts were made during a limited (afternoon/evening) portion of the day. The seasonal patterns cannot be entirely eliminated because the previous investigations (Hickey and Craighead 1977, Craighead and Oppenheim 1982) usually relied on a single census period. Our data have been edited to compare to the temporal bounds of prior investigations but we know some species, e.g., black-legged kittiwake, exhibit significant variation within these periods. The test results and assessments are presented below.

Results

Cape Peirce. Despite the previous seabird investigations that have taken place at Cape Peirce there are no tabular summaries or analyses of numbers of birds on study plots at this location. We have extracted the counts made by Peterson and Sigman in 1976 that were made on the same range of dates (9-19 June and 10-15 July) and during the same Portionof the 24 hr cycle (the equivalent of 12:00-20:00 ADT) for comparison with our results. Note that these counts are but a small fraction of the census data collected during their study.

Average counts made in the two years (there were usually multiple counts within each sample period) were compared using the Friedman Test procedure. Since only two years were contrasted this procedure is equivalent to a matched-pairs test. Counts were compared for each sample period. Threeof the seabird species we encountered on our study plots were either unrecorded (glaucous-winged gull and tufted puffin) or very rarely encountered (horned puffin) in 1976. None of these species were common in 1984 and it is doubtful that a significant change in abundance has occurred. Results of comparisons of abundance for the remaining species are described below.

<u>Pelagic cormorant</u>--Average counts of pelagic cormorants on Cape Peirce study plots are summarized in Table 3. Average counts were higher in 1984 than in 1976 during both sample periods; however in neither case were differences statistically significant (June: T=1.78, p>0.1; July: T=2, p>0.1).

<u>Black-legged kittiwake</u>--Average counts of black-legged kittiwakes on Cape Peirce study plots are summarized in Table 4. Average counts were lower in 1984 than in 1976 during both sample periods, particularly in July; however in neither case were differences statistically significant (June: T=0.11, p>0.5; July: T=0, p=1.0).

<u>Common murre</u>--Average counts of common murres on Cape Peirce study plots are summarized in Table 5. Average counts were lower in 1984 than in 1976 during both sample periods; however in neither case were differences statistically significant (June: T=0.11, p>0.5; July: T=0.12, p>0.5).

<u>Sk. George Island (Pribilof Islands)</u>. Comparisons of counts on St. George Island study plots are made below. In the statistical analyses (Friedman test) each strata/plot combination was treated as a distinct plot although analyses are based on all strata (e.g., Plot 24 Strata 1 and

Table 3. Average counts of pelagic cormorants on Cape Peirce study plots.

	9-19 June		10-15 July	
Plot	1976	1984	1976	1984
2	0.7	1.0	0.0	0.0
5	0.0	0.0	0.0	0.0
6	0.0	2.7	0.0	0.5
7	16.0	13.0	10.0	13.0
9	0.0	1.3		
10	0.0	2.0	0.0	0.5
11	0.0	0.0	0.0	0.0
12	0.0	0.0	0*0	0.0
13	7.0	10.0	5.5	10.5
TOTAL	23.7	30.0	15.5	24.5

Table 4. Average counts of black-legged kittiwakes on Cape Peirce study plots.

	9-19 June		10-15 July	
PLOT	1976	1984	1976	1984
2	1.8	3	1.3	15.5
5	318	104	210	24
6	20.5	11.33	8.5	11.5
7	189.5	57.67	135	26
9	122.5	93.67		
10	1	30	0	2
11	28	225.67	12	71.5
12	171.3	151	80	66.5
13	39.3	57.67	28	24
TOTAL	891.9	734.01	474.8	241

Table 5. Average counts of common murres on Cape Peirce study plots.

PLOT	9-19 June		10-15 July	
	1976	1984	1976	1984
2	19.9	21.33	25.5	30.5
5	460.7	375	427	302.5
6	0	2.67	0	0
7	692.5	166.67	584.5	130.5
9	589	507		
10	6.3	68.33	10	24
11	35.5	309	29	253.5
12	252.7	266	267.5	216.5
13	205.3	167	175	137.5
TOTAL	2261.9	1883	1518.5	1095

Plot 24 Strata 2 are both treated as sample units). Values for study plots during 1984 represent the average of up to three counts (sample Periods 2-4).

Northern fulmar--Counts on plots censused in all three years of study are summarized in Table 6. On St. George Island the 1984 counts were bracketed by those from 1976 and 1982 and tended most towards those in 1976.

Counts are significantly different among years (T=14.62, df=2, $p<0.001$). Attendance by fulmars was significantly lower in 1982 than 1976; however, the 1984 counts are not significantly different from either extreme.

Red-faced cormorant--Counts of red-faced cormorants on plots sampled each year are summarized in Table 7. In both strata in which cormorants were recorded, the trend has been a decrease in abundance. Counts among years are significantly different (T=7.86, df=2, $p<0.025$). It appears that both the 1982 and 1984 counts are much lower than 1976, but this has not been statistically verified. Total counts in 1984 are 20-25% of those made in 1976.

Black-legged kittiwake--Counts on plots censused during all three years of study are summarized in Table 8. The St. George Island counts suggest a steady decline over the three study years with 1984 counts being about half the 19?6 counts. This trend was evident in all strata (1, 2, 3, and 5) for which multi-year data are available.

The Friedman analyses confirm the among-year differences (T=24.45, df=2, $p<0.001$). Multiple comparisons reveal that the 1984 counts were significantly lower than the preceding years.

Red-legged kittiwake--Counts of red-legged kittiwakes on study plots censused in 1976, 1982 and 1984 are shown in Table 9. On St. George the total counts on the study plots decreased during each year of study.

Differences among years were significant (T=8.07, df=2, $p<0.025$). Two groups--1984/1982 and, 1982/1976--were identified as relatively homogeneous subgroups by the multiple comparisons procedures.

Table 6. Counts of northern fulmars in different plots, different strata, and different years on St. George Island, Alaska.

NORTHERN FULMAR

	1976	1982	1984
STRATUM 1			
Plot # 8	22	30	23
9	24	22	29
10	36	34	23
11	0	0	0
12	5	11	5
13	15	7	10
14	12	8	5
15	27	16	24
16	0	0	0
17	11	8	16
18	2	2	3
19	10	6	7
20	0	0	0
24M	5	17	16
26	2	0	
39B	1	8	13
45	17	3	8
46	0	2	3
47	28	20	8
48	10	4	9
49	0	0	0
50	0	0	0
51	10	4	5
52	4	4	4
53	0	1	0
ZAPADNI	4	2	3
Subtotal	245	209	215

Table 6 (cont. d)

NORTHERN FULMAR

	1976	1982	1984
STRATUM 2			
Plot # 2	4	8	4
21	0	0	#
22	1]	0	0
23	'26	79	98
24T	59	23	4%
25	51	35	41
27	99	100	123
28	87	57	42
29	40	13	27
30	45	27	99
31	3	1	5
32	44	24	41
33	47	29	59
34	0	0	0
35	108	75	101
36	72	27	27
37	17	17	23
38U	15	10	12
39	80	71	79
subtotal	8X-	5%	.927
STRATUM 3			
40	0	Q	0
STRATUM 5			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	1142	805	1042

Table 7. Counts of red-faced cormorants in different plots, different strata, and different years on St. George Island, Alaska.

	RED-FACED CORMORANT		
	1976	1982	1984
STRATUM 1			
Plot # 8	2	0	0
9	1	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	1
15	0	8	1
16	0	2	0
17	0	3	0
18	1	0	1
19	2	0	0
20	0	0	0
24M	0	0	0
26	12	1	3
38B	0	0	0
45	2	0	0
46	3	0	0
47	0	0	1
48	13	1	4
49	0	0	0
50	0	0	0
51	0	0	0
52	4	2	1
53	9	3	0
ZAPADNI	18	5	4
Subtotal	67	25	16

	RED-FACED CORMORANT		
	1976	1982	1984
STRATUM 2			
Plot # 2	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24T	0	0	0
25	0	0	0
27	7	0	0
28	0	0	0
29	0	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0	0	0
34	0	0	0
35	2	0	0
36	2	4	2
37	0	0	1
38U	1	0	0
39	0	0	0
Subtotal	12	4	3
STRATUM 3			
40	0	0	0
STRATUM 5			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	79	29	19

Table 8 . Counts of black-legged kittiwakes in different plots, different strata, and different years on St. George Island, Alaska.

BLACK-LEGGED KITTIWAKES

	1976	1982	1984
STRATUM I			
Plot # 8	6	5	3
9	38	24	6
10	2	2	2
11	8	1	1
12	4	5	2
13	0	1	1
14	34	5	2
15	6	9	2
16	5	4	1
17	8	5	2
18	0	6	2
19	26	15	10
20	0	1	0
24M	0	0	0
26	3	0	0
38B	1	0	0
45	5	12	6
46	31	44	31
47	20	16	10
48	17	13	21
49	21	0	2
50	5	5	0
51	50	45	25
52	103	82	57
53	49	37	41
ZAPADNI	46	36	29
Subtotal	488	373	256

Table 8 (cont.)

BLACK-LEGGED KITTIWAKES

	1976	1982	1984
STRATUM 2			
Plot # 2	3	0	0
21	0	2	1
22	0	0	0
23	1	1	4
24T	9	29	22
25	25	15	14
27	41	33	25
28	21	29	16
29	12	10	5
30	20	6	3
31	0	1	1
32	3	10	4
33	18	19	12
34	1	0	0
35	27	16	11
36	14	3	1
37	22	20	13
38U	5	4	0
39	57	51	29
Subtotal	279	249	161
STRATUM 3			
40	17	9	4
STRATUM 5			
42	4	3	0
43	21	7	4
Subtotal	25	6	4
TOTAL	809	637	425

Table 9. Counts of red-legged kittiwakes in different plots, strata, and years on St. George Island, Alaska.

RED-LEGGED KITTIWAKE	1976	1982	1984
STRATUM 1			
PLOT # 8	0	2	0
9	7	7	7
10	7	9	2
11	0	0	0
12	1	0	0
13	0	0	0
14	17	0	1
15	0	5	7
16	0	1	1
17	0	1	1
18	0	1	0
19	0	0	0
20	0	0	0
24M	0	0	0
26	1	0	0
38B	1	1	2
4s	1	2	6
4	6 7	1	3
47	1	48	20
48	6	4	2
49	59	0	11
50	4	9	4
51	18	14	22
52	15	14	8
53	94	59	60
ZAPADNI	45	23	28
Subtotal	284	201	185

Table 9 (cut)

RED-LEGGED KITTIWAKE	1976	1982	1984
STRATUM 2			
Plot # 2	22	16	4
2 1	6	8	0
22	6	3	0
23	14	14	19
24T	16	5	2
25	3	1	0
27	60	97	48
28	50	58	17
29	18	5	1
30	16	6	5
31	0	1	0
32	0	20	10
33	475	433	141
34	46	0	0
35	3	14	6
36	8	3	8
37	42	54	27
38U	67	18	8
39	6 7	45	53
Subtotal	919	801	349
STRATUM 3			
Plot * 40	169	153	110
STRATUM 5			
Plot # 42	362	255	149
43	580	491	412
Subtotal	942	746	561
TOTAL	2314	1901	1205

Common murre--Comparisons of counts on study plots sampled during all three years of study at St. George Island can be made from Table 10. These data suggest that little appreciable variation in common murre attendance has occurred among years. The 1984 total is bracketed by the totals of the other two years.

A similar conclusion may be drawn from the Friedman analyses. Counts among years were not found to be significantly different ($T=1.87$, $df=2$, $p>0.25$).

Thick-hued murre--Counts of thick-billed murres on plots sampled each year on St. George Island are presented in Table 11. These data reveal a decrease in bird attendance during each year of study. Similar trends are evident in all strata. There are counts available for all but Stratum 4. Relative to 1976, the 1984 counts appear to be down approximately 25%.

The Friedman Tests confirm that differences exist among years ($T=30.41$, $df=2$, $p<0.001$). Multiple comparisons segregated 1976 as having higher counts than either 1982 or 1984.

Parakeet auklet--Summaries of plot counts among years are provided in Table 12 for St. George Island. The only consistent finding is that the counts in all strata for 1984 are the lowest recorded. Total counts on St. George have fluctuated widely. The Friedman analysis confirms the occurrence of significant among-year variability ($T=33.17$, $df=2$, $p<0.001$). Multiple comparisons revealed that counts in 1982 were significantly higher than either of the other study years.

These data are only presented for completeness. We have little confidence in the reliability of the methods we used for monitoring auklet populations and therefore refrain from making any inferences about the actual trend in populations.

Crested auklet--Very few crested auklets were recorded during our counts. This, combined with the doubtful validity of making direct comparisons of the data in order to infer population changes for auklets, makes any conclusion tenuous. The records of counts are summarized by year in Table 13 for St. George Island. Our counts for this species on

Table 10. Counts of common murres in different plots, different strata, and different years on St. George Island, Alaska.

COMMON MURRE

		1976	1982	1984
STRATUM 1				
Plot #	8	2	7	3
	7	0	8	2
	10	15	21	9
	11	52	59	68
	12	22	29	3
	13	0	0	1
	14	28	0	8
	15	0	0	0
	16	0	12	9
	17	6	10	0
	18	0	4	0
	19	16	2	6
	20	0	0	0
	24M	54	12	17
	26	574	822	580
	38B	0	13	11
	45	8	0	5
	46	0	61	122
	47	3	2	3
	4s	2	0	2
	49	0	0	0
	50	3	2	0
	51	0	0	0
	52	0	0	0
	53	3	0	0
	ZAPADNI	23	50	17
Subtotal		811	1114	866

Table 10 (cont.)

COMMON MURRE

		1976	1982	1984
STRATUM 2				
Plot #	2	100	15	75
	21	0	0	0
	22	0	0	0
	23	0	0	1
	24T	123	80	73
	25	83	92	108
	27	10	11	19
	28	93	90	132
	29	21	4	26
	30	137	67	107
	31	38	40	24
	32	55	100	80
	33	2	36	0
	34	0	0	0
	35	0	13	22
	36	2	18	7
	37	15	55	16
	38U	0	0	0
	39	89	100	98
Subtotal		768	721	788
STRATUM 3				
	40	0	0	0
STRATUM 5				
	42	1	7	8
	43	0	0	0
Subtotal		1	7	8
TOTAL		1580	1842	1662

Table 11. Counts of thick-billed murres in different plots, different strata, and different years on St. George Island, Alaska.

THICK-BILLED MURRE

	1976	1982	1984
STRATUM 1			
Plot # 8	307	258	198
9	295	273	268
10	348	354	300
11	115	109	94
12	180	198	118
13	105	96	112
14	177	82	141
15	193	160	109
16	169	161	109
17	148	120	111
18	70	90	75
19	91	94	105
20	58	33	38
24M	779	476	493
26	155	67	127
38B	181	610	424
45	202	61	192
46	184	196	221
47	156	161	118
48	237	141	233
49	31	17	7
50	119	50	3
51	96	65	65
52	52	34	73
53	188	92	106
ZAPADNI	675	563	342
Subtotal	5311	4561	4172

Table 11 (cont.)

THICK-BILLED MURRE

	1976	1982	1984
STRATUM 2			
Plot # 2	466	33	224
21	104	49	64
22	174	51	121
23	268	200	226
24T	825	486	555
25	857	335	513
27	979	1227	866
28	704	561	543
29	592	338	515
30	640	480	377
31	210	138	157
32	371	299	356
33	1202	1745	1251
34	116	98	65
35	682	420	528
36	760	262	236
37	769	680	612
38U	459	182	117
39	530	547	320
Subtotal	10708	8131	7673
STRATUM 3			
40	113	75	69
STRATUM 5			
42	185	178	105
43	196	156	173
Subtotal	381	334	278
TOTAL	16513	13101	12192

Table 12. Counts of parakeet auklets in different plota, different strata, and different years on St. George Island, Alaska.

PARAKEET AUKLET

	1976	1982	1984
STRATUM 1			
Plot # 8	60	655	1
9	23	51	1
10	22	56	0
11	1	8	2
12	11	26	0
13	9	11	1
14	15	28	4
15	14	34	4
16	7	20	3
17	12	28	4
18	6	41	8
19	6	15	14
20	4	5	0
24M	11	44	3
26	4	3	3
38B	0	22	28
45	18	39	4
46	11	13	0
47	14	32	3
48	11	24	1
49	0	0	0
50	4	3	0
51	19	22	2
52	0	0	0
53	2	4	0
ZAPADNI	115	71	106
Subtotal	399	1255	192

Table 12 (cont.)

PARAKEET AUKLET

	1976	1982	1984
STRATUM 2			
Plot # 2	6	0	0
21	0	0	0
22	1	0	5
23	3	14	2
24T	12	75	15
25	60	83	13
2-i	26	55	7
28	77	109	16
'29	61	119	37
30	56	72	10
.31	11	6	2
32	16	13	12
33	16	19	31
34	8	9	12
35	3	25	1
36	0	17	11
37	1	39	19
38U	1	15	5
39	43	70	15
Subtotal	401	740	213
STRATUM 3			
40	0	0	0
STRATUM 5			
42	0	0	0
43	3	9	1
Subtotal	3	9	1
TOTAL	803	2004	406

Table 13. Counts of crested auklets in different plots, different strata, and different years on St. George Island, Alaska.

	CRESTED AUKLET		
	1976	1982	1984
STRATUM 1			
Plot # 8	1	1	0
9	0	0	0
10	0	5	0
11	0	0	0
12	0	0	0
13	0	4	0
14	2	2	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
24M	0	0	0
26	0	0	0
38B	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
50	0	0	0
51	4	5	1
52	0	0	0
53	0	0	0
ZAPADNI	0	0	0
Subtotal	7	17	1
STRATUM 2			
Plot # 2	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24T	2	16	4
25	16	20	0
27	0	0	0
28	12	20	12
29	26	6	19
30	38	1	2
31	15	2	4
32	24	10	7
33	0	0	0
34	0	0	0
35	1	2	0
36	0	0	0
37	0	2	0
38U	0	0	9
39	0	3	4
Subtotal	134	82	61
STRATUM 3			
40	0	0	0
STRATUM 5			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	141	99	62

St. George are the lowest yet recorded; however; differences among years are not significant (T=4.67, df=2, p>0.05).

Least auklet--The plot count data are summarized by year in Table 14. The total counts on St. George have been remarkably stable over the three years of investigations; although the variability by strata or on a plot-by-plot basis has been extreme. Friedman analyses reveal no significant differences among years (T-4.73, df=2, p>0.05).

Horned puffin--Total counts of horned puffins on St. George Island were very similar in all three years in the same set of plots (Table 15). This similarity of counts is surprising considering the marked among-year variability within strata and within plots. Overall differences among years were not significant (T=6.97, df=2, p<0.05).

Tufted puffin--Counts of tufted puffin by year are summarized in Table 16. During 1984 more tufted puffins were recorded than during any preceding year. Differences among years were significant (T=7.92, df=2, p<0.025).

St. Paul Island (Pribilof Islands). The timing of censuses on St. Paul has been relatively similar during all years. To the extent that date is indicative of stage of "seasonal abundance (if indeed these cycles of abundance are constant over years) the comparison among years for St. Paul may better represent actual population changes than do the comparisons for St. George.

Northern fulmar--On St. Paul Island, the 1984 counts are highest (Table 17), although they are very similar to the 1982 counts. The counts during both 1982 and 1984 are approximately double those from 1976. However, these changes in attendance were not significant (T=0.5, df=2, p>0.75).

Red-faced cormorant--Counts of red-faced cormorants on St. Paul Island during each year of study are summarized in Table 18. The 1984 surveys resulted in the lowest counts thus far, especially in comparison

Table 14. Counts of least auklets in different plots, different strata, and different years on St.' George Island, Alaska.

	LEAST AUKLET		
	1976	I 982	1984
STRATUM 1			
Plot # 8	23	47	0
9	2	20	0
10	9	40	0
11	1	0	0
12	0	23	0
13	5	0	0
14	13	16	0
15	10	39	2
16	12	33	0
17	13	50	5
la	8	25	9
19	0	7	9
20	1	4	0
24M	0	11	2
26	7	0	0
38B	0	0	29
45	1	0	3
46	0	0	0
47	3	26	2
4.9	2	5	0
49	0	0	0
50	0	0	0
51	0	10	1
52	0	0	0
53	0	3	0
ZAPADNI	8	102	166
Subtotal	118	461	228

Table 14 (cont.)

	LEAST AUKLET		
	1976	1982	1984
STRATUM 2			
Plot # 2	0	0	0
21	0	0	0
22	0	1	3
23	0	10	0
24T	1	35	2
25	122	9	
27	57	2	10
28	126	1	93
29	76	1	64
30	57	6	46
31	2	1	4
32	0	2	24
33	0	0	0
34	0	1	0
35	0	2	0
36	0	0	6
37	0	0	5
38U	0	0	1
39	0	21	15
Subtotal	441	91	274
STRATUM 3			
40	0	0	0
STRATUM 5			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	559	552	502

Table 15. Counts of horned puffins in different plots, different strata, and different years on St. George Island, Alaska.

HORNED PUFFIN

	1976	1%2 .	1984
STRATUM 1			
Plot # 8	9	15	12
9	3	10	7
10	4	6	5
11	1	1	1
12	0	4	2
13	0	3	1
14	3	4	7
15	2	3	8
16	2	3	4
17	2	4	8
18	3	10	6
19	0	8	7
20	0	0	4
24M	3	2	6
26	2	0	0
38B	2	4	6
45	8	22	3
46	0	1	0
47	2	14	2
48	0	18	4
49	0	0	0
50	0	0	0
51	4	5	3
52	0	2	0
53	0	0	0
ZAPADNI	15	19	18
Subtotal	65	158	114

Table 15 (cont.)

HORNED PUFFIN

	1976	1982	1984
STRATUM 2			
Plot # 2	2	0	0
21	0	0	0
22	0	0	
23	0	3	4
24T	4	6	10
25	9	4	14
27	6	10	7
28	11	4	14
29	14	4	11
30	19	5	8
31	6	0	5
32	2	2	4
33	2	5	6
34	4	2	2
35	9	3	20
36	26	4	0
37	2	3	7
38U	6	3	2
39	54	18	18
	176	76	133
STRATUM 3			
40	0	0	0
STRATUM 5			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	241	234	247

Table 16. Counts of tufted puffins in different plots, different strata, and different years on St. George Island, Alaska.

TUFTED PUFFIN

	1976	1982	1984
STRATUM 1			
Plot # 8	0	0	
9	0	0	0
10	0	0	1
11	0	0	0
12	0	0	0
13	0	0	0
14	0	4	3
15	0	2	3
16	0	0	1
17	0	1	2
18	0	0	0
19	0	0	0
20	0	0	0
24M	0	0	1
26	0	0	0
38B	0	0	1
45	0	0	0
46	0	0	0
47	0	0	0
48	0	3	1
49	0	0	0
50	0	0	0
51	2	2	
52	0	0	0
53	0	0	0
ZAPADNI	2	2	3
Subtotal	4	14	18

Table 16 (cent.)

TUFTED PUFFIN

	1976	1982	1984
STRATUM 2			
Plot # 2	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24T	0	2	2
25	1	2	4
27	7	1	4
28	2	0	3
29	3	0	3
30	4	4	
31	3	0	4
32	1	0	0
33	0	0	0
34	0	0	0
35	1	5	14
36	1	0	0
37	0	0	0
38U	0	0	0
39	2	0	1
Subtotal	25	14	36
STRATUM 3			
40	0	0	0
STRATUt'15			
42	0	0	0
43	0	0	0
Subtotal	0	0	0
TOTAL	29	28	54

Table 17. Counts of northern fulmars in different plots. different strata, and different years on St. Paul Island, Alaska.

	NORTHERN FULMAR		
	t 9?6	1982	1984
STRATUM 1			
Plot # 1	0	0	0
2SW	0	0	0
3	0	0	0
5SW	0	0	1
5NE	0	0	0
7	0	0	0
9	2	2	3
10	3	3	1
15	4	4	2
16	1	1	3
17	0	1	0
18	0	0	0
19	2	1	1
20	1	0	0
22	3	26	10
23	17	20	8
RIDGE WALL	3	7	41
Subtotal	36	65	70
STRATUM 2			
11	0	0	0
12	0	0	0
13	0	0	0
14	2	6	3
Subtotal	2	6	3
TOTAL	38	71	73

Table 18. Counts of red-faced cormorants in different plots, different strata, and different years on St. Paul Island, Alaska.

	RED-FACED CORMORANT		
	1976	1982	1'324
STRATUM I			
Plot # 1	14	3	1
2SW	4	17	1
3	10	1	0
5SW	15	13	6
5NE	3	0	0
7	2	4	1
9	1	1	1
10	4	1	2
15	7	0	3
16	0	0	0
17	1	0	0
18	8	0	2
19	1	0	0
20	0	0	0
22	1	6	1
23	2	0	0
RIDGE WALL	64	7	1
Subtotal	137	53	19
STRATUM 2			
11	0	0	0
12	23	8	15
13	2	0	3
14	3	0	1
Subtotal	28	8	19
TOTAL	165	61	38

to 1976. Friedman analysis showed very significant differences among years ($T=11.31$, $df=2$, $p< 0.005$). Multiple comparisons isolated 1976 as having significantly higher counts than any subsequent survey year.

Black-legged kittiwake--The count data are summarized in Table 19. These data show that attendance on study plots in 1984 was intermediate between 1976 and 1982. The Friedman results indicate significant among-year variability ($T=6.74$, $df=2$, $p<0.005$). The multiple comparisons found the extremes--1982 (low) and 1976 (high)--to be significantly different but 1984 to be intermediate and not significantly different from either extreme.

Red-legged kittiwake--The number of red-legged kittiwakes on the St. Paul Island study plots is relatively small but the overall trend in counts suggests a decline each year of study (Table 20). This apparent decline was not widespread enough to produce conclusive evidence of an among-year change ($T=0.21$, $df=2$, $p>0.75$).

Common murre--Counts of common murres made on St. Paul Island (Table 21) show that a marked decrease in number of common murres occurred between 1976 and 1982. Attendance may have increased slightly in 1984 but the actual counts are not much greater than those in 1982.

The apparent large changes in numbers of common murres results from the rapid change in abundance on a few plots. The direction of change was rarely uniform over plots and because of this feature, differences among years were not found tobe significant using the Friedman test ($T=5.79$, $df=2$, $T>0.05$).

Thick-billed murre--The count data from St. Paul do not provide a clear pattern of change (Table 22). The 1982 counts on St. Paul are substantially less than those in 1976; however, the 1984 counts are midway between those of the previous two studies.

The Friedman tests confirm these observations. There were significant differences among years ($T=15.5$, $df=2$, $p<0.001$); in 1982 there were significantly fewer thick-billed murres than in 1976. The 1984

Table 19. Counts of black-legged kittiwakes in different plots, different strata, and different years on St. Paul Island, Alaska.

	BLACK-LEGGED KITTIWAKES		
	1976	1982	1984
STRATUM 1			
Plot # 1	35	30	78
2SW	26	24	50
3	47	46	48
5SW	93	79	128
5NE	14	18	14
7	47	20	36
9	94	56	53
10	44	60	62
15	50	62	84
16	60	24	24
17	24	4	5
18	40	23	14
19	43	26	27
20	15	11	14
22	66	81	38
23	80	56	53
RIDGE WALL	914	390	620
Subtotal	1692	1010	1348
STRATUM 2			
11	21	10	5
12	78	68	64
13	40	34	32
14	20	23	13
Subtotal	159	135	114
TOTAL	1851	1145	1462

Table 20. Counts of red-legged kittiwakes in different plots, different strata, and different years on St. Paul Island, Alaska.

	RED-LEGGED KITTIWAKE		
	1’376	1982	19s4
STRATUM 1			
Plot # 1	9	3	4
2SW	0	0	0
3	2	3	0
5SW	0	1	1
5NE	0	0	0
7	0	0	2
9	5	2	1
10	0	0	0
15	2	0	2
16	1	0	0
17	1	0	0
18	3	4	3
19	0	0	0
20	0	0	0
22	2	9	5
23	11	7	12
RIDGE WALL	61	35	23
Subtotal	97	64	53
STRATUM 2			
11	0	0	0
12	0	10	4
13	1	13	9
14	6	2	3
Subtotal	7	25	16
TOTAL	104	89	69

Table 21. Counts of common murres in different plots, different strata, and different years on St. Paul Island, Alaska.

	COMMON MURRE		
	1976	1982	1984
STRATUM 1			
Plot # 1	15	0	23
2SW	2	0	0
3	3	15	12
5SW	0	81	8
5NE	1	0	0
7	256	2	1
9	104	75	76
10	648	0	268
15	11	113	4
16	106	0	20
17	21	0	0
18	192	0	18
19	133	118	92
20	0	0	0
22	6	11	0
23	25	0	12
RIDGE WALL	752	417	428
Subtotal	2275	832	962
STRATUM 2			
11	0	0	0
12	0	0	0
13	0	11	3
14	184	6	29
Subtotal	184	17	32
TOTAL	2459	849	994

Table 22. Counts of thick-billed murres in different plots, different strata, and different years on St. Paul Island, Alaska.

	THICK-BILLED MURRE		
	1976	1982	1984
STRATUM 1			
Plot # 1	72	9	35
2SW	26	26	31
3	79	57	88
5SW	266	179	215
5NE	120	27	37
7	142	117	77
9	133	191	137
10	284	157	231
15	206	107	196
16	187	26	123
17	88	59	72
18	254	72	159
19	179	48	134
20	37	82	68
22	563	308	347
23	1073	259	511
RIDGE WALL	2179	1383	2040
Subtotal	5888	3107	4501
STRATUM 2			
11	40	38	38
12	193	49	97
13	110	186	157
14	369	244	289
Subtotal	712	517	581
TOTAL	6600	3624	5082

counts were intermediate and not significantly' different from the two other study years.

Parakeet auklet--Counts of parakeet auklets on St. Paul Island are summarized by year in Table 23. Analysis of these data using the Friedman test resulted in a significant test statistic ($T=20.67$, $df=2$, $p<0.001$). Multiple comparisons showed that counts in 1984 were significantly lower than in either of the other years of study.

Crested a-.-Crested auklets were recorded on only 2 of the plots sampled during all three years of study. Too few data were obtained to warrant statistical tests of changes among years. The highest counts were recorded in 1984.

Least auklet--Counts of least auklets on plots on St. Paul Island are summarized in Table 24. The total counts have fluctuated considerably over the three years of study but no consistent directional trend is noticeable. The Friedman analysis confirm among-year variability in abundance ($T=9.03$, $df=2$, $p<0.025$).

Horned puffin--Total counts of horned puffins at St. Paul show some variability (Table 25) but do not suggest any long-term (since 1976) changes in population. The Friedman analysis did not reject the hypothesis of constant abundance among years ($T=0.86$, $df=2$, $p>0.5$). As with auklets, we doubt that these data would be a sensitive indicator of the status of puffin population levels.

Tufted puffin--The limited tufted puffin data (Table 26) do not indicate any significant change among years ($T=0.50$, $df=2$, $p>0.5$).

Discussion

At Cape Peirce there were no statistically significant changes of seabirds on study plots between, 1976 and 1984.

Numbers of red-faced cormorants counted on plots declined among years more obviously than did counts of other species (Fig. 28); they declined

Table 23. Counts, of parakeet auklets in different plots, different strata, and different years on St. Paul Island, Alaska.

PARAKEET AUKLET

	1976	1982	1984
STRATUM 1			
Plot # 1	1	0	0
2SW	16	0	0
3	14	3	0
5SW	28	10	2
5NE	5	5	2
7	7	0	0
9	16	6	0
10	8	6	0
15	2	2	0
16	17	23	3
17	5	3	1
18	3	20	9
19	8	4	0
20	0	9	0
22	44	27	0
23	42	38	1
RIDGE WALL	696	71	95
Subtotal	912	227	113
STRATUM 2			
11	5	6	0
12	3	3	1
13	13	0	1
14	15	19	0
Subtotal	36	28	2
TOTAL	948	255	115

Table 24.. Counts of least auklets in different plots, different strata, and different years on St. Paul Island, Alaska.

	LEAST AUKLET		
	1976	1982	1984
STRATUM 1			
Plot # 1	0	0	0
2SW	11	0	0
3	19	0	0
5SW	10	18	27
5NE	1	1	0
7	0	0	1
9	0	5	1
10	0	7	1
15	0	28	0
16	7	17	6
17	0	0	0
18	0	14	5
19	7	11	3
20	0	0	0
22	3	9	0
23	0	11	0
RIDGE WALL	246	255	139
Subtotal	304	376	183
STRATUM 2			
11	0	5	0
12	0	0	0
13	0	14	1
14	0	0	1
Subtotal	0	19	2
TOTAL	304	395	185

Table .25. Counts of horned puffins in different plots, different strata, and different years on St. Paul Island, Alaska.

	HORNED PUFFIN		
	1976	1982	1984
STRATUM 1			
Plot # 1	0	0	0
2SW	1	0	0
3	2	0	2
5SW	2	3	7
5NE	0	0	2
7	0	0	0
9	5	6	3
10	0	1	1
15	5	12	2
16	4	9	1
17	5	3	0
18	0	4	4
19	2	2	5
20	1	1	2
22	8	15	2
23	11	5	10
RIDGE WALL	113	71	120
Subtotal	159	132	161
STRATUM 2			
11	1	0	0
12	1	0	1
13	0	0	1
14	3	0	4
Subtotal	5	0	6
TOTAL	164	132	167

Table 26. Counts of tufted puffins in different plots, different strata, and different years on St. Paul Island, Alaska,

TUFTED PUFFIN	1976	1982	1984
STRATUM 1			
Plot # 1	0	0	0
2SW	0	0	0
3	0	0	0
5SW	0	0	0
5NE	0	0	0
7	0	0	0
9	1	0	0
10	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	1	0
19	0	0	0
20	0	0	0
22	0	0	0
23	0	4	0
RIDGE WALL	13	26	28
Subtotal	14	31	28
STRATUM 2			
11	0	0	0
12	0	0	0
13	0	0	0
14	1	0	0
Subtotal	1	0	0
TOTAL	15	31	28

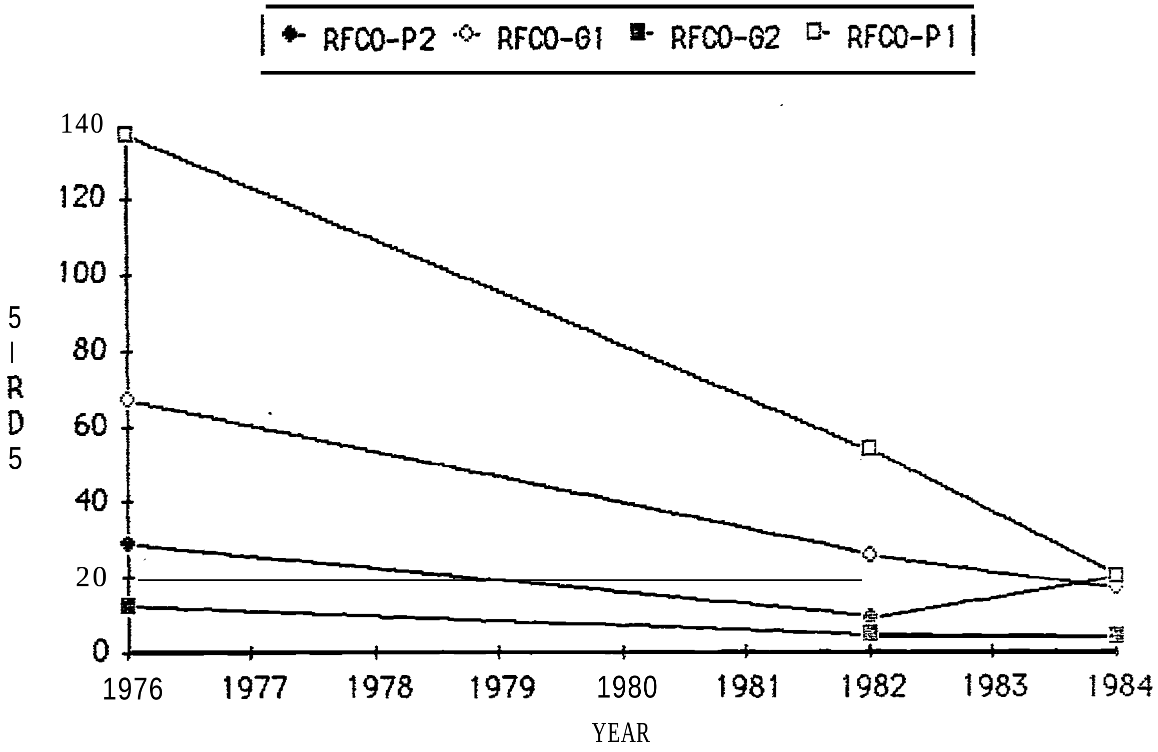


Figure 28. Trends in counts of red-faced cormorants in different strata in different years at different colonies. RFCO=red-faced cormorant; P1, P2=St. Paul Island, Strata 1 and 2; G1, G2= St. George Island, Strata 1 and 2.

linearly from 1976 to 1984 in both colonies. However, on St. Paul, 1984 counts exceeded 1982 counts in Stratum 2. Counts varied to some extent within years as a consequence of short-term variability in bird attendance, but the much larger differences among years suggested that a real population decline had occurred between 1976 and 1984.

Counts of black-legged kittiwakes on St. George Island were lower in 1984 than in earlier years (Fig. 29); this trend was not as marked on St. Paul Island (Fig. 30). These trends are difficult to interpret because seasonal changes also occurred during count periods. Because kittiwake reproductive success and productivity have been very low on the Pribilofs, especially on St. George since 1980, (see Johnson and Baker, this volume) low recruitment may be one cause of the apparent population decline. It is encouraging that August counts, which probably include subadult prospectors and adult nonbreeders, are about double July counts; these birds may breed in future years.

Figure 31 shows a decline of red-legged kittiwakes in all strata on St. George Island in 1984; more subtle declines apparently have occurred on St. Paul (Fig. 32). Productivity of red-legged kittiwakes has been low on the Pribilofs for several years, especially on St. George Island (see Johnson and Baker, this volume). As with black-legged kittiwakes, poor recruitment, along with a lowered attendance of adults at the colony, may be factors contributing to the apparent decline of red-legged kittiwakes. An influx of birds was recorded in August, after the breeding season; these may have been subadults prospecting for nesting sites to use in 1985.

The abundance of common murres on plots varied greatly among plots, replicates, and years (Fig. 33). At this stage of our analyses, there are no clear patterns to this variation. Substantial decreases on theSt. Paul plots from the 1976 counts to the 1982 and 1984 counts suggested that nesting populations (or effort) might have declined. Craighead and Oppenheim (1982) observed similar (but not statistically significant) decreases between 1976 and 1982. Statistical verification of such changes in common murre populations remain difficult, these birds nest in larger aggregations than many other species, and thus present special sampling problems.

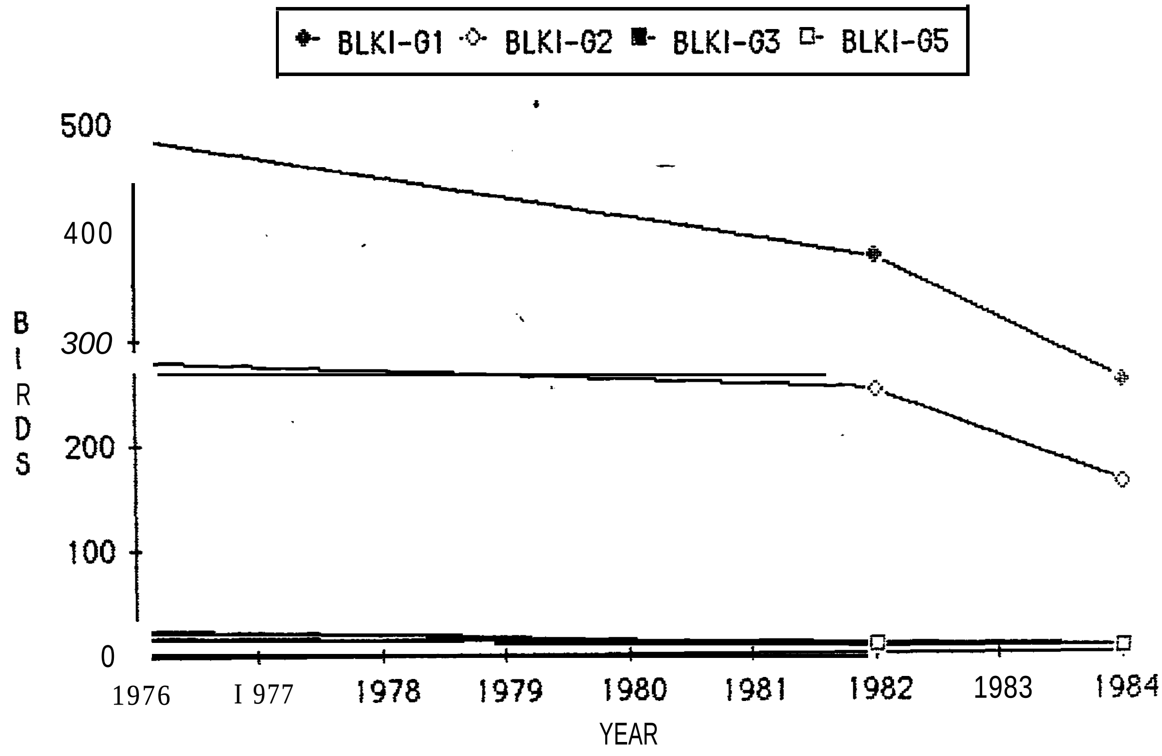


Figure 29. Trends in counts of black-legged kittiwakes in different strata in different years at St. George Island. BLKI=black-legged kittiwakes, G1, G2, G3, G5= St. George Island Strata 1, 2, 3 and 5.

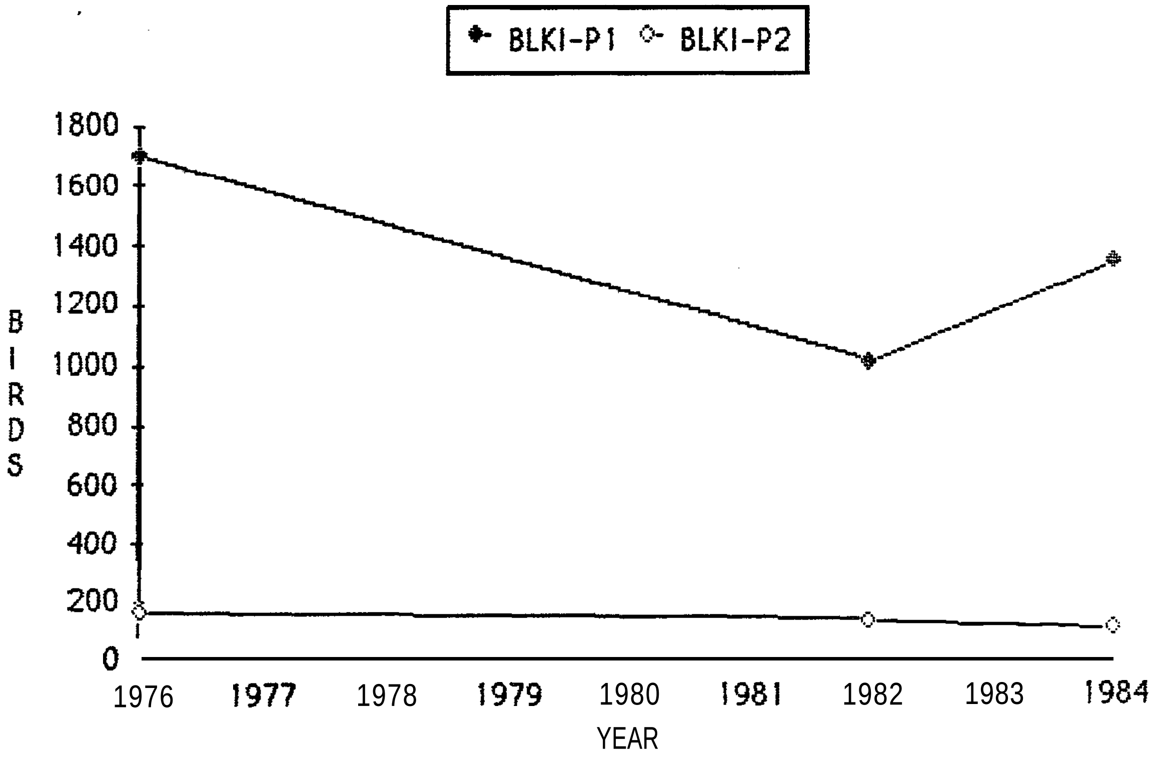


Figure 30. Trends in counts of black-legged kittiwakes in different strata in different years at St. Paul Island. BLK1= black-legged kittiwake, P1 and P2 = St. Paul Island, strata 1 and 2, respectively.

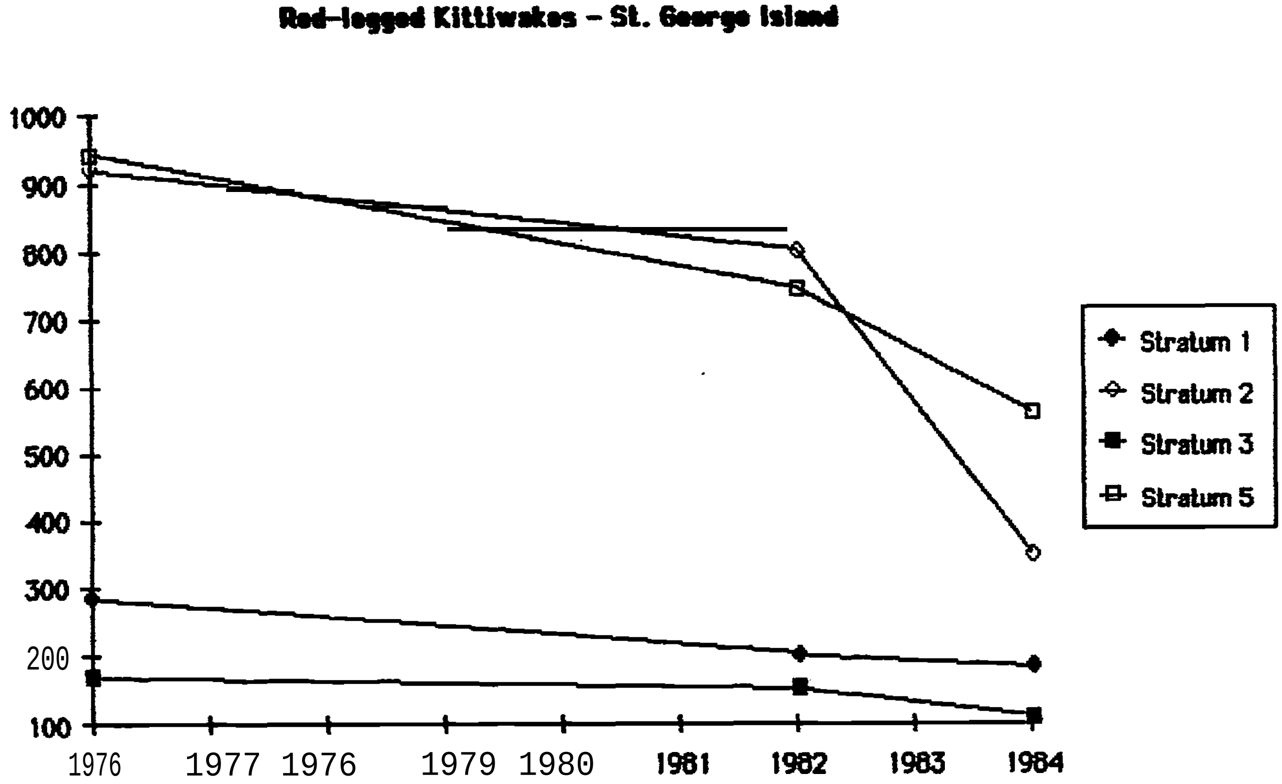


Figure 31. Trends in counts of red-legged kittiwakes in different strata in different years at St. George Island. RLK1 = red-legged kittiwake, G1-G5 = St. George Island, strata 1-5, respectively.

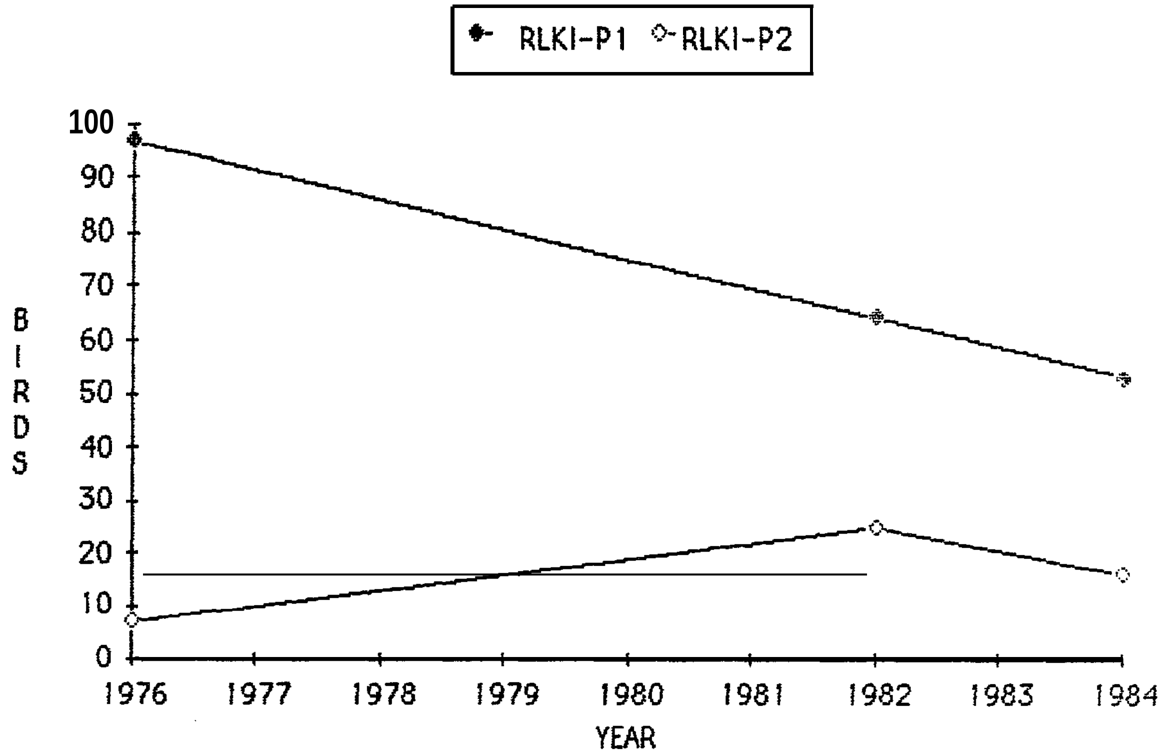


Figure 32. Trends in counts of red-legged kittiwakes in different strata in different years at St. Paul Island, RLK1 = red-legged kittiwake, P1 and P2 are strata 1 and 2.

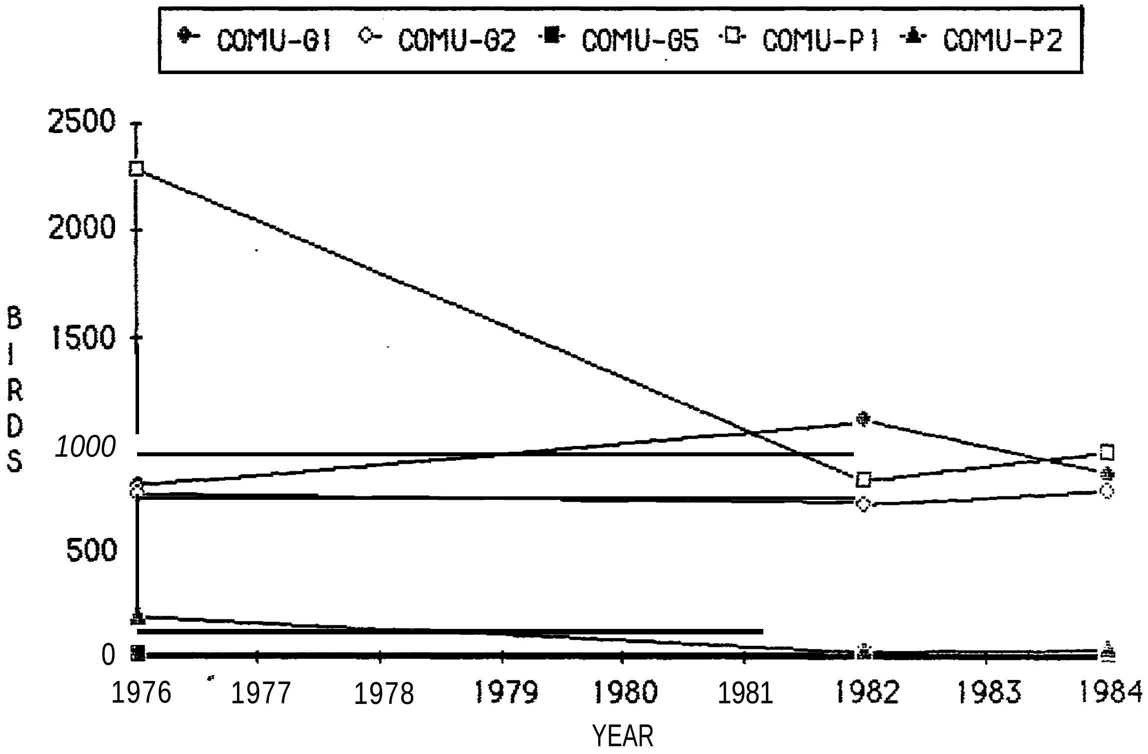


Figure 33. Trends in counts of common murres in different strata in different years at different colonies. COMU = common murre; G1-G5 = St. George Island strata 1-5; P1 and P2 = St. Paul Island strata 1 and 2.

Thick-billed murres appear to have declined slightly on St. George Island between 1976 and 1982, and perhaps between 1982 and 1984 (Fig. 34). Low counts were evident on St. Paul in 1982 but attendance had rebounded in 1984 on St. Paul (Fig. 35).

In some species, what appear to be year-to-year changes in abundance might have resulted from differences among years in the timing of counts. For example, black-legged kittiwake and common murre counts on St. George, but not onSt. Paul, were lower in 1984 than in 1982. Because the 1984 counts took place earlier on St. George than on St. Paul, it is possible that a normal seasonal increase in colony attendance by these birds caused the annual difference in counts, especially if counts in 1982 on both islands were later than the 1984 St. George counts,

Population Estimation

Methods

Population estimates of seabird colonies in Alaska, and probably elsewhere, are primarily made simply by making gross visual counts of numbers of birds either from a boat or aircraft. While of unknown accuracy or precision, these estimates probably suffice to give general indices of colony sizes and species composition

More detailed studies of seabird population sizes have been based on mean density/area estimates. These have been of two types: one type of estimate is based on the extrapolation of densities in known areas (sample -plots) to the remainder of the colony (e.g., Petersen and Sigman 1977). The alternative approach has been to photographically sample the colony and base the estimates on extrapolations of counts of birds in the photographs (Hickey and Craighead 1977).

Our strategy at population estimation was based on sampling study plots. We selected this approach over the photographic method for the following reasons:

1) Photo-interpretation takes a large time investment such that under the time limitation permitted, no replication of counts could be made.

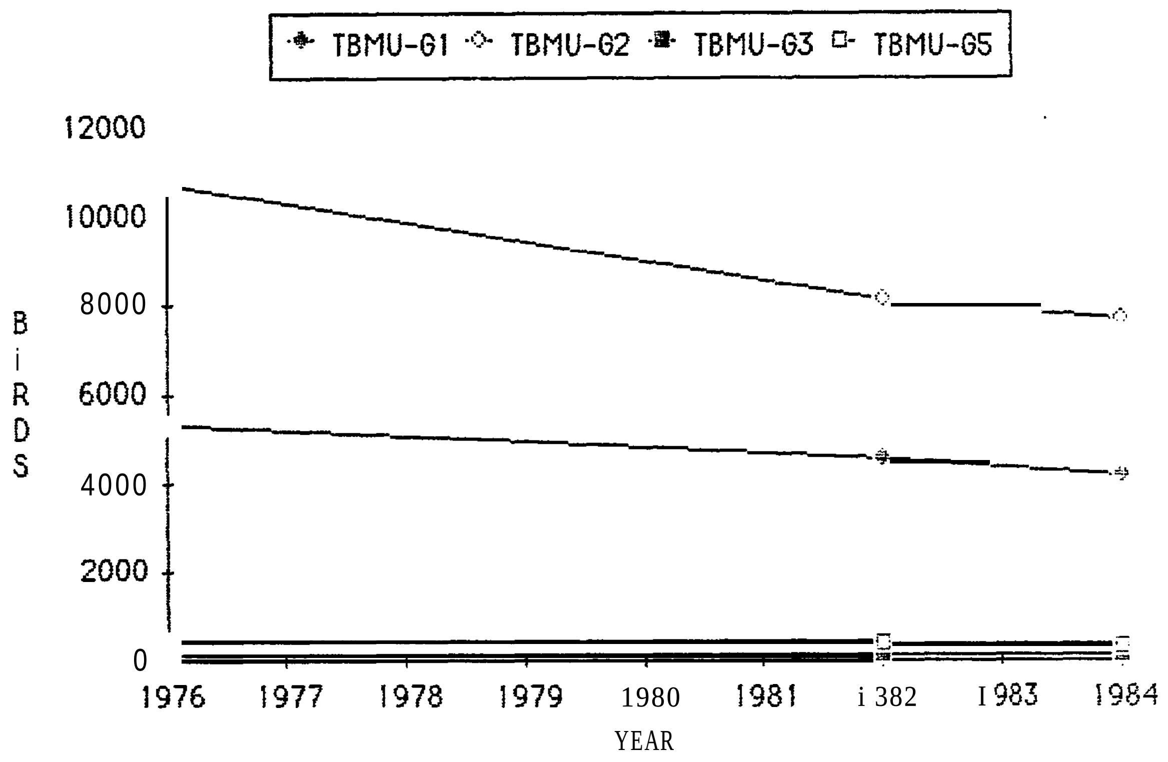


Figure 34. Trends in counts of thick-billed murres in different strata in different years on St. George Island. TBMU = thicked-billed murre; G1-G5 = St. George Island strata 1-5.

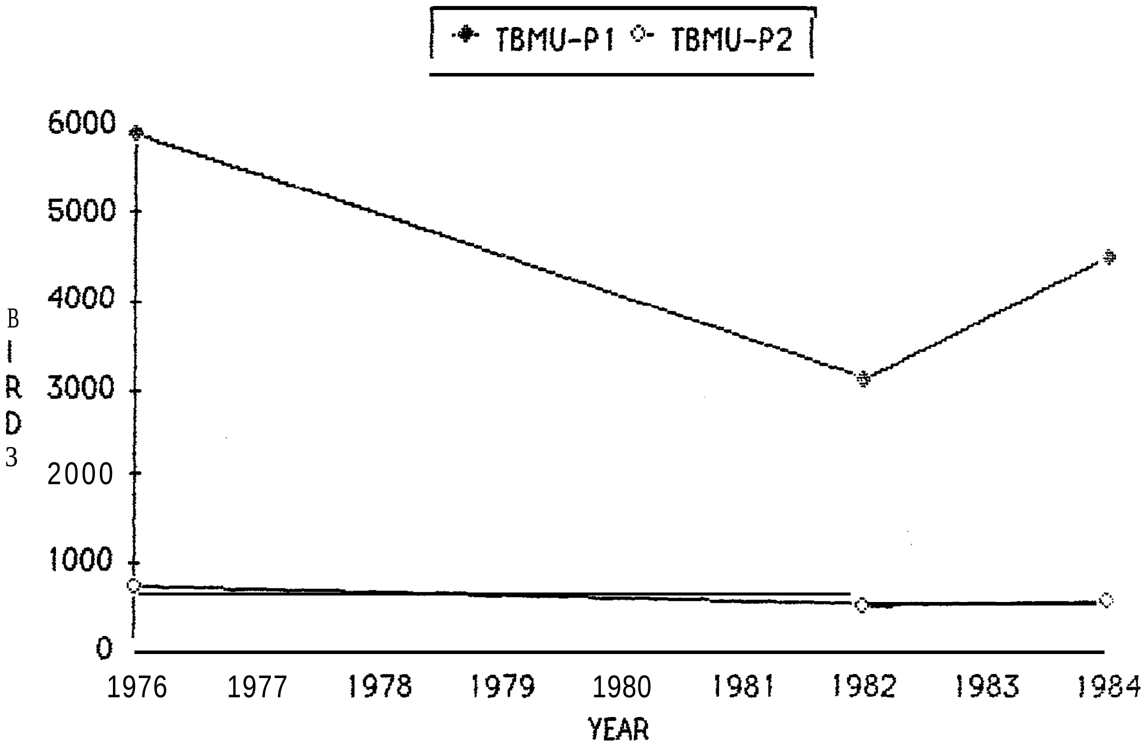


Figure 35. Trends in counts of thick-hilled murres in different strata in different years on St. Paul Island. TBMU = thick-billed murre; P1 and P2 = St. Paul Island strata 1 and 2.

2) Although the sampling method outlined by Hickey and Craighead (1977) permitted calculation of standard errors among samples of photographic counts, no confidence limits could be calculated for species population estimates. only "white birds" were counted in the photographs and correction factors of unknown precision were used to translate the "white bird" populations into individual species of seabirds.

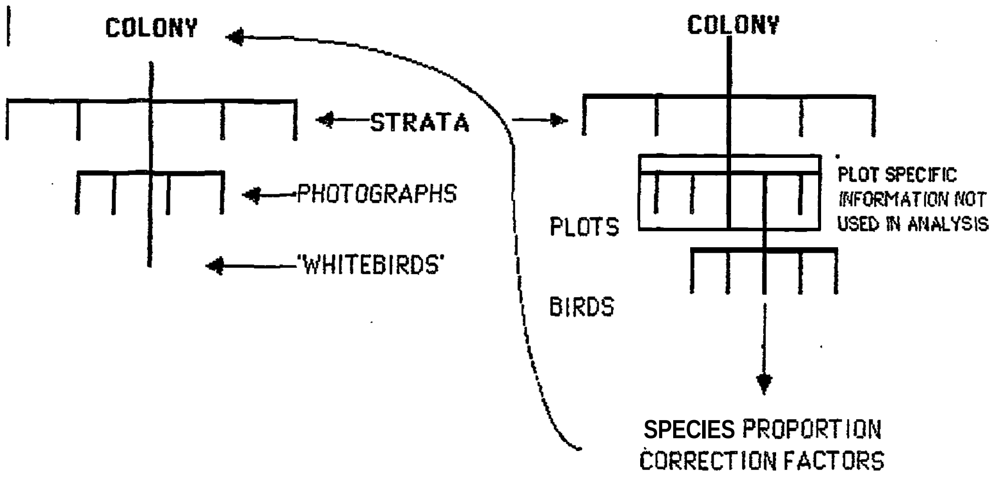
3) photographic censusing has been shown to be a useful tool in censusing seabirds; however without extreme care it is subject to considerable bias (underestimation) due to the inability to resolve individual birds in photographs. Although recognized by Hickey and Craighead (1977), the error introduced by this problem is not incorporated into their estimates.

Since one of our objectives was to derive statistically supportable estimates with known confidence limits, the photographic method in its present form, was inappropriate. Although the work by Hickey and Craighead (1977) provides a good, well-documented base for improving their method, we felt a better and quicker selection could be obtained starting with sample plots rather than photographic sample techniques.

Our sampling scheme incorporated the use of strata suggested by Hickey and Craighead (1977) and introduced the use of counting clusters (aggregation) of birds. The importance of counting clusters is discussed later in this section. A comparison of the estimation design used by Hickey and Craighead (1977) with ours is shown in Figure 36. The procedure used by Petersen and Sigman (1977) is not detailed in their report but appears to be a simple version of the methods we employed, i.e., without the use of strata or cluster counting stages.

__Examination Of Assumptions.__ There are three steps in our estimation scheme that we wish to ascertain the necessity/validity of including. These are cluster counting, use of strata, and extrapolation based on area.

PHOTOGRAPH BASED ESTIMATES



CLUSTER COUNT

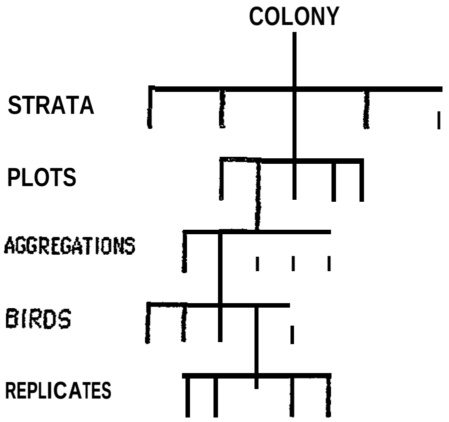


Figure 36. Comparison of population estimation techniques used by Hickey and Craighead (1977) and this study. The photograph based method requires two parallel sampling programs; photography to estimate numbers of birds, sample plots to determine species composition. The cluster count method is simpler (only one type of sampling) but requires an independent measure of occupied cliff area.

Clustering. One of the features of seabird colonies that led us to seek a refinement of past methods of seabird population estimation was the observation that birds are often clumped. The tendency for this to occur is summarized for a selection of species from St. George Island--Strata 1 plots in Figure 37. All species had a predominance of cluster size 1 (i.e., single birds), however, the "tailedness" of the distribution was quite varied. At one extreme were species such as northern fulmar which usually occurred in ones or twos. Most species followed this pattern (occasionally group sizes were larger, but average group size rarely exceeded two). Thick-billed murres exhibited a similar pattern although larger group sizes were more frequent. The shape of the thick-billed murre graph closely approximates a common mathematical distribution known as log-series distribution. The distribution of species showing the northern fulmar pattern also fit log-series distributions, especially when larger samples are taken and the occurrence of a few larger clusters is more evident.

Common murres, in contrast, have extremely long-tailed distributions. Although only a few very large groups are present they are so much larger than the others they contain a large proportionof the birds. In Figure 37 almost half of the common murres represented in the graph are accounted for in the one group at the right hand extreme. The shape of this graph approximates a negative-binomial distribution. In the tests presented earlier for among-year and seasonal trends in abundance there were often large differences in the absolute number of birds, but a failure to find significant differences between groups. For example, on St. Paul Island, the changes in number of common murres on study plots among years were proportionally greater than for thick-billed murres; however, differences were not significant for the common murres but were highly significant for thick-billed murres. In part, this appears to be due to common murre changes occurring as a few large differences on individual plots, whereas the thick-billed murres change in abundance more uniformly across plots--the statistical tests emphasize these more uniform tendencies which increase our confidence in extrapolating to make whole colony inferences.

Most population estimation schemes rely on simple sampling principles that may include such features as stratification and/or subsampling. These schemes make very few assumptions about the distributions of the

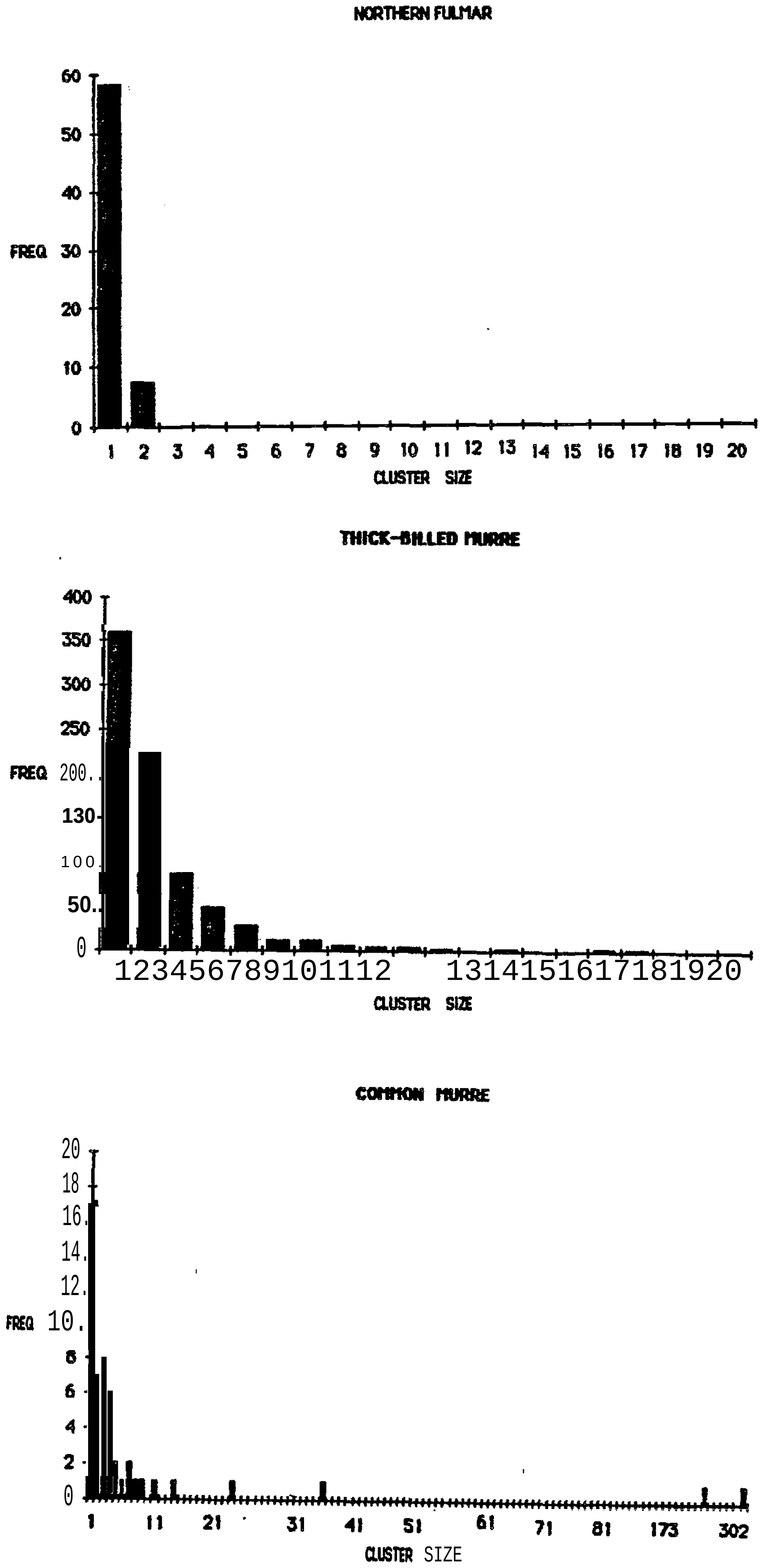


Figure 37. Frequency distribution of cluster sizes (aggregations) of seabirds.

sample data set and may be referred to as "model-free". Model-free estimators are appropriate for complex sample "designs or if there are several attributes of interest. However, in order to be flexible enough to accommodate many situations, these procedures are frequently suboptimal for any one specific case. A simple sampling theory approach is to extrapolate the mean density of seabirds in study plots to the area of the total colony (mean density/area estimator) as was done by Hickey and Craighead (1977) when extrapolating counts in photographs to the total island cliff area. However, for studies involving seabird population estimation where there is only one attribute of interest, abundance, analysis of the frequency distribution may justify the assumption of known mathematical forms (e.g., log-series or negative binomial distribution) permitting results from classical mathematical_ theory to be applied.

The use of model-based estimates (i.e., a model for the frequency distribution of abundance) has been applied in other areas of statistical ecology (e.g., see Boland 1983), later in this section we explain the use of this methodology for seabird population estimation

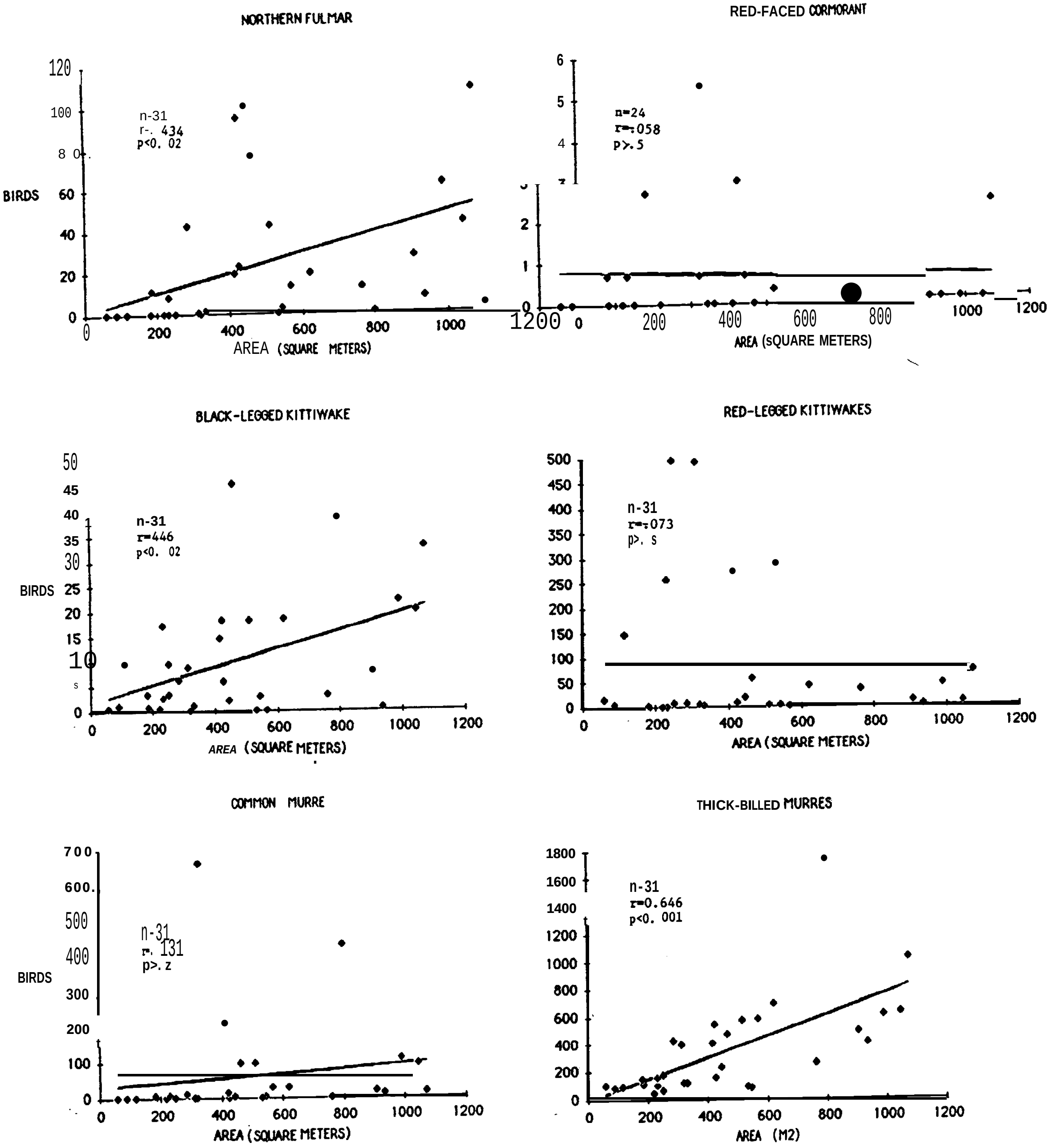
Strata--Using a stratified sample procedure can often improve (reduce the variance) of estimates. The value of stratification at the Pribilofs was well documented by Hickey and Craighead (1977) by the distribution of seabirds among strata. For example, red-faced cormorant were restricted to the lowest two strata and red-legged kittiwakes were most abundant in the highest stratum.

Area--Probably all population estimation schemes used in seabird studies rely on extrapolating counts in sampled areas (study plots) to the area of the entire colony. Use of area to extrapolate study plot counts to total colony population requires that we assume that counts of birds are related to area; that we know the area of the study plots; and that we know the total area to be extrapolated to. These topics are discussed below.

Is seabird abundance a function of sample area? This assumption was evaluated by testing for correlation between abundance and area on our study plots. The area of study plots was determined by projecting photographic slides taken of the plots from the same vantage that counts were made and planimetering the area centered within the count area. Birds (murres and/or kittiwakes) in the picture were used as scaling factors for size. The results are summarized in Figures 38 and 39. Surprisingly, this seemingly intuitive assumption is not always correct. The trend for red-faced cormorant and red-legged kittiwakes are negative but non-significant Significant positive correlations were found only for northern fulmar, black-legged kittiwake, and thick-billed murres at St. George Island. None of the correlations for Cape Peirce seabirds were significant. Only the thick-billed murre on St. George exhibited a moderately strong correlation in support of this fundamental hypothesis.

Area of colony. The ratio of the area of the colony to the area sampled is the factor that is used to extrapolate plot counts to colony population size. Existing estimates of cliff area in the study colonies are available only for the Pribilof Islands (Hickey and Craighead 1976). Even these estimates are inappropriate for our needs (but were suitable for the photographic methods of Hickey and Craighead). Because seabird study plots were selected based on cliffs with birds; we need to know the total cliff area occupied by birds, not total cliff area. Otherwise population estimates will be biased and much too large. A survey of cliff availability to birds is much beyond the scope of this study. Preliminary " estimates of cliff availability on St. George Island were made as follows.

Population estimates for St. George Island were derived by Hickey and Craighead (197'7) using a photo-interpretation technique. They also provided counts of seabirds on the same study plots we used. Use of these multiple sources of data permitted us to estimate the area of cliff occupied by each species of seabird. The number of seabirds present in 1976 were estimated using the total area of cliffs in each stratum and the number of birds recorded on study plots (only study plots common to 1976 and 1984 were used). This estimate is certainly too large, however, the ratio of this number to the independent population estimates determined by Hickey and Craighead (1977) provides a correction factor for reducing total areas to areas of seabird cliff habitat. We calculated this correction factor for each species and strata.



Figure' 38. Relationship between number of birds and study plot area on St. George Island.

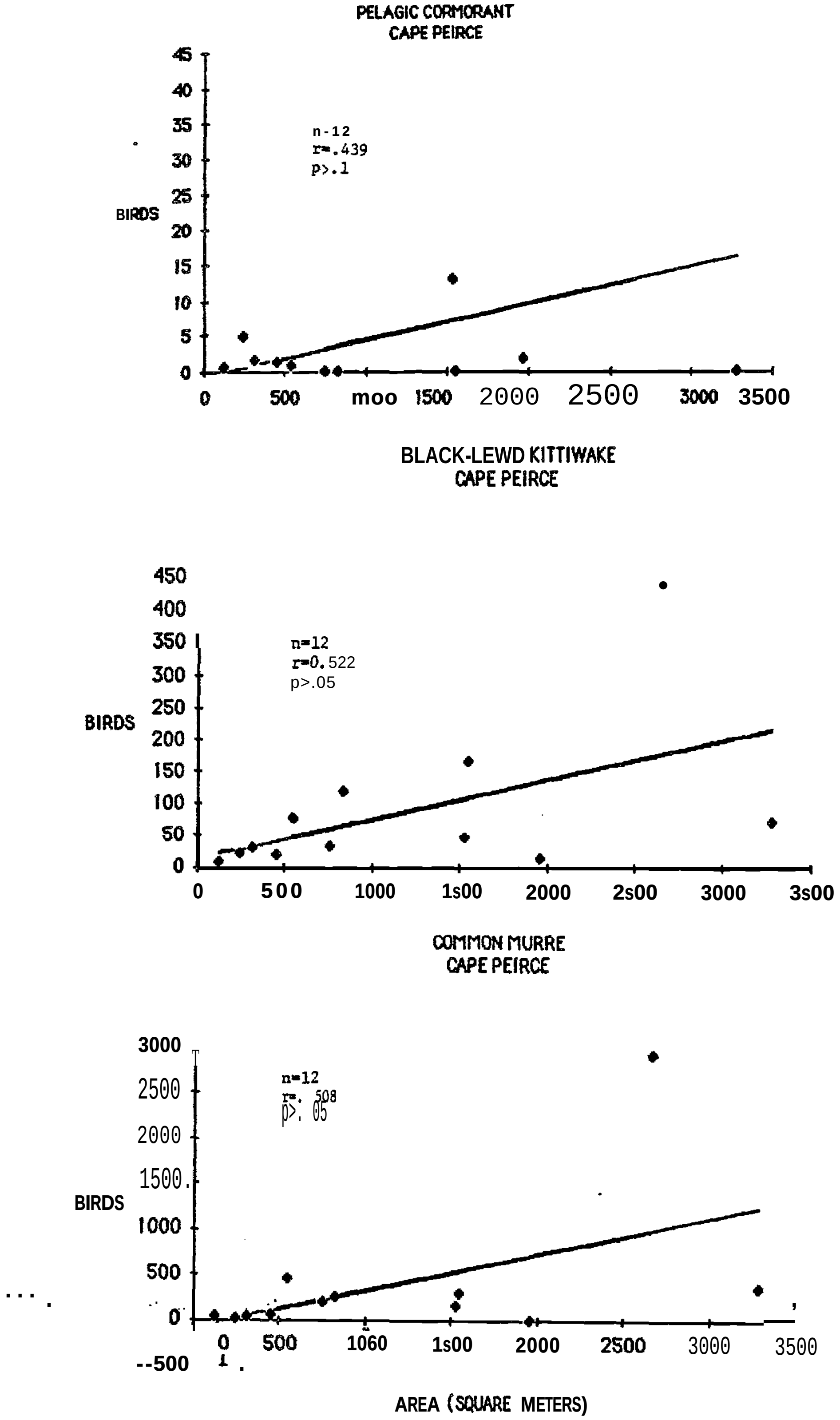


Figure 39 . Relationship between number of birds and study plot area at Cape Peirce.

Second, it incorporates the sampling design, i.e., stratification and enumeration of clusters. This specification of a probability model for the data yields the estimates by the technique of maximizing the probability function (likelihood) with respect to the model parameters (see Silvey 1970). The variance of these estimates may be derived directly using a technique called the delta-method (see Serfling 1980).

Model-based estimation and goodness-of-fit--An important aspect of model-based estimation is the selection of a model. It is clear that for a variety of abundance patterns there should be a variety of probability models. And thus, before maximum likelihood estimation can occur it is necessary to select among a set of alternative models (frequency distributions). The models from which we selected when fitting the cluster size frequency distributions to known mathematical distribution were: (1) Poisson, (2) log-series, and (3) negative binomial). As described earlier, individual species may vary as to which model would be most appropriate; this leads to a goodness-of-fit problem. In the model selection process for abundance data, as will be detailed later, it is possible to use a standard Chi-squared goodness-of-fit procedure (see Rao 1975). These procedures are only appropriate for independent, identically distributed, random variables. These standard assumptions are not met in this study, therefore we have used alternate methods, as detailed below.

Construction of the population estimates

Probability models. There are several features of the abundance data that need to be incorporated into the model for the data. Of primary importance is aggregation of the birds on cliffs (i.e., clumping of birds into clusters). Additionally, the aspect of stratification of the sample area needs to be accounted for. The following model for clustering of individuals uses the techniques detailed in Patil et al. (1978). The assumptions of this model are as follows:

Let $\{N\}$ be the number of clusters within the colony.

Let $\{Y_j, j=1,...,N\}$ be the number of individuals within clusters $1,...,N$.

Then the total number of individuals within the colony may be expressed as

$$X = \sum_{j=1}^{N} Y_j \qquad (1)$$

This expression for the abundance of individuals in the colony has several consequences. Most importantly it accommodates the occurrences of species that do not cluster. This is specified by letting $Y_{j=1}$ for $j=1,\ldots,N$ and thus letting N be the total number of individuals in the colony.

To utilize this model for estimation of′ the total population, we must incorporate the sampling design. Thisis the step that introduces the probability model for the sampled plots within strata. There are two distinct frequency distributions of interest. They are:

(1) The distribution of the number of clusters (N) on a plot,

(2) The distribution of the size (Y_j) of clusters within a plot.

Additionally, to allow for the heterogenity of areas within the colony, the estimates will be based on strata; i.e., separate frequency distributions will be fit to each strata and then combined and extrapolated to the entire colony. To extrapolate to the entire colony it is necessary to utilize the parameterization of the frequency distributions given above. Considering the form of the total population as a function of the number of clusters and cluster size, we can construct a parametric form for the number of individuals on plots. This form is the mean or expectation of the distribution of the number of individuals on a plot. This is written as

$$E(H_i) = E(N_i)\ E(Y_j)$$

where E(.) is the expectation of the random variable within. In other words, to extrapolate the number of birds on a plot (and strata) to the entire colony, the expectation of the number of clusters times the expectation of the size of the cluster must be estimated and then enlarged to the entire size of the colony. To accomplish this it is necessary to estimate the parameters of the above expectations. The form of these parameters depends on the respective distributions. Thus it is necessary to fit several mathematical distributions to the cluster size/frequency distributions to estimate these parameters. As we mentioned earlier, maximum likelihood estimates will be used for this task.

Implementation of goodness-of-fit. Some criteria are required for evaluating which model is most appropriate. Two SUCh criteria that were applied are based on the Chi-squared goodness-of-fit test, and the likelihood ratio test. The Chi-squared test is one of the more commonly applied tests used to specify if the chosen model is correct. It is applicable when N independent observations are classified into one of K distinct categories. Taking O(i) to be the 'observed" number of individuals in the i category and E(i) the 'expected" number of individuals in that category, then the statistic is given by

$$X^2 = \sum_{j=1}^{N} \frac{(O_j - E_j)^2}{E_j} \qquad (2)$$

If we assume that the model from which the E's were computed is correct, the statistic converges (as N gets large) to a X2 random variable. Thus, large values of the statistic suggest that the model is inappropriate; this is true even if the model (and thus the E's) depend upon parameters that have been estimated in some efficient manner. These details are well documented in Rao (1973:371). Using these previously defined statistics, one can develop a diagnostic for discriminating between models, e.g., choose the model that was 'least rejected" (largest P-value) according to the X2 goodness-of-fit test. Ripley (1980) discusses the use of similar diagnostics. Although methods based on the above Chi-squared goodness-of-fit statistics are intuitively appealing and reasonably well understood, methods based on the likelihood of the data are usually considered superior (Serfling 1980:347) and are applicable in the non-independent case. One such procedure, proposed by Cox (1961, 1962) is based on the ratio of the maximized likelihoods for two competing models. This diagnostic selects as superior the model with the largest maximized likelihood. Cox further develops this into a test statistic for testing between models which is, in the large sample independent case, approximately normal. These two diagnostics were employed in selecting the model s to be used in estimating population totals. The Chi-squared procedure was used only in determining the cluster size distributions, however, the likelihood procedure was applied to overall models as well as to the component distributions.

Implementation of maximum likelihood. The maximum likelihood estimation procedure is based on the probability law (frequency distribution) for the data when the distribution is a function of some unknown parameter β.

For the discrete case with observed $(x_1,\ldots,x_n)=\underline{x}$
for the random variable $(X_1,\ldots X_n)=\underline{X}$ let
$f(\underline{x};\beta)=P(\underline{X}=\underline{x})$ and $l(\underline{x};\beta)=\log(f(\underline{x};\beta))$

This method estimates the value of the parameter to be that which makes the data most probable; i.e., the estimate maximizes $l(\underline{x};\beta)$ as a function of β. This maximization can often be accomplished using elemetary calculus techniques--the maximum occurs where the derivative of $l(\underline{x};\beta)$ is 0. This may be termed ‘solving the normal equations’ occasionally this yields closed-form estimates. In other cases, the normal equations have no closed-form solutions and numerical techniques are required. To illustrate these ideas, some specific examples are included. Suppose one observes n independent plots of size $A_1,\ldots,A_n$ with observed number of clusters per plot as $x_1,\ldots,x_n$ and assume that the X_i has a Possion (ΔA_i) frequency distribution. Therefore

$$l(\underline{x};\Delta) = \sum_{j=1}^{n} \{(-\Delta A_j)+x_j\log(\Delta A_j)-\log(x_j!)\} \tag{3}$$

Solving these normal equations yields

$$\hat{\Delta} = \sum_{j=1}^{n} x_j \Big/ \sum_{j=1}^{n} A_j \tag{4}$$

which is unbiased with variance

$$\Delta / \sum_{j=1}^{n} A_j \tag{5}$$

In the previous example a closed-form solution existed. In the majority of cases this is not true and it is necessary to numerically maximize the likelihood. This is an iterative procedure called a Newton-Raphson procedure (see Chambers [1977] for further details concerning implementation).

Results

Cape Peirce.

Common murre--Estimates of common murre populations were calculated for the five study periods at Cape Peirce. The performance of the estimation, i.e., the size of the confidence intervals expressed as a percentage of the mean and the ratio of the confidence interval calculated by our methods compared to a standard estimate based on mean density extrapolation to area can be computed as these are independent of the total colony size. The results are summarized below.

Period	95% Confidence Intervals % of Total Population	Ratio of C.I.
1	17	0.29
2	18	0.31
3	19	0.30
4	20	0.36
5	19	0.34

Our 95% confidence limits were always within ± 20% of the population estimate. Common murres frequently are highly aggregated on cliffs and the distribution of their cluster size approximates a negative-binomial. distribution. Use of a population estimator based on this distribution results in confidence intervals about one-third (Ratio of C.I. ~0.33) of what they would have been using a simple mean density/area estimator; this is a substantial improvement.

Black-legged kittiwake--An analysis of the black-legged kittiwake population at Cape Peirce is similar to that described for common murres, and yields the results summarized below.

Period	95% Confidence Interval % of Total Population	Ratio of C.I.
1	19	0.57
2	24	0.63
3	26	0.63
4	30	0.55
5	25	0.54

Our population estimates for black-legged kittiwakes are not as precise as for common murres; however, ±25% is very good considering the intensity of sampling (only 12 plots). Our estimate, based on a log-series model was almost twice as precise (Ratio of C.I. of 0.5) as a mean density/area estimator.

St. George Island (Pribilof Isl--Precision of population estimates were calculated for the non-cavity cliff-nesting seabirds using the counts made during sample Period 2 (early July). The performance of our estimators are given in Table 27.

The performance criteria listed in Table 27 show that our estimators performed as well as and usually much better than the mean density/area method commonly used. It is not surprising that red-faced cormorant populations could not be estimated very precisely; the numbers or plots were not related to the area sampled (Figure 37).

Discussion

Our experimentation with different types of population estimation procedures points to several techniques that could greatly improve seabird

Table 27. Evaluation of precision of maximum likelihood estimator in relation to mean estimate and estimates based on mean density/area estimator.

	95% Confidence Interval ±% of Total Population[1]	Ratio of C.I.[2]
Northern fulmar	15	0.25-0.47
Red-faced cormorant	112	0.68-1.03
Black-legged kittiwake	50	0.45-0.60
Red-legged kittiwake	36	0.29-0.98
Common murre	26	0.29-0.34
Thick-billed murre	10	0.53-0.56

[1] Based on totals in two strata.

[2] Ratio is of confidence intervals of maximum likelihood estimator/C.I. of mean density/area estimator. Range based on Strata 1 and 2 individually.

population estimation strategies. Stratification is supported as being an important component of the sampling program. Although we did not do any empirical evaluation of the gains in precision inherent in stratifying, the study plot data and summaries presented in Hickey and Craighead (1977) provide evidence of pronounced changes in abundance with cliff height. For example, no red-faced cormorants occurred above Stratum 2.

The cluster sampling technique proved to be a useful addition to the counting procedure. Some species, most notably common murres, were highly aggregated and the estimates for these species were markedly improved over mean density/area estimates. For all species, estimates based on cluster counting and the maximum likelihood estimates had much narrower confidence intervals than mean density/area estimates. Of the species studied, the cluster size distribution of all except common murre best approximated a log-series distribution; common murre frequency distributions were negative binomial.

Hickey and Craighead (1977) reported their 95% confidence interval to be within 50% of the mean estimate. Craighead and Oppenheim (1982) revised this interval to 36%. How these numbers were derived is unclear; presumably they are basedon the variance of counts of whitebirds from the photographs, i.e., not species by species. Actual confidence limits of individual specis could not be calculated (Hickey and Craighead 1977). Our methods resulted in better precision for four or five of the six species (dependingon whether the comparison is with 36 or 50%). On a species by species basis, the mean density estimate is less precise than the methods we used. The most numerous species on the Pribilofs, thick-billed murre, could be estimated ±10% using the maximum likelihood estimation procedure.

There are some drawbacks to our procedure compared to the Hickey-Craighead method. Although we have achieved better precision, we cannot determine an accurate total estimate without better estimates of the total area of seabird habitat. Hickey and Craighead avoided this problem by taking random samples of photographs to represent all cliff areas (regardless of presence of birds). Their method does not permit accurate species identification (whitebird was the limit of their selection) and risks losing important differences in population trends among species or mixing species with disparate distributional characteristics (e.g., pooling common and thick-billed murres) since one must assume that whitebird abundance is a precise indicator of each individual species. Further, it takes longer to acquire and analyze photographic data, and this type of analyses could result in pooled counts over too broad a period of time. Our results indicate that large changes in the number of birds on study plots may occur on a scale as small as three days. Repeated sampling of study plots is likely a more viable alternative than many photo surveys for large colonies such as St. George.

Unfortunately, it appears that none of the studies thus far have been intensive enough to yield reliable, useful population estimates. The analyses reported upon here indicate that use of stratification, cluster counting, and maximum likelihood estimation will result in much more precise estimates than we have had in the past. It will be necessary for successful implementation of this approach, as well as others, to place additional emphasis on determining the areal extent of colonies (i.e., what fraction of the colony are we sampling) before we can confidently extrapolate results from study plots to total colonies.

For some species, such as red-faced cormorant, our data reveal very poor relationships between number of birds and area sampled. Before extrapolations are legitimate, a better understanding of what seabird habitat is, will be necessary. It appears that we do not know exactly how much suitable habitat we have sampled, nor how much to extrapolate to.

SUMMARY

Our population study focused on four areas of research: the documentation of diurnal trends in abundance, seasonal trends in abundance, among-year trends in abundance, and an analysis of methods to improve population estimators. The last two topics, population trend and population size, are the major topics of interest in a monitoring and/or management program; however the first two components of the study determine limitations on how we should sample to permit realization of monitoring goals. A firm understanding of diurnal and long-term temporal (seasonal) variability should precede a monitoring program and should be incorporated into its study design; however, this is seldom done.

Our analysis results indicate that some concerns have been overstated and others have Been overlooked. Diurnal cycles in attendance were pronounced early in the season but diminished as incubation got underway. We suspect such cycles may become more prevalent late in the season but have little data to support this conjecture. Our results showed that censuses should be conducted during the incubation period when counts may be made over a broad segment of the day. The practice of making a series of 24-hour counts at the start of a study and using that "pattern" to compensate better counts made later in the study (to correct for time of day) may impose a non-existent pattern on the birds. Further, this technique may inflate the actual population estimates since it appears that the cycle is introduced by the comings and goings of non-breeding birds, whereas nesting birds appear to occupy their sites with great fidelity. If counts are conducted early (or late?) in the year when diurnal cycles are pronounced, the timing of censuses should be based on the species of particular interest. Most species exhibit distinct cycles that are not in phase with each other.

Diurnal variability was much less pronounced than anticipated and the longer term patterns in attendance were more pronounced than anticipated. In extreme cases, large changes in the number of birds occupying cliffs were noted in periods as short as three days. The most stable number of birds present on the cliffs appeared to be during the mid-incubation period. Earlier and later, non-breeding birds ("prospectors") appear at the colonies and inflate the counts.

The influence of seasonal trends may be very important in assessing among-year trends in population size. On St. George Island, the timing of censuses of seabirds have spanned a range of dates of approximately one month, thus confounding our ability to distinguish among-year from within-year patterns in variability.

For many species the counts on the Pribilofs in 1984 were lower than counts made in 1976 or 1982, and usually much lower than in 1976. In general these changes were more pronounced on St. George than on St. Paul.

A summary of results for the cliff-nesting species, excluding cavity nesters, is as follows:

	St. George		St. Paul	
	Significance	**1984**	**Significance**	**1984**
Northern fulmar	●**1	12	n.s.	
Red-faced cormorant	●	L	●S	L
Black-legged kittiwake	●**	L	●*	I
Red-legged kittiwake	n.s.		n.s.	
Common murre .	n.s.		n.s.	
Thick-billed murre	●**	L	●**	I

[1] **Differences** occur among-year: *=p<0.05, ● *=p<oeol, ● **=p<o.ool.

[2] **Position** of 1984 relative to 1976 and 1982: I=intermediate, L=lowest.

The most convincing evidence for a substantial decrease in population size has been for red-faced cormorant, where numbers were much reduced on study plots in 1984 relative to 1976 on both St. George and St. Paul. For the remaining species, apparent changes in abundance were not significant (common murre and red-legged kittiwake), or there were significant changes in abundance but counts in 1982 were low and counts in 1984 were intermediate (northern fulmar), or different trends occurred on the two islands (black-legged kittiwake and thick-billed murre). Although it is quite possible that different population trends could occur on the two islands, the tendency in 1984 to have low counts on St. George but not on St. Paul, and the fact that counts on St. Paul were made at more similar times each year than were those on St. George, leads us to the suspicion that the counts on St. George may reflect seasonal as well as yearly effects.

Another possibility is that the counts of birds on the cliffs is a function of nest success. In years of high nest failure (1982 and to a lesser extent 1984; see Johnson and Baker, this volume) the adult birds may leave the colony early. If this is the case, plot counts may be a reflection of current nesting effort rather than size of the adult population. Nonetheless, the counts on St. Paul did reveal significant among-year differences that indicated low counts in 1982 and some recovery in 1984.

The counts of birds on study plots seemed to suggest. more differences among years and/or season than were found to be significant. This apparent lack of sensitivity was due to the nature of the tests, which gave each plot equal weighting in the tests even though many more birds occurred on some compared to others. This attribute is desirable in that it does not allow trends on one large plot to overshadow those on several smaller plots which have trends in the opposite direction. To increase precision, our population estimation analyses describe maximum likelihood estimators that optimally fit the seabird data to mathematical distributions of known properties. We consider it worthwhile to pursue this and other avenues of research with applications that may assist in quantifying and testing for population trends.

With respect to the population estimation analyses, we have found that the method of stratification implemented by Hickey and Craighead (1977) is useful in improving population estimates based on changes in occurrence or density of some species among strata. The cluster counting and maximum likelihood estimator procedures we tested always improved our estimates of population size over those estimates achieved with mean density/area estimators. Our ability to estimate populations ranged from very good for thick-billed murres (± 10%) to poor for red-faced cormorant (± 100%). While some refinement of these methods is possible, the most profitable investment of time would be in determining the area of study plots and the area of the cliffs which extrapolations are to be made; currently this is the factor limiting the derivation of accurate population estimates.

CONCLUSIONS

With reference to our objective of monitoring populations of seabirds at Cape Peirce and the Pribilof Islands-we make the following conclusions:

(1) No among-year differences in seabird attendanceat Cape Peirce were founnd. We did document very rapid short-term changes in abundance at this colony during 1984.

(2) Many differences were found in counts taken in various years on the Pribilof Islands. Segregating among-year from within-year trends is difficult or impossible.

Overall it appears that counts in 1982 and 1984 are low relative to 1976 but the position of 1984 relative to' 1982 is more difficult to ascertain. The most supportable evidence of an actual population decrease is for the red-faced cormorant. The magnitude of this change cannot be stated as our analyses indicate that counts of this species are not correlated with plot size and thus all population estimates are suspect. Counts on study plots, however, have decreased approximately 76%.

(3) The data base for monitoring seabirds at these colonies may not be adequate for measuring potential impacts of OCS activity. Most of the existing baseline (including 1984) consists of attempts to get a set of counts in a series of years. Our analyses indicate that the timing of these counts is critical if legitimate comparisons are to be made to detect among-year changes. Further, we suggest that the analytical procedures used have not adequately extracted all the relevant information contained in the plot counts to enable the determination of changes in abundance. A more through appraisal of analysis and data collection procedures will be essential to provide reliable monitoring of seabird populations.

In terms of achieving our original objectives, we had mixed success. The most important findingof our research was that our analysesof the implicit assumptions of the studies we were repeating were often invalid. Our analysis of diurnal and seasonal patterns of seabird attendance demonstrates that single point-in-time counts of seabirds are of limited use in monitoring seabirds. Because the 'baseline" studies on the Pribilof Islands in 1976 and 1982 are of single counts, it is impossible to test for differences in plot attendance among years (1976, 1982, and 1984) independent of short-term variability in cliff attendance. Monitoring of trends over time is certainly possible, but will require substantially more effort than has been expended.

Population estimation also posed difficulties in that the final step of extrapolating counts on study plots to the total colony proved unsatisfactory. The assumption that cliff area could be used to extrapolate seabird counts was erroneous or weak. Although this precluded the derivation of supportable population estimates, we found that the changes in methodology we tested, i.e., "cluster counting" of birds and the use of maximum likelihood estimators, markedly improved precision of estimates as compared to the mean density/area type estimators of previous studies. In order to obtain estimates of total population sizes it will be necessary to obtain improved description of seabird cliff habitat and measurement of the availability of these habitat types.

In summary" we feel a more critical examination of the seabird monitoring strategy be undertaken before the MMS program becomes firmly established. A monitoring program demands that studies be comparable among years; however an uncritical philosophy of reporting prior baseline studies (often designed with different research foci) may preclude meeting current objectives. We recommend that emphasis be placed on determining the most effective means of monitoring trend. To achieve this, improvements in plot selection, sampling intensity (spatial and temporal) and analytical procedures all need to be addressed. A lower, albeit important, research format should be improving the technique for estimating actual population size.

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APPENDICES

APPENDIX 1a

Sample schedule for seabird population plots at Cape Peirce.

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
1	13 JUNE	16 JUNE	19 JUNE	12 JULY	15 JULY
2	13 JUNE	16 JUNE	19 JUNE	12 JULY	15 JULY
3	13 JUNE	16 JUNE	? 9 JUNE	12 JULY	15 JULY
4	13 JUNE	16 JUNE	19 JUNE	12 JULY	15 JULY
5	11 JUNE	15 JUNE	18 JUNE	10 JULY	13 JULY
6	11 JUNE	15 JUNE	18 JUNE	10 JULY	13 JULY
7	11 JUNE	15 JUNE	18 JUNE	10 JULY	13 JULY
8	11 JUNE	15 JUNE	18 JUNE	10 JULY	13 JULY
9	12 JUNE	15 JUNE	18 JUNE	10 JULY	13 JULY
10	9 JUNE	14 JUNE	17 JUNE	11 JULY	14 JULY
11	9 JUNE	14 JUNE	17 JUNE	11 JULY	14 JULY
12	9 JUNE	14 JUNE	17 JUNE	11 JULY	14 JULY
13	9 JUNE	14 JUNE	17 JUNE	11 JULY	14 JULY

APPENDIX lb

Sample schedule for seabird population plots on St. George Island

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD S
1	27 JUNE	?1 JULY			12 AUG
2	27 JUNE	11 JULY			12 AUG
s	25 JUNE				
6	25 JUNE				
7	25 JUNE				
a	25 JUNE	10 JULY		30 JULY	14 AUG
9	25 JUNE	10 JULY		30 JULY	14 AUG
10	25 JUNE	10 JULY		30 JULY	14 AUG
11	25 JUNE	10 JULY		30 JULY	14 AUG
12	25 JUNE	10 JULY		30 JULY	14 AUG
13	25 JUNE	10 JULY		30 JULY	14 AUG
14	25 JUNE	10 JULY		30 JULY	14 AUG
15	25 JUNE	10 JULY		30 JULY	14 AUG
16	25 JUNE	10 JULY		30 JULY	14 AUG
17	25 JUNE	10 JULY		30 JULY	14 AUG
18	25 JUNE	10 JULY		30 JULY	14 AUG
19	25 JUNE	10 JULY		30 JULY	14 AUG
20	25 JUNE	10 JULY		30 JULY	14 AUG
21	26 JUNE	10 JULY		28 JULY	14 AUG
22	26 JUNE	10 JULY		2a JULY	14 AUG
23	26 JUNE	10 JULY		2a JULY	14 AUG
24	26 JUNE	10 JULY		28 JULY	14 AUG
25	26 JUNE	10 JULY		2a JULY	14 AUG
26	26 JUNE	10 JULY			14 AUG
2?	26 JUNE	IO JULY			14 AUG
2a	25 JUNE	11 JULY			14 AUG
29	25 JUNE	11 JULY			14 AUG
30	25 JUNE	11 JULY			14 AUG
31	25 JUNE	11 JULY			14 AUG
32	25 JUNE	11 JULY			14 AUG
33	25 JUNE	9 JULY			11 AUG
34	25 JUNE	9 JULY			11 AUG
35	25 JUNE	9 JULY			11 AUG
36	25 JUNE	9 JULY			
37	25 JUNE	9 JULY			11 AUG
38	25 JUNE	9 JULY			11 AUG
39	27 JUNE	11 JULY			12 AUG
40	27 JUNE	11 JULY			12 AUG
41	27 JUNE				12 AUG
42	27 JUNE	12 JULY			12 AUG
43	27 JUNE	12 JULY			12 AUG
44	27 JUNE				12 AUG
45		3 JULY	22 JULY	29 JULY	13 AUG
46	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
47	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
4a	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
43	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
50		3 JULY	22 JULY	29 JULY	[3 AUG
51	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
52	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
53	24 JUNE	3 JULY	22 JULY	29 JULY	13 AUG
54	27 JUNE				12 AUG
55	27 JUNE				12 AUG
61 (ZAPADNI)	25 JUNE	a JULY		30 JULY	14 AUG
62(VILLAGE)	29 JUNE	7 JULY		3 I JULY	15 AUG

APPENDIX 1c

Population plot sample dates on St. Paul.

PLOT	PERIOD 1	PERIOD 2
1	i 3 JULY	4 AUG
2s	13 JULY	4 AUG
2N	13 JULY	4 AUG
3	13 JULY	4 AUG
4	13 JULY	
5S	13 JULY	5 AUG
5N	13 JULY	5 AUG
6	13 JULY	5 AUG
7	13 JULY	5 AUG
8		5 AUG
9	13 JULY	5 AUG
10	?3 JULY	4 AUG
11	14 JULY	5 AUG
12	14 JULY	5 AUG
13	14 JULY	6 AUG
14	14 JULY	6 AUG
15	15 JULY	6 AUG
16	15 JULY	7 AUG
17	15 JULY	7 AUG
18	15 JULY	7 AUG
19	15 JULY	7 A M
20	15 JULY	6 AUG
21	15 JULY	6 AUG
22	14 JULY	6 AUG
23	14 JULY	6 AUG
24	14 JULY	6 AUG
25	14 JULY	6 AUG
26	14 JULY	6 AUG
27	14 JULY	6 AUG
28	14 JULY	6 AUG
29	15 JULY	6 AUG
31RIDGE WALL	16 JULY	8 AUG
ZAPADNI		7 AUG

APPENDIX 2

Information about automatic 35 mm cameras used to monitor productivity and population plots on the Pribilif Islands and at Cape Peirce during 1984.

Camera*	Lens	Film
Olympus OM-2 with 250 frame bulk film magazine and l-h timer chip	Vivitar 70-210 mm Zoom, f:4.0	EKTACHROME 200 250 frame bulk spool

Camera Locations and Dates of Operations

St. George Island, Pribilof Islands		Cape Peirce	
Location	Date	Location	Date
Zapadni (TBMU population plot)	23 June-10 Aug	VECO (COMU, BLKI population plot)	7-20 June
High Bluff 1 (RLKI population plot)	23 June-12 Aug		10-17 July
High Bluff 2 (RLKI productivity plot)	23 June-12 Aug	DUH (COMU productivity plot)	7-20 June 10-17 July
High Bluff 3 (TBMU productivity plot)	23 June-12 Aug		
Marvin Gardens (TBMU population plot)	27 duly-n Aug		
Ulukala Ridge (Least Auklet attendance)	27 July-1 Aug		

● Cameras were protected by a Plexiglas housing with a glass viewing ''port, and were mounted on aluminum base-plates anchored to the ground by poles and sand bags.

APPENDIX 3

Raw counts and trends in the seasonal abundance of seabirds on study plots at Cape Peirce.

Pelagic Cormorant

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
1	5	8	8	2	1
2	1	1	1	0	0
3	2	3	0	2	1
6	3	3	2	0	1
7	12	10	17	22	4
8	40	41	42	26	58
9	0	2	2	0	0
10	1	2	3	1	0
13	9	7	14	12	9
TOTAL	73	77	89	65	74

Glaucous-winged Gulls

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
6	0	0	11	1	4
8	0	1	5	6	10
TOTAL	0	1	16	7	14

APPENDIx 3 (cont'd)

Black-legged Kittiwakes

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
1	28	26	34	11	11
2	6	3	0	19	12
3	38	35	22	12	38
4	51	32	36	29	18
5	140	10%	64	7	41
6	25	5	4	8	15
7	71	55	47	15	37
8	695	490	47 1	195	350
9	121	77	83	33	57
10	71	10	9	4	0
11	303	198	176	119	24
12	208	152	93	93	40
13	77	43	53	35	13
TOTAL	1834	1234	1092	585	656

Common Murres

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIC415
1	14	18	25	18	25
2	25	21	18	35	26
3	6	0	32	0	106
4	215	181	217	170	161
s	372	3%7	366	249	356
6	6	2	0	o	0
7	1%7	188	125	116	145
8	3591	3240	2801	236%	2539
9	428	486	607	337	374
10	32	%3	90	29	19
11	298	327	302	244	263
12	247	276	275	264	16Q
13	150	201	150	151	124
TOTAL	5s71	5410	5008	3981	4307

APPENDIX 3 (cent'd]

Horned Puffins

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
1	1	1	0	0	2
2	1	0	0	0	0
3	0	7	0	0	1
4	4	18	2	2	4
5	5	7	8	6	9
7	0	0	0	0	2
8	0	0	0	1	0
12	3	0	0	0	0
TOTAL	14	33	10	9	18

Tufted Puffins

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5
3	0	0	0	2	0
4	1	4	0	3	4
8	0	0	0	2	1
9	0	0	5	0	0
12	0	0	0	1	0
TOTAL	- i -	4	5	8	5

APPENDIX 4

Raw counts of seabirds recorded during plot censuses on St. George Island.

Northern Fulmar

STRATUM - 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PER1054	PERIOD 5	MEAN 2-4
5	13					
7	94					
8	38	27		19	47	23
9	39	43		14	61	29
10	17	25		21	58	23
12	19	7		3	15	5
13	10	8		11	16	10
14	7	4		6	21	5
15	10	23		25	33	24
17	19	12		19	29	16
18	2	1		4	13	3
19	4	6		7	10	7
24	28	13		18	20	16
26	0	1			4	1
32	39	29			16	29
35	76	55			125	55
37	8	12			14	12
38	31	13			7	13
45		16	5	3	2	8
46	0	2	5	3	2	3
47	16	6	3	14	32	8
48	5	11	4	12	31	9
51	8	8	3	4	13	5
52	6	10	2	1	14	4
53	0	0	0	0	1	0
61	3	1		5	12	3

APPENDIX 4 (**cont'd)**

Northern Fulmar (cont'd)

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
STRATUM -2						
2	1	4			5	4
23	102	86		109	124	98
24	34	45		46	87	46
25	50	36		45	55	41
27	65	123			83	123
28	99	42			110	42
29	50	27			62	27
30	56	99			89	99
31	3	5			13	5
32	20	12			34	12
33	61	59			32	59
35	30	46			51	46
36	46	27				27
37	10	11			19	11
38	17	12			17	12
39	46	79			117	79
STRATUM - 3						
1	2	4			2	4
STRATUM- 5						
44	1	0			0	0
55	17				35	"

APPENDIX 4 **(cont'd)**

Red-faced Cormorants

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
13	0	0		0	1	0
14	0	0		1	1	1
15	0	1		0	0	1
16	0	0		0	1	0
17	1	0		0	3	0
18	0	0		1	0	1
19	1	0		0	0	0
20	0	0		0	4	0
26	2	3			1	3
37	0	1			0	1
33	6	0			1	0
45		0	1	0	0	0
47	0	1	1	1	1	1
40	3	6	3	3	1	4
49	1	0	0	0	0	0
52	0	1	1	0	0	1
53	0	0	0	0	1	0
61	3	5		2	10	4
62	1	0		0	0	0
STRATUM- 2						
36	0	2				2
37	1	1			0	1
33	0	0			0	0

APPENDIX 4 (cent'd)

Black-legged Kittiwakes

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
5	7					
6	13					
7	2					
8	3	1		4	3	3
9	16	7		5	24	6
10	4	0		3	2	2
11	4	0		1	3	1
12	2	3		1	4	2
13	0	0		1	1	1
14	3	0		3	2	2
15	0	3		1	8	2
16	1	0		2	2	1
17	1	1		2	2	2
18	1	0		3	2	2
19	15	5		14	14	10
26	1	0			4	0
32	0	0			1	0
35	3	1			4	1
37	0	8			8	8
33	0	0			2	0
45		10	5	4	10	6
46	31	24	24	45	50	31
47	18	8	9	14	20	10
43	12	12	26	25	17	21
49	1	1	2	2	3	2
50			0	0	2	0
51	33	17	29	30	40	25
52	59	26	58	88	80	57
53	32	39	42	42	59	41
61	29	15		43	39	29
62	31	21		49	50	35

APPENDIX 4 (control)

Black-1egged **Kittiwakes (cont'd)**

STRATUM -2						
PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
21	1	0		1	0	1
23	“ 4	0		7	2	4
24	14	21		23	0	22
25	17	13		14	14	14
27	9	25			32	25
23	4	16			22	16
29	5	5			7	5
30	19	3			9	3
31	0	1			1	1
32	0	4			5	4
33	16	12			10	12
3'3	11	10			31	10
36	0	1				1
37	0	5			13	5
39	48	29			89	29
STRATUM- 3						
1	23	8			16	8
40	3	4			3	4
STRATUM - 4						
41	24				31	
STRATUM - 5						
42	0	0			1	0
43	3	4			3	4
44	4				0	
55	4				2	

APPENDIX 4 (cont'd)

Red-legged **Kittiwakes**

STRATUM - 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
6	32					
7	9					
9	8	7		6	12	7
10	1	3		0	2	2
14	o	0		1	2	1
15	11	5		9	13	7
16	0	0		1	1	1
17	1	0		2	1	1
19	3	o		0	0	0
32	9	7			19	7
35	21	0			2	0
37	17	11			19	11
33	3	2			8	2
45		3	13	1	1	6
46	0	1	5	4	3	3
47	4	15	22	23	22	20
48	0	4	0	1	2	2
49	6	13	13	7	5	11
50		2	5	5	9	4
51	9	14	17	34	23	22
52	1	8	6	10	7	8
53	40	44	68	69	66	60
61	14	30		26	15	28
62	56	61		98	132	80

STRATUM - 2

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
2	6	4			9	4
23	12	13		25	9	19
24	0	0		3	35	2
25	1	0		0	0	0
27	31	48			87	48
28	30	17			48	17
29	4	1			8	1
30	0	5			5	5
32	0	3			4	3
33	203	141			315	141
34	1	0			1	0
35	14	6			20	6
36	28	8				8
37	42	16			14	16
38	35	8			*44*	8
39	18	53	"		*66*	53

APPENDIX 4 **(cont'd)**

Red-legged **Kittiwakes (cont'd)**

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERN304	PERIOD 5	MEAN 2-4
STRATUM - 3						
1	33	40			52	40
40	127	110			138	110
STRATUM- 4						
41	279				451	
STRATUM - 5						
42	163	149			268	149
43	470	412			588	412
44	444				493	
54	263				268	
55	218				369	

l’hick-bi~led **Murres**

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
5	174					
6	258					
7	140					
8	220	186		210	239	198
9	259	308		227	370	268
10	340	286		314	373	300
11	62	82		105	97	94
12	123	84		151	179	118
13	96	98		125	111	112
14	87	162		120	130	141
15	88	107		111	124	109
16	143	111		107	131	109
17	124	102		119	118	111
18	54	82		68	91	75
19	132	98		111	131	105
20	27	44		31	44	38
24	192	461		504	342	483
26	58	127			127	127
32	163	166			148	166
3s	288	263			184	263
37	166	244			141	244
38	559	424			411	424
45		94	336	145	190	192
46	193	158	265	241	268	221
47	140	93	143	117	99	118
48	184	148	254	296	291	233
49	17	6	7	8	9	7
50		3	4	2	0	3
51	77	40	77	79	80	65
52	67	61	79	80	61	73
53	74	98	109	111	127	106
61	175	395		288	480	342
62	49	64		137	136	101

APPENDIX 4 (cent'd)

Thick-billed **Murres (cont'd)**

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
STRATUM- 2						
2	369	224			445	224
21	22	94		73	84	84
22	45	121		120	156	121
23	85	246		205	246	226
24	330	646		463	830	555
25	215	496		534	539	515
27	178	866			654	866
28	522	548			681	548
29	465	515			637	515
30	562	377			601	377
31	132	157			126	157
32	219	190			155	190
33	858	1251			959	1251
34	68	65			64	65
35	108	265			84	265
36	269	236				236
37	325	368			231	363
38	115	117			127	117
39	367	320			503	320
STRATUM- 3						
1	143	89			243	89
40	120	69			107	69
STRATUM- 4						
41	1588				1756	
STRATUM- 5						
42	156	105			131	105
43	201	173			142	173
44	264				135	
54	186				186	
55	337				384	

APPENDIX 4 (cent'd)

Parakeet **Auklets**

STRATUM -,1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
5	19					
6	12					
7	14					
8	13	2		0	0	1
9	11	1		0	0	1
10	1	0		0	0	0
11	8	3		0	5	2
13	0	2		0	0	1
14	1	?		i	0	4
1s	0	8		0	0	4
16	0	6		0	0	3
17	0	7		0	Q	4
18	0	16		0	0	8
19	0	26		2	1	14
24	8	6		0	0	3
26	7	3			0	3
32	0	5			0	5
35	10	1			0	1
37	5	10			0	10
33	24	28			0	28
45		10	1	0	1	4
46	10	0	0	0	0	0
47	2	8	0	0	1	3
48	8	0	0	3	0	1
50		0	0	1	0	0
51	2	2	1	2	0	2
53	2	0	0	0	0	0
61	0	195		16	2	106
62	29	19		23	0	21

APPENDIX 4 (cent'd)

Parakeet **Auklets** (cent'd)

STRATUM- 2

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PER1OD 5	
22	0	9		0	0	5
23	11	4		0	0	2
24	22	28		2	0	15
25	28	21		5	0	13
27	31	7			1	7
28	0	16			0	16
29	0	37			0	37
30	0	10			1	10
31	0	2			0	2
32	0	7			0	7
33	6	31			0	31
34	3	12			0	12
35	2	0			0	0
36	7	11				11
37	10	9			0	9
33	12	5			2	5
39	0	15			1	15
STRATUM- 3						
1	0	0			2	0
STRATUM- 5						
43	0	1			0	1
55	6				0	

APPENDIX 4 (cont'd)

Crested Auklets

STRATUM - 1 PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	Mean (Periods 2-4)
5	4					
7	2					
8	5	0		0	0	0
10	1	0		0	0	0
35	15	o			0	0
38	23	0			0	0
48	0	0	0	1	o	0
51	0	4	0	Q	o	1
STRATUM - 2						
24	I	a		0	0	4
25	8	o		0	0	0
28	o	12			0	12
29	0	19			0	19
30	o	2			0	2
31	0	4			0	4
32	0	7			0	7
37	I	0			#	0
3a	o	9			0	9
39	0	4			0	4

APPENDIX 4 (cent'd)

Least Auklets

STRATUM- 1

PLOT	PERIOD 1	PEIW3112	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
5	39					
6	17					
7	32					
8	18	0		0	0	0
9	9	0		0	0	0
10	10	0		0	0	0
15	0	4		0	0	2
17	0	9		0	0	5
18	0	17		0	0	9
19	0	17		0	0	3
24	17	3		0	0	2
32	0	10			0	10
35	1	0			0	0
37	2	3			0	3
38	63	29			0	29
45		9	0	1	0	3
46	2	0	0	I	0	#
47	5	5	0	0	0	2
43	5	0	0	0	0	0
51	10	3	0	0	0	1
53	1	0	0	0	0	0
61	0	327		4	1	166
62	14	3		0	0	2

STRATUM- 2

PLOT	PERIOD 1	PEIW3112	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
22	0	5		0	0	3
23	3	0		0	0	0
24	38	4		0	0	2
25	57	2		0	0	1
27	22	10			0	10
23	0	93			o	93
29	0	64			0	64
30	0	46			0	46
31	0	4			0	4
32	0	14			0	14
36	3	6				6
37	3	2			0	2
38	0	1			0	1
39	0	15			0	15

STRATUM- 5

PLOT	PERIOD 1	PEIW3112	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
55	I				o	

APPENDIX 4 (cont'd)

Horned Puffins

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
5	3					
7	6					
8	13	12		12	16	12
9	11	9		5	6	7
10	s	5		4	1	5
11	0	2		0	2	1
12	#	0		3	2	2
13	3	0		2	4	1
14	3	5		9	6	7
15	12	5		11	7	8
16	0	3		5	0	4
17	2	5		11	2	8
1%	3	2		10	2	6
19	15	2		12	4	7
20	0	2		6	3	4
24	13	11		0	9	6
32	1	1			2	1
35	2	20			30	20
37	1	0			3	0
38	15	6			4	6
45		0	7	1	5	3
46	1	0	1	0	1	0
47	4“	1	0	6	4	2
48	3	0	2	11	4	4
51	7	0	1	8	2	3
52	0	0	0	0	1	0
53	2	0	1	0	4	0
61	5	14		21	20	18
62	2	8		7	3	8

APPENDIX 4 (cent'd)

Horned Puffins (control)

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
STRATUM - 2						
2	0	0			2	0
22	0	1		1	1	1
23	0	5		3	12	4
24	3	17		2	16	0
25	1	17		11	17	4
27	4	7			5	7
28	12	14			23	4
29	20	11			17	1
30	7	8			11	8
31	2	5			0	5
32	4	3			3	3
33	3	6			9	6
34	3	2			1	2
35	0	0			1	0
36	3	0				0
37	0	7			9	7
38	1	2			6	2
39	40	18			53	18
STRATUM- 3						
1	0	0			1	
STRATUM - 4						
41	1				0	
STRATUM - 5						
55	1				2	

APPENDIX 4 (cent'd)

Tufted Puffins

STRATUM - 1

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
6	1					
7	1					
8	0	0		1	0	1
10	0	0		1	0	1
14	3	1		5	0	3
15	2	1		4	0	3
16	1	0		1	0	1
17	2	0		4	o	2
20	1	0		0	0	0
24	0	1		0	1	1
26	1	0			1	0
35	9	14			4	14
38	2	1			0	1
45		0	1	0	1	0
43	1	0	2	0	1	1
50		0	0	0	1	0
51	2	0	2	2	0	1
52	1	1	0	0	0	0
61	0	3		3	2	3
62	3	6		0	0	3

STRATUM 2

PLOT	PERIOD 1	PERIOD 2	PERIOD 3	PERIOD 4	PERIOD 5	MEAN 2-4
24	1	2		2	3	2
25	1	2		6	0	4
27	2	4			0	4
28	2	3			1	3
29	4	3			0	3
30	9	1			0	1
32	4	4			1	4
39	0	1			0	1

APPENDIX 5

Number of 'nests" (kittiwakes in incubation posture) recorded on St. George Island study plots during 1984. The date and/or accuracy of counts varied markedly among plots; hence these values should be interpreted as minimum estimates.

PLOT	RED-FACED CORMORANT	BLACK-LEGGED KITTIWAKE	RED-LEGGED KITTIWAKE
1	0	2	11
2	0	0	1
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	3	4
10	0	0	1
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	2	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	11
24	0	8	0
25	0	9	0
26	0	0	0
27	0	13	33
28	0	4	10
29	0	1	0
30	0	2	3
31	0	0	0
32	0	3	6
33	0	0	0
34	0	0	0
35	0	5	0
36	0	1	2
37	1	1	1
38	0	0	4
39	0	3	2
40	0	0	1
41	0	1	4
42	0	0	8
43	0	0	21
44	0	0	6
45	0	3	1
46	0	0	0
47	1	7	1
48	0	1	0
49	0	1	0
50	0	0	1
51	0	1	2
52	0	0	0
53	0	0	2
54	0	0	4
55	0	0	0
56	0	0	0
57	0	0	0
58	0	0	0
59	0	0	0
60	0	0	0
61	0	4	2
62	0	3	27
63	0	0	0
64	0	0	0
65	0	0	0
66	0	0	0
67	0	0	0
68	0	0	0
69	0	0	0
70	0	0	0
Total	2	78	169

APPENDIX 6

Raw counts of seabirds censused on study plots on St. Paul Island, Alaska.

Northern Fulmar

STRATUM - 1		
PLOT	PERIOD 1	PERIOD 2
5S	1	1
9	3	4
10	1	4
15	2	5
16	3	3
17	0	1
19	1	5
22	10	32
23	4	15
31	41	44
32		3
Subtotal	66	117
STRATUM -2		
14	3	9
21	8	29
23	4	5
29	11	22
Subtotal	26	65
TOTAL	92	182

APPENDIX 6 (control)

Red-faced Cormorants

PLOT	PERIOD 1	PERIOD 2
STRATUM - 1		
1	1	10
2s	1	2
3	0	1
5s	6	0
6	1	0
7	1	0
9	1	0
10	2	3
15	3	0
18	2	0
31	1	6
32		73
Subtotal	18	22
STRATUM- 2		
12	15	2
13	3	0
14	1	0
21	0	1
22	1	0
27	0	1
28	2	0
Subtotal	22	4
TOTAL	4	26

APPENDIX 6 (cent’d)

Black-1egged Kittiwakes

STRATUM- 1		
PLOT	PERIOD 1	PERIOD 2
1	7a	92
2S	50	72
2N	36	48
3	48	71
4	13	
5s	128	159
5N	14	16
6	13	20
7	36	64
8		24
9	53	75
10	62	45
15	84	81
16	24	37
17	5	9
18	14	23
19	27	32
20	14	21
22	14	33
23	21	50
31	620	761
32		519
Subtotal	1328	1689
STRATUM- 2		
11	5	19
12	64	141
13	32	4a
14	13	36
21	21	28
22	34	92
23	32	40
24	46	69
25	24	2%
26	19	52
27	25	51
28	13	28
29	11	20
Subtotal	339	652
TOTAL	1667	2341

APPENDIX 6 (cent’ d)

Red-legged **Kittiwakes**

PLOT	PERIOD 1	PERIOD 2
STRATUM - 1		
1	4	8
5S	1	0
7	2	1
9	1	9
15	2	5
16	0	1
18	3	5
22	4	11
23	7	10
31	23	27
32		5
Subtotal	47	77
STRATUM- 2		
12	4	8
13	9	10
14	3	5
21	2	1
22	1	2
23	5	4
24	32	48
25	2	2
26	5	3
27	43	44
2%	4	6
Subtotal	110	133
TOTAL	157	210

APPENDIX 6 (cent 'd)

Common Murres

PLOT	PERIOD 1	PERIOD 2
STRATUM - 1		
1	23	59
3	12	65
5S	8	15
7	1	2
8		2
9	76	116
10	268	394
15	4	2
16	20	22
17	0	1
18	18	15
19	92	107
23	12	8
31	426	502
32		567
Subtotal	962	1308
STRATUM - 2		
13	3	0
14	29	23
25	35	3%
Subtotal	67	61
TOTAL	1029	1369

APPENDIX 6 (cent' d)

Thick-billed **Murres**

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2
1	35	36
2S	31	38
3	88	136
'4	59	
5S	21s	347
5N	37	37
6	43	25
7	77	126
8		130
9	137	175
10	231	310
15	196	263
16	123	94
17	72	76
18	159	151
19	91	134
20	68	8%
22	195	275
23	402	527
31	2040	2058
32		1891
subtotal ,	4197	4571

STRATUM- 2

11	38	51
12	97	102
13	157	199
14	289	342
21	81	79
22	152	189
23	·109	122
24	94	110
25	74	74
26	232	204
27	1	4
28	151	238
29	247	300
subtotal	1722	2014
TOTAL:	5919	6885

APPENDIX 6 (cent 'd)

Parakeet **Auklets**

STRATUM- 1

PLOT	PERIOD 1	PERIOD 2
5S	2	1
5N	2	0
6	2	0
16	3	0
17	1	0
18	9	1
22	0	2
23	1	3
31	95	62
32		5
Subtotal	113	69

STRATUM - 2

PLOT	PERIOD 1	PERIOD 2
12	1	3
13	1	0
21	0	4
23	0	1
28	3	0
29	2	3
Subtotal	7	11
TOTAL	120	80

APPENDIX 6 (cent'd)

Least Auklets

STRATUM - 1		
PLOT	PERIOD 1	PERIOD 2
5s	27	0
7	1	0
9	1	0
10	1	0
16	6	0
18	5	0
19	3	0
20	0	1
31	139	2
Subtotal	183	3
STRATUM- 2		
13	1	0
14	1	0
21	3	1
29	3	0
subtotal	8	1
TOTAL	191	4

APPENDIX" 6 (cent' d)

Horned Puffins

STRATUM- 1		
PLOT	PERIOD 1	PERIOD 2
3	2	0
4	1	
5S	7	10
5N	2	2
8		10
9	3	6
10	1	2
15	2	8
16	1	3
17	0	2
18	4	0
19	5	2
20	2	1
22	2	5
23	10	2
31	120	120
32		97
Subtotal	161	163
STRATUM- 2		
12	1	1
13	1	2
14	4	9
21	2	6
22	0	1
26	0	1
28	2	1
29	3	6
Subtotal	13	27
TOTAL	174	1'30

APPENDIX 7

Number of “nests” (kittiwakes in incubation posture) recorded on St. Paul Island study plot during 1984. The date and/or accuracy of counts varied markedly among plots; hence these values should be interpreted as minimum estimates.

PLOT	RED-FACED CORMORANT	BLACK-LEGGED KITTIWAKE	RED-LEGGED KITTIWAKE
1	0	18	1
2S	o	6	0
2N	o	7	0
3	0	8	0
4	0	3	0
5S	1	22	0
5N	o	6	0
6	0	3	0
7	0	3	1
9	1	4	0
11	0	3	0
12	7	11	1
13	0	12	3
14	0	7	1
15	0	20	0
16	0	8	0
17	0	1	0
18	1	2	1
19	0	5	0
20	0	6	0
21	0	8	2
22	1	10	2
23	0	14	1
24	0	11	8
25	0	5	1
26	0	4	?
27	0	7	4
28	0	2	1
29	0	5	.,0
31	0	155	9“
32	0	32	1
TOTAL	11	408	38

CHAPTER III

PRODUCTIVITY STUDIES*

By

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* Johnson, S.R. and J.S. Baker. 1985. Chapter III. Productivity Studies. Pages 191 to 256. In: S.R. Johnson (Ed.). Population Estimation, Productivity, and Food Habits of Nesting Seabirds at Cape Peirce and the Pribilof Islands, Bering Sea, Alaska. Report by LGL Ecological Research Associates, Inc. to Minerals Management Service, Anchorage, Alaska. 330 p.

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INTRODUCTION

Productivity of seabirds appears to be sensitive to environmental changes, such as disturbance or prey availability that might be caused by OCS development activities. Because of this, and because productivity has a major influence on subsequent population levels of seabirds, it is an important factor to consider in seabird monitoring programs. .

Changes in productivity over a period of years may be a percursor of subsequent changes in colony size, and thus monitoring of production rates could provide an early warning of development-caused reductions in seabird numbers. However, there are substantial natural variations in production from year to year and these could easily mask man-caused reductions observed in single-year studies. Very long time-series of data are necessary to filter out the noise of natural variability and to allow the detection of changes in productivity that might be caused by OCS development or other external factors. Productivity data are probably of most use in the interpretation of later changes in the observed sizes of colonies; they are probably of limited use as an early-warning signal unless catastrophic changes occur.

METHODS

General Definitions and Procedures

The term 'avian productivity has become ambiguous. Interpretations of the term range from (1) the average number of large chicks produced per nest that had eggs, to (2) the average number of large chicks per nest alive at the end of the study, regardless of whether or not eggs were laid. Two useful measures of productivity are the number of fledglings produced per pair of birds having laid eggs (i.e., per 'breeding' pair), and the number of fledglings produced for the colony as a whole. The latter is the more useful measure; it could be estimated from the former, given an accurate estimate of colony size.

Productivity in this study has been defined as the mean number of chicks per nest (or site, in the case of murres) still alive in study plots at the termination of field investigations. Only completed nest platforms were considered kittiwake 'nests'; only sites where murre eggs were seen were considered murre 'nests'. Because fledging occured over a six- to eight-week period (when all potential species in the colonies were considered), it was not possible within the time constraints of this project, to measure total numbers of chicks that fledged.

We used different subsets of our data to calculate more than one value of murre productivity. Analysis of one subset conformed to procedures adopted by others studying murres at these locations in the past, thereby making our values comparable to theirs. Analysis of other subsets provided what we feel are more accurate estimates of productivity. It is difficult to accurately evaluate the productivity of murres, partly because they do not construct traditional nests. Many workers (see Hunt et al. 1981) have used the average number of adult murres present on study plots as an estimator of the actual number of nests or nesting pairs present, because it is always difficult to determine the precise number of murre eggs or chicks present. Inevitably, some eggs (or chicks) appear in the plot late in the study; such eggs could be late first-eggs or replacements for those lost earlier. Late-appearing chicks at sites where no eggs were seen pose a more difficult problem; if these are included in the counts of chicks that hatched, then hatching success and productivity estimates are biased upward. Whereas, if they are ignored, estimates are biased downward. In this study, we have considered several measures in our estimates of murre productivity; breeding performance and productivity tables give several estimates based on the different measures. Footnotes on tables provide details of calculations.

Reproductive success (number chicks alive/number eggs laid) was computed for murres and black-legged kittiwakes for comparison with earlier studies (murres) and to satisfy assumptions of binomiality (kittiwakes) for Likelihood Ratio Tests (see discussion below and Appendix 7).

Statistical Methods

One of our major goals in this project was to produce statistically valid estimates of productivity or reproductive success (means with 95% confidence intervals) using stratified ratio procedures outlined in

Cochran (1977:164-169). However, this approach was inappropriate because there was zero productivity in a large number of individual study plots. Instead, the following more appropriate and reliable procedure was used to determine productivity (or reproductive success) and to derive confidence intervals:

P (proportion) = x/n,

where x = # eggs hatched, or the # young fledged, and

n = # of nests, breeding sites, or the # of eggs laid.

100 $(1-\alpha)$%C.I. for $\hat{P}$ is givenby

$$\hat{P} \pm Z_{\alpha/2}\sqrt{\frac{\hat{P}\hat{q}}{n}}$$

where $\alpha/2$ is the upper percentile of a normal distribution*

Likelihood Ratio Tests (Rao 1975) were used to determine whether there were significant differences in productivity (or reproductive success) among years, and among different strata and different plots for each key species nesting on St. George and St. Paul islands and at Cape Peirce. Bonferroni Multiple Comparisons (Graybill 1976) were used to determine which productivity values (which years) were different from each other.

We attempted to produce an estimate of the number of active common murre nest sites by conducting a detailed computer analysis of digitized data from the DUH productivity plot at Cape Peirce. The location of each common murre in each frame of 35 mm film exposed by an automatic camera at this plot was digitized using an Apple II micro-computer, a Hi-Pad digitizer and computer software developed by LGL. The procedures used in this analysis are described in Appendix 1.

Field Methods

Pribilof Islands

Thirteen productivity plots were established at the Pribilof Islands in 1984--6 on St. Paul and 7 On St. George (Fig. 1). The 6 productivity plots on St. Paul had been previously established (and documented with photographs) by Hunt et al. (1981) during the mid to late 1970's. The 7 productivity plots on St. George were new ones established by us in 1984. The intensity of sampling and the principal species present (common and thick-billed murres, black-legged and red-legged kittiwake) in each productivity plot at the Pribilofs are summarized in Tables 1 and 2.

The census of each plot was conducted from the same observation point on each visit. The locations of' all observation points at Cape Peirce were marked with wooden stakes or l-m aluminum poles. Observation points on St. Paul were identical to those used by Hunt's observers.

Productivity plots were censused throughout the day (0740-2300 h YDT). The single observer was not concealed and made observations over distances of 3-30 m. On the initial visit to a plot, a sketch map was drawn; during this and all subsequent visits the locations of kittiwake nests and murre sites were confirmed with respect to their locations on the sketch map or added to it. The amount of time spent at a productivity plot was dependent on 1) the weather conditions during the census period (frequently poor to impossible; for a summary, see Appendix 2), 2) the behavior of the birds being watched, 3) other work demands and 4) the number of birds present on the plot. The average time spent watching productivity plotsat St. Paul was 1.1 ± 0.3 h (n=14 timed watches); the average time at St. George was 0.5 ± 0.4 h (n=37). Each productivity plot was photographed to provide documentation of the area being censused.

Cape Peirce

Constraints on the total number of days available for study at Cape Peirce in 1984 were principally budgetary. The timing of the two study periods (6-21 June, 10-17 July) coincided with the average laying and hatching dates of the principal species nesting at the colony; these dates

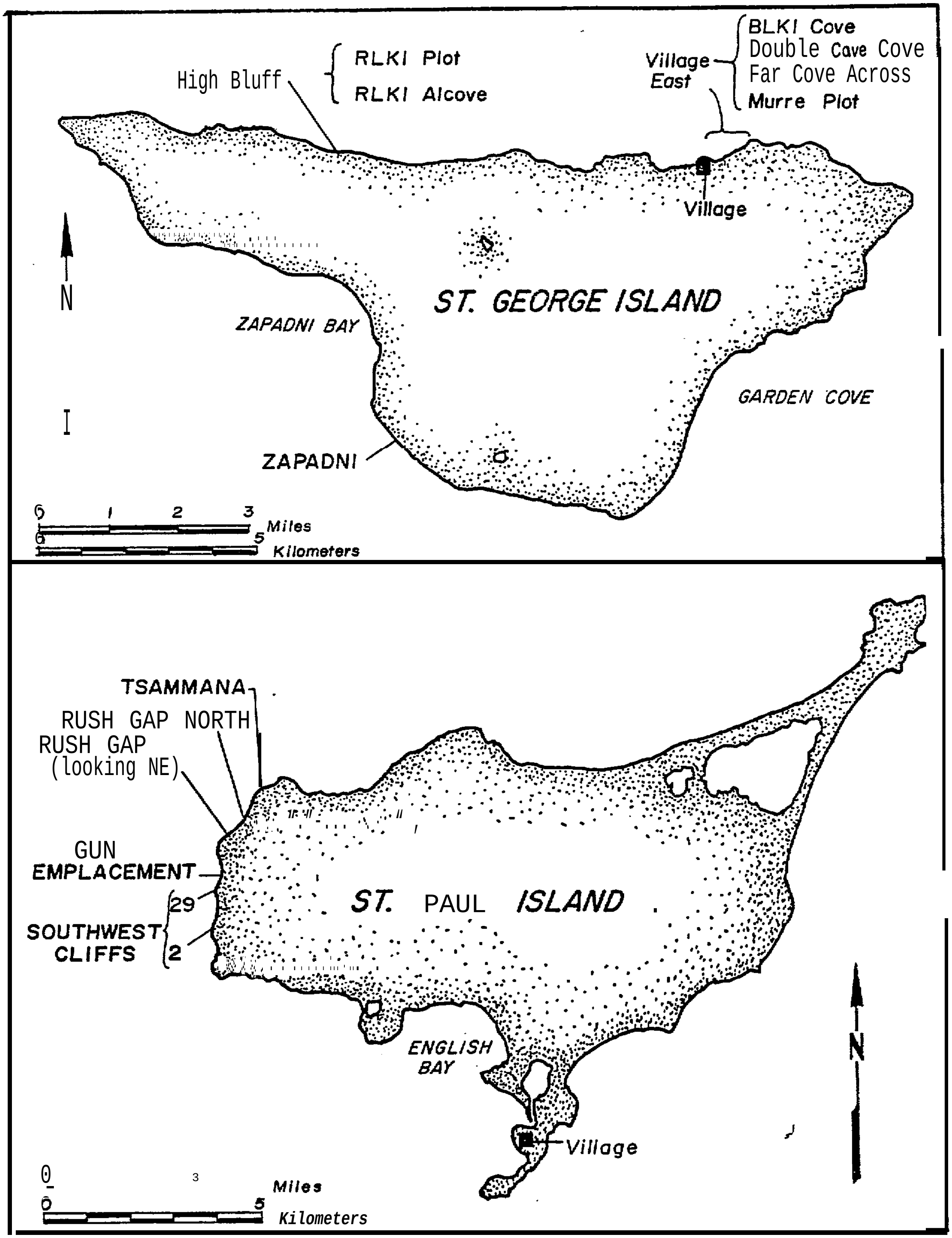

Figure .1. Locations of productivity plots on St. George and St. Paul islands, Bering Sea, Alaska.

Table 1. Sampling schedule of principal species of seabirds nesting on productivity plots on St. George Island, Pribilof Islands, Alaska, June-August, 1984.

Name of Plot	Principal Species Sampled	Sampling Dates June	July	August
Zapadni (2)	TBMU	27	3, 10, 11, 19 25, 29	12
Village East Murre Plot (1)	TBMU, BLKI RLKI	25	3, 7, 10, 23 25, 29, 31	10, 13
Village East BLKI Cove (1)	BLKI, TBMU, RLKI	26	5, 7, 13, 22 24, 29, 31	10
Village East (1) Far Cove Across	BLKI, RLKI	26, 30	7, 13, 22, 25 29	11
Village East (1) Double Cave Cove	RLKI, BLKI	26, 30	7, 13, 22, 25 29	11
High Bluff RLKI Plot (5)	RLKI, BLKI		11, 20, 26	12
High Bluff (5) RLKI Alcove	RLKI		12, 20, 26	1, 12

Numbers in parentheses represent the elevational stratum for each plot.

Table 2. Sampling schedule of principal species of seabirds nesting on productivity plots on St. Paul Island, Pribilof Islands, Alaska, July-August, 1984.

Name Of Plot	Principal Species Sampled	Sampling Dates	
		July	August
Tsammana (1)	BLKI, RLKI	14, 15	4
Rush Gap North (2)	TBMU, BLKI	14, 15	4, 5
Rush Gap-Looking Northeast (2)	TBMU, BLKI	15	4, 7
Gun Emplacement (2)	RLKI, BLKI, TBMU	14, 15	4
Southwest-29 (2)	TBMU, BLKI, RLKI	15, 16	4,6
Southwest-2 (1)	TBMU	15, 16	4, 5, 6

Numbers in parentheses represent the elevational stratum for each plot.

were determined through a review of the available literature. No provision was made for a third visit to the colony during the fledging period. Field studies commenced on 6 June, were interrupted from 21 June to 10 July, and ended on 17 July.

Of the 8 productivity plots established at Cape Peirce in 1984, 4 were originally established (and documented with photographs) by Petersen and Sigman (1977) in 1976, another 1 was originally established and documented by Lloyd (D. Lloyd, unpub. data) in 1981, and three new plots were established by us in 1984 (Fig. 2, Tables 3 and 4). Our sampling procedures on the 8 productivity plots followed methods described by Birkhead (1974) for common murres and by Nettleship (1976) for black-legged kittiwakes (Type I censuses; Birkhead and Nettleship 1980). The intensity of sampling and the principal species present (common murre and black-legged kittiwake) in each productivity plot at Cape Peirce are summarized in Table 4.

The census of each plot was conducted from the same observation point on each visit. For future reference, the locations of all observation points were marked in the field with a 1-m aluminum pole. Many of these locations correspond to locations originally marked with wooden stakes by Petersen and Sigman (1977).

Productivity plots were censused in the afternoon or evening (1400-2400 h ADT), after population plots had been censused. Common murre productivity plots were censused in the late evening (1’700-2400) when the number of murres present (especially during June) appeared to be lowest (Table 5).

Table 5. Numbers of common murres present in two productivity plots at Cape Peirce in June and July, 1984.

Plot	Date	Hours (Alaska Daylight Time)				
		1900	2000	2100	2200	2300
DUH	14 June	255	254	215	191	158
	12 July	172	180	170	164	-
HOKN	12 June	185	171	149	131	59
	11 July	206	198	203	201.	-

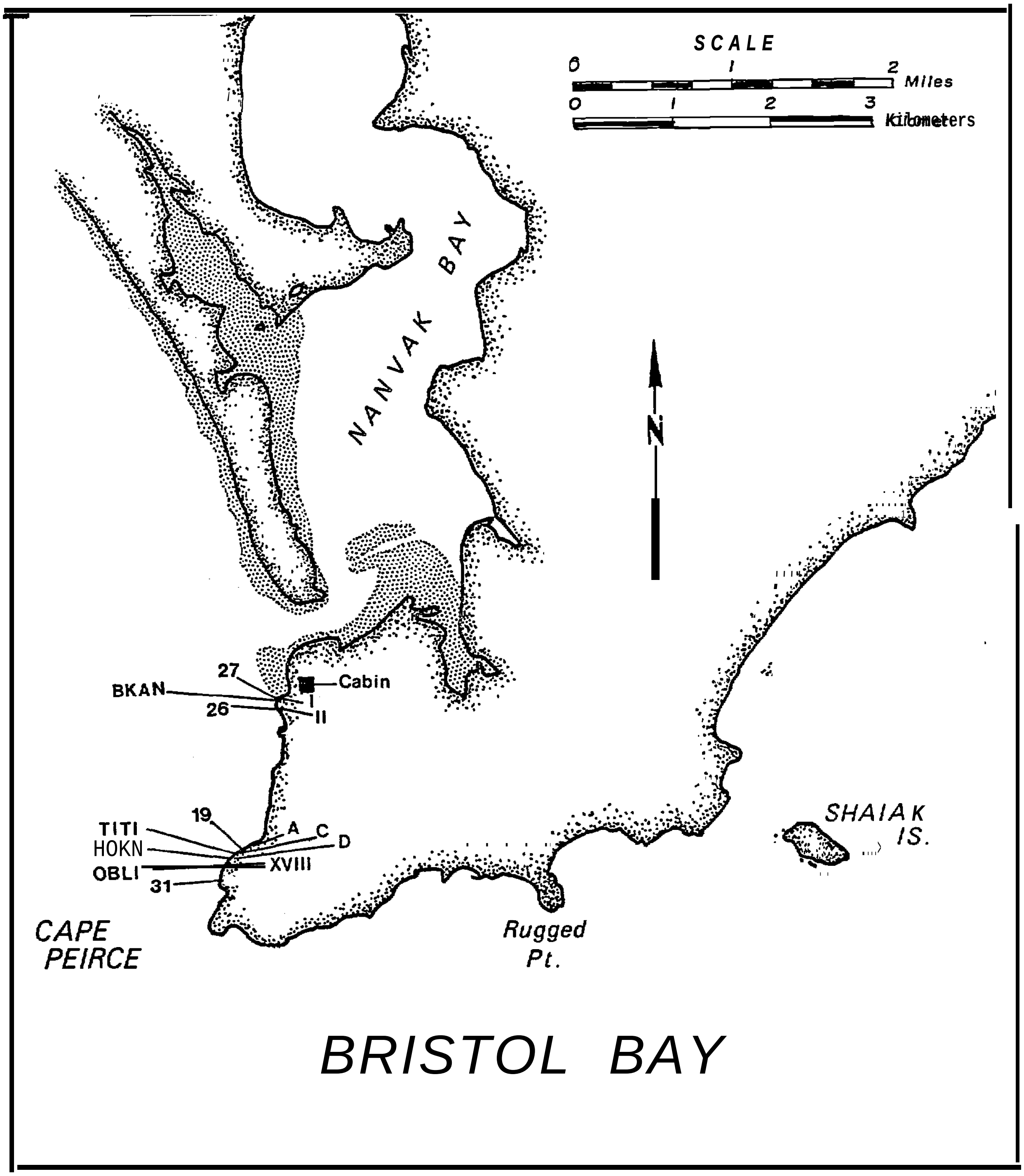

Figure 2. Locations of productivity study plots (27, BKAN, 26,...) and observation sites (I, II, A, ...) at Cape Peirce, Alaska.

Table 3. Identifications of productivity plots investigated during studies of seabirds at Cape Peirce, Alaska, during 1984, with synonyms used during earlier studies.

Plot (Colony) Name		
1984 (This Study)	1981 (D. Lloyd, unpub. Data)	1976 (Petersen and Sigman 1977)
DUH*	DUH	Colony 19, subcolony 3
SPEC		Colony 31
LKA	LKA	Colony 27
BKAS	BKAS	Colony 26
BKAN	BKAN	
HOKN		
TITI		
OBLI	-	-

*This plot was photographed hourly using a 35 mm time-lapse camera.

Table 4. Sampling schedule of principal species of seabirds nesting on productivity plots at Cape **Peirce,** Alaska, June-July, 1984.

Name of Plot	Principal Species Sampled	Sampling Dates June	Sampling Dates July	Observation Site
DUH	COMU, BLKI	9, 14, 17, 7-20*	2+, 12, 15; 10-I7*	A
SPEC (l-4)	COMU, BLKI	11-12, 14-15, 7, 26+	1+, 10, 13, 16	XVIII
LKA	BLKI	10, 13, 18, 23+	1+, 11, 15	I
BKAS	BLKI	13, 16, 18, 23+	1+, 12, 15	II
BKAN	BLKI, COMU	13, 16, 18, 23+	1+, 12, 15	I
HOKN	COMU, BLKI	12, 16, 18	11, 14, 16	c
TITI	BLKI	12, 16, 18	11, 14	C
OBLI	BLKI	12-13, 15, 18	11, 14	D

*35-mm time-lapse cameras continuously sampled (hourly) during these 14- and 8-day periods, respectively.

‘Sampling on these dates was conducted by USFWS personnel.

Observers at production plots were not concealed; the average distance over which observations were made varied from about 5-15 m. On the initial visit to a plot, a sketch map of it was drawn; during this initial visit, and all subsequent visits, the locations and contents of kittiwake nests and murre egg sites were numbered and marked on the sketch map (or a copy of it). Much effort was expended during each visit to determine the contents of black-legged kittiwake nests, and the presence of eggs on ledges occupied by common murres. The amount of time spent by an observer at a productivity plot was dependent on 1) the species being watched, 2) the amount of help available to watch the plot, 3) the weather conditions during the census period (see Appendix 3 for a summary of the Cape Peirce weather during June and July), and the behavior of the birds being watched. Some censuses required less than an hour, others required 5 or 6 hours. The average time spent watching at common murre productivity plots at Cape Peirce was 3.6 ± 0.5 h (n = 20 watches); the average time spent watching at black-legged kittiwake plots was 2.2 ± 1.3 h(n= 20 watches). No cormorants were present on most productivity plots at Cape Peirce, therefore they have not been considered in this chapter. An attempt was made during each census of a productivity plot to count all adult murres and kittiwakes present at the beginning of each hour of observation. Each productivity plot was photographed several times during the June and July study periods to provide documentation of the area being censused and the overall distribution of birds and nests/sites on each plot.

An inventory (visual estimates of numbers of birds present) of the entire Cape Peirce and Shaiak Island seabird colonies was conducted from a boat during a period of calm seas on 10 June; also on this date, 35 mm color photographs were taken of the entire mainland portion of the Cape Peirce seabird colony.

RESULTS

The results of Likelihood Ratio Tests indicated no significant differences in 1984 estimates of productivity or reproductive success of key seabird species nesting in separate elevational strata or in separate plots on either St. George or St. Paul islands in the Pribilofs and no significant differences among plots at Cape Peirce (Appendices 4-6). As a result, all measures of productivity for each strata and plot have been pooled; a single value is presented for each key species at each colony that was studied in 1984.

Pribilof Islands

Black-legged Kittiwake

Black-legged kittiwakes constructed 57 nests in 6 productivity plots in 3 different strataon St. George Island in 1984 (Table 6). Eggs were recorded in 32 of these nests and the average clutch size was 1.31 (Table ?). Over half (22; 52%) of the 42 black-legged kittiwake eggs recorded in 57 nests on St. George Island were found on first visits (25-26 July) to 4 of the 6 productivity plots. Hence, most of the eggs had been laid before our study began; as a consequence, we were unable to document the actual phenology of egg laying by this species on St. George Island. Only 8 (19%) of the 42 kittiwake eggs hatched in 1984. These were first recorded during the 22-25 July period; 4 of the 8 chicks were known to have hatched during this same two-day period. Of the 8 chicks that hatched, 4 were still alive at the end of the study (13 August). An additional 4 chicks were recorded in nests in productivity plots, although the eggs from which they hatched were never seen. Including these 4 additional eggs, the total productivity of black-legged kittiwakes on St. George Island in 1984 was about 14% (Table 7).

Black-legged kittiwakes constructed 101 nests on 5 productivity plots in 2 different strata on St. Paul Island in 1984 (Table 6). Eggs were recorded in 21 (20.8%) of these and the average clutch size was 1.1 (Table 7)* All 23 kittiwake eggs recorded in 101 nests on St. Paul Island were recorded during the first 2 visits (14-16 July) to 4 of the 5 productivity plots. Similarly, all 4 chicks that hatched from the 23 eggs were recorded on 4 August, the first visit to productivity plots on St. Paul Island since 16 July. Consequently, very little can be said about the phenology of hatching of this species on St. Paul Island. Of the 23 eggs recorded on productivity plots, only 4 (17%) hatched and only 2 of these chicks were alive at the end of the study-on 13 August; an additional 4

Table 6. Breading performance of black-legged kittiwakes at the Pribilof Islands, Alaska, 1984.

Island and Plot Name	Total # Nest Attempts	Fate of Nest Known	Status at End of Study (13 August) Eggs Clutch Size 0	1	2	Hatched*	Failed	Still Unhatched	?	Chicks Alive*	Dead	Other**
St. George												
High Bluff”	1	1	1	0	0	0	o	0	0	0	0	0
Zapadni	1	1	0	1	0	0	0	1	0	0	0	0
Far Cove Across	15	13	6	5	2	1 (1)	8	0	1	1 *(1)*	0	0
Double Cave Cove	10	8	4	2	2	3 (1)	3	0	1	2 (1)	1	0
Murre Plot	2	2	‘o	2	0	1	2	0	0	0	1	0
BLKI Cove	28	24	6	1 2	6	3 (3)	21	0	1	9 (2)	2	1
ALL PLOTS	57	49	17	22	10	8 (5)*	34	1	3	4 (4)*	4	- T -
St. Paul												
Tsammana	50	49 ‘	35	13	1	2 (1)	11	1	0	1 (1)	1	0
Rush Gap North	1	1	1	0	0	o	1	0	0	0	0	0
Rush Gap Looking NE	25	24	22	2	0	0 (1)	2	0	0	0	0	1
Gun Emplacement	16	13	11	1	1	o (3)	0	0	0	0 (3)	0	0
SW 29	9	5	2	3	0	2 (1)	1	0	3	1	1	1
ALL PLOTS	101	92	71	19	2	4 (6)*	18	1	3	2 (4)*	2	2
ALL PLOTS BOTH ISLANDS	158	141	88	41	12	12 (11)*	52	2	6	6 (8)*	6	3

*Chicks still alive that hatched from eggs that were undetected, are in parentheses in the 'Alive' column. The eggs (inferred) from which these live chicks hatched (Plus any others that died) are in parentheses in the ‘Hatched’ column,

**'Other' includes unknown and missing chicks.

Table 7. Productivity of black-legged **kittiwakes** at St. George Island, **Pribilof** Islands, Alaska, 1976-1984*.

	1976	1977	1978	1979	1980	1981	1984
x clutch size	1.42	1.46	1.20	-	-	1.37	1.31
n= # nests with eggs	19	'78	68			59	32
Hatching Success (# chicks hatched per # eggs laid)	.70- .93	.73- .94	.57- .77			.38- .77	.19- .28
Fledging Success (# chicks alive at end of study/# chicks hatched)	.6Q- .79	.41- .53	.51- .72			.11- .23	.50- .62
Reproductive Success (# chicks alive at end of study/# eggs laid)	.78	.43	.61			.09	.19
Productivity (# chicks alive . at end of study/# nest attempts)	.62	.45	,22	.40	.38	,.07	.14
95% Confidence Interval of Reproductive Success	.62- .93	.35- .53	.50- .72			.03- .15	.07- .31
95% Confidence Interval of Productivity Estimate	.45- .78	.36- .55	.17- .27	.32 .48	.29- .47	.02- .12	:05- .23
n = # nest attempts (platforms)	34	110	229	146	106	102	57

● 1976-1978 data are from Hunt et al. (1981) and Hunt (unpub. data); D. Lloyd calculated the 1979 productivity value from data collected by Hunt and co-workers; 1980-1981 data are from D. Lloyd (unpub. data).

chicks were recorded in nests on productivity plots, although the eggs from which they hatched were never seen. Including these 4 additional eggs, the productivity of black-legged kittiwakes on St. Paul Island in 1984 was 6% (Table 8). Overall productivity for this species on the Pribilof Islands (St. George and St. Paul) in 1984 was about 9%.

Red-legged Kittiwake

Red-legged kittiwakes constructed 149 nests in the 6 productivity plots in 2 different strata on St. George Island in 1984 (Table 9). Eggs were recorded in only 41 (20%) of these nests; clutch size was 1. Most red-legged kittiwake eggs (31 of 41; 76$) recorded in the 149 nests were laid before detailed productivity counts were initiated (25 June-13 July). As a consequence, determination of a meaningful schedule of egg laying by this species on St. George Island was not possible.

Only 3 (7%) of the 41 eggs laid by this species hatched; all 3 chicks were still alive at the end of the study. An additional 16 chicks whose eggs were never seen also were recorded on the productivity plots and were alive at the end of the study. Plots were visited too few times during the hatching period to enable a precise determination of 'hatching dates on either island. However, on St. George, chicks were first recorded in nests during the 20 July-12 August period, andon St. Paul during the 15 July-4 August period; 1 chick was known to hatch on 15 July on St. Paul Island. The overall productivity of red-legged kittiwakes on St. George Island in 1984 was 13% (Table 10).

On St. Paul Island, red-legged kittiwakes built 39 nests in the4 productivity plots in2 separate strata (Table 11). Eggs were seen in only six of these 39 nests and the average clutch size was 1.00. Two (33%) of these 6 eggs eventually hatched but none were alive at the end of the study. However, 4 other chicks, whose eggs were never seen, were recorded in nests on plots; all 4 of these chicks were alive at the end of the study. Including these 4 chicks, the productivity of red-legged kittiwakes on St. Paul Island in 1984 was 10%.

The overall maximum productivity of red-legged kittiwakes on the Pribilof Islands (St. George andSt. Paul) in 1984 was 12%(23/188, Table 9)*

Table 8. Productivity of black-legged **kittiwakes** at St. Paul Island, **Pribilof** Islands, Alaska, **1975-1984***.

	1975	1976	1977	1978	1979	1984
x clutch size	1.42	1.49	**1.52**	1.33	1.47	1.10
n = # nests with eggs	85	70	102	110	87	21
Hatching Success (# chicks hatched/# eggs laid)	.60- .82	.72- .88	.59- .85	.74- .84	.73- .88	.17- .35
Fledging Success (# chicks alive **at** end of study/ # chicks hatched)	.47- .64	.57- .69	**.52-** .74	.58- .66	.50- .60	.50- .60
Reproductive Success (# chicks alive at end of study/# eggs laid)	.67	.63	.44	.50	●66	.26
Productivity (# chicks alive at end of study/# nest attempts)	***.44***	●52	.43	.36	.54	.06
95% Confidence Interval of Reproductive Success	**.59-** .75	●54- .73	.36- .52	.42- .58	.58- .75	.08- .44
95% Confidence Interval of Productivity Estimate	●37- .51	.43- .61	.36- .51	**.29-** .43	.46- .62	.01- .10
n= # nest attempts (platforms)	185	127	**157**	203	158	106

● 1975-1979 data are from Hunt et al. (1981) and Hunt **(unpub.** data).

Table 9. Breeding performance of red-legged kittiwakes at the Pribilof Islands, Alaska, 1984.

Island and Plot Name	Total # Nest Attempts	Fate of Nest Known	Status at End of Study (13 August)									
			Eggs							Chicks		
			Clutch Size									
			0	1	2	Hatched●	Failed	Still Unhatched	?	Alive●	Dead	Other
St. George												
High Bluff	103	88	62	26	0	3 (11)	21	2	4	3 (9)●	0	2
Far Cove Across	7	6	1	5	0	0 (1)	5	0	0	0	0	1
Double Cave Cove	19	10	6	4	0	0 (5)	4	0	4	0 (5)	0	0
RLKI Alcove	14	12	9	3	0	0 (1)	3	0	1	0 (1)	0	0
Murre Plot	4	4	2	2	0	0	2	0	0	0	0	0
BLKI Cove	2	1	0	1	0	0 (1)	1	0	0	0 (1)	0	0
ALL PLOTS	149	124	80	41	0	3 (19)	36	2	9	3 (16)	0	3
St. Paul												
Tsammana	4	4	3	1	0	0	0	1	0	0	0	0
Rush Gap												
Looking NE	9	9	8	1	0	0	1	0	0	0	0	0
Gun Emplacement	24	14	11	3	0	1 (5)	2	0	5	0 (4)	1	1
SW 29	2	2	1	1	0	1	0	0	0	0	1	0
ALL PLOTS	39	29	23	6	0	2 (5)	3	1	5	0 (4)	2	1
ALL PLOTS BOTH ISLANDS	188	150	103	47	0	5 (24)	39	3	14	3 (20)	2	4

● Chicks still, alive that hatched from eggs that were undetected are in parentheses in the 'Alive' column. The eggs (Inferred) from which these live chicks hatched (plus others that died), *are in* parentheses in the 'Hatched' column.

Table 10. Productivity of red-legged kittiwakes at St. George, Island, Pribilof Islands, Alaska, 1976-1984*.

	1976	1977	1978	1979	1980	1981	1984
x clutch size n = # nests with eggs	1.00 39	1.00 168	1.00 72			1.00 31	1.00 41
Hatching Success (# chicks hatched/ eggs laid)	.79- .87	.78- .85	.57- .81			.45- .87	.07- .37
Fledging Success (# chicks alive at end of study/ # chicks hatched)	.76- .84	.79- .86	.53- .76			.33- .64	.86 1.00-
Productivity (# chicks alive at end of study/ # nest attempts)	.30- .45	.54	.13	.18	.W	.11	.13
95% Confidence Interval of **Productivity** Estimate	.20- .39	.48- .61	.09- .18	.07- .28	.19- .35	.04- .18	-07- .18
n = # nest attempts (platforms)	88	240	235	52	123	79	149

*1976-1978 data are from Hunt et al. (1981) and Hunt (unpub. data); D. Lloyd calculated the 1979 productivity value from data collected by Hunt and co-workers; 1980-1981 data are from D. Lloyd (unpub. data).

Table **11.** Productivity of red-legged **kittiwakes** at St. Paul Island, **Pribilof** Islands, Alaska, 1975-1984*.

	1975	1976	1977	1978	1979	1984
x̄ clutch size	1.00	1.00	1.00	1.00	1.00	1.00
n= # nests with **eggs**	23	56	57	24	24	6
Hatching Success (# chicks hatched/ eggs laid)	.78- .91	.88- ●93	.82- 991	●54- ●71	.63- .71	.33 .64
Fledging Success (# chicks alive at end of study/ # chicks hatched)	.81- ●94	.92- .98	.81- .89	.65- .85	.76- .8’7	0.0- *57
Productivity (# chicks alive at end of **study/** # nest attempts)	.34	.63	.54	.10	.34	.09
95% Confidence Interval of Productivity Estimate	.21- .47	.52- .74	.43- .65	.04- .15	.21- .46	.01- .18
n= # nest attempts (platforms)	50	76	78	112	56	39

● 1975-1979 data are **from** Hunt et al. (1981) and Hunt (unpub. data).

Thick-billed Murre

The average number of adult birds recorded on the 3 murre productivity plots in the 2 strata sampled on St. George Island was 126, and the total number of eggs recorded on these same plots was 104 (Table 12). The schedule of appearance of 60 eggs on three plots is shown in Table 13. The fates of' 49 (47%) of the 104 total eggs were unknown or uncertain. The fates of55 eggs were certain, and 42 (73%) of these hatched (Table 12). At least 40 of the 42 chicks that hatched were still alive at the end of the study (13 August) and an additional 26 chicks were recorded at sites where eggs were never seen. Thus, a total of 66 thick-billed murre chicks were alive at sites on productivity plots on St. George Island at the end of the study. This represents a reproductive success for this species of 33-72%, depending on which measure of productivity is chosen (see Table 14).

The average number of adults counted on 5 murre productivity plots on the2 strata sampled on St. Paul Island was 146 and the total number of eggs recorded on these plots was 129. The fates of 102 (79%) of these eggs was unknown or uncertain. The fates of 27 eggs were certain; only 6 (22%) of these hatched. Four of the 6 chicks that hatched were still alive at the end of the study and an additional 3 chicks were recorded " whose eggs were never seen. Thus, the reproductive success of thick-billed murres on St. Paul Island in 1984 was 3-15%, depending on which measure of productivity is considered (Table 15).

The overall reproductive success of thick-billed murres on the . Pribilof Islands (St. George and St. Paul) in 1984 was 26.8% (this value was calculated by pooling data from both islands).

Cape Peirce

Black-legged Kittiwake

Black-legged kittiwakes built 275 nests in 11 productivity plots at Cape Peirce in 1984 (Table 16). Eggs were recorded in only 99 (36%) of these nests and the mean clutch size of nests with eggs was 1.35. Most of the kittiwake eggs (109 of 134; 78$) were laid before the 10-13 June

Table 12. Breeding performance of thick billed murres (*Uria lomvia*) at the Pribilof Islands, Alaska, June-August, 1984.

Island Plot Name	X # Adults on Plots (A)	Total # Eggs Recorded	# Eggs of Known Fate (C)	Status at End of Study (13 August 1984)					
				Eggs				Chicks	
				Hatched*	Failed	Still Unhatched	?*	Alive*	Dead
St. George									
Murre Plot	73	54	31	26 (24)	3	2	23	24 (20)	2
BLKI Cove	12	12	5	3 (2)	2	0	7	3 (2)	0
ZAPADNI	41	38	19	13 (7)	5	1	19	13 (4)	0
ALL PLOTS	126	104	55	42 (33)	10	3	49	40 (26)	2
St. Paul									
Gun Emplacement	1	1	0	0	0	0	1	0	0
Rush Gap North	43	41	12	2 (3)	5	5	29	1 (1)	1
Rush Gap Looking NE	48	44	0	0	0	0	44	0	0
SW 29	31	24	7	2 (2)	1	4	17	2 (2)	0
SW2	23	19	8	2	5	1	11	1	1
ALL PLOTS	146	129	27	6 (5)	11	10	102	4 (3)	2
ALL PLOTS BOTH ISLANDS	272	233	82	48 (38)	21	13	151	44 (29)**	4

*Sites of unknown or undetermined status, including sites where eggs were seen once or more but their fates were never determined. Eggs from this category, along with those undetected (but logically inferred) from which chicks hatched are in parentheses in the 'Hatched' column. Chicks that hatched from eggs that were undetected are in parentheses in the 'Alive' column.

Table 13. Schedule of first appearance of 60 thick-billed murre eggs on three productivity plots on St. George Island, Alaska, 25 June-29 July, 1984.

Sampling Interval			New Eggs (Seen for First Time)	
Interval	Date	visit #	#	%
I	25-2'7 June	1	12	20
II	3 July	2	18	30
III	7-11 July	3-4	11	18
IV	19-23 July	5	10	17
v	25-29 July	6-7	9	15
I-V	25 June-29 July	1-7	60	100

Table 14. Productivity of thick-billed murres at St. George Island, Pribilof Islands, Alaska, 1977-1984*.

Measure of Productivity	1977	1978	1981	1984** A	1984** B	1984** C
Number of Eggs	51	90	88	126	104	55
Hatching Success (chicks hatched/ estimate of # of eggs laid)	.59- .84	.61- .70	.65- .88	.60	.73	.76
Fledging Success (# chicks alive at end of study/ # chicks hatched)	.35- .97	.70- .86	.17- .23		.88	.95
Reproductive Success (# chicks alive at end of study/estimate of # of sites occupied)	.29- .57	.49- .52	.15- .16	.33- .52	.38- .63	.72
95% Confidence Interval of Minimum Estimate of Reproductive Success	.17- .42	.39- .59	.01- .22	.23- .40		
n = # chicks alive at end of study+	15-29	44-47	13-15	40-66	40-66	40

*1977-1978 data are from Hunt et al.(1981); 1981 data are from D. Lloyd (unpub. data).

**Three different estimates based on different measures of productivity; see Table 12 for origin of A, B, C.

+Studies ended after fledging during 1977, 1978 and 1981, and before fledging (mid-August) during 1984, therefore results are not directly comparable among years.

Table 15. Productivity of thick-billed murres at St. Paul Island, Pribilof Islands, Alaska, 1976-1984*.

Measure of Productivity	1976	1977	1978	1984**		
				A	B	C
Number of Eggs	47	102	114	146	129	27
Hatching Succes (# chicks hatched/ estimate of # of eggs laid)	.85	.66- .84	.74- .79	.04- .08	.05- .09	.22
Fledging Success (# chicks alive at end of study/# chicks hatched)	.85	.42- .84	.77- .91	-	.64	.67
Reproductive Success (# chicks alive at end of study/estimate of # sites occupied)	.72	.35- .62	.61- .68	.03- .05	.03- .05	.15
95% Confidence Interval of Minimum Estimate of Reproductive Success	.59- .85	.26- .45	.53- .70	<0.1- .05		
n = # chicks alive at end of study+	34	36-63	70-78	4-7	4-7	4

*1976-1978 data are from Hunt et al. (1981) and Hunt (unpubl. data).

**Three different estimates based on different measures or productivity; see Table 12 fOr Origin Of A, B and C.

+Studies ended after fledging in 1976-1978 and before fledging (mid-August) during 1984, therefore results are not directly comparable among years.

Table 16. Breeding performance of black-legged kittiwakes at Cape Peirce, Alaska, 1984.

			Status at End of Study (16 July)						
			Eggs					Chicks	
	Total #*	Fate of	Clutch Size						
Plot Name	Nest Attempts	Nest Known	0	1	2	Hatch	Failed	Alive	Dead
BKAN	29	29	14	7	8	0	23	0	0
BKAS	10	10	4	2	4	0	10	0	0
LKA	55	55	50	4	1	0	6	0	0
SPEC (R)	69	69	48	15	6	0	27	0	0
SPEC (M)	17	17	7	8	2	0	12	0	0
SPEC (L)	13	13	7	6	0	0	6	0	0
OBLIQUE (R)	21	21	15	4	2	0	8	0	0
OBLIQUE (T)	16	16	16	0	0	0	0	0	0
OBLIQUE (L)	22	22	10	8	4	0	16	0	0
TITI	12	12	4	4	4	0	12	0	0
HOKN	11	11	1	6	4	2	12	1	1
ALL PLOTS	275	275	176	64	35	2	132	1	1

*Platforms constructed.

period when detailed productivity counts were first made at Cape Peirce. Of the 134 eggs laid, only 2 (1.5%) hatched; these 2 chicks were present in different nests on 1 plot when we arrived on 11 July for our second visit to the colony. When all nests were last checked on 16 July, only 1 chick remained alive.

Overall productivity of black-legged kittiwakes on plots at Cape Peirce in 1984 was less than 1% (Table 17). An additional census of 150 randomly selected black-legged kittiwake nests at the tip of Cape Peirce (in the center of the colony) on 14 July revealed only 2 live chicks (1.3%) and no nests with eggs.

Common Murre

In 1984, 190 common murre eggs were seen on 7 plots where an average of 487 adults were recorded (mean for all seven plots on all days sampled) (Table 18). The fates of 29 of the 190 eggs were unknown or uncertain; the status of the remaining 161 eggs, as of the end of the study (16 July), is shown in Table 19. The schedule of first appearance of common murre eggs at Cape Peirce is shown in Table 20. Over 86% (164 of 190) of all eggs recorded at murre productivity plots were seen during the first three visits to each plot during the 10-day period, 9-18 June. The remaining 26 eggs appeared during July; some of these eggs no doubt were replacements for eggs lost during June.

Searches commenced on 11 July and ended on 16 July for common murre chicks on 6 plots where eggs had survived during our first visit to Cape Peirce (6-20 June); some information on productivity was gathered for 5 of 6 murre productivity plots on 1 and 2 July by USFWS personnel at Cape Peirce. 0fthe18 chicks recorded during July, 5 hatched between 13 and 16 July and 5 others hatched between 2 and 16 July. Information on the 8 other chicks was insufficient to determine (within reasonable limits) when they hatched.

It is probable that some of the 45 common murre eggs remaining at sites on the last day of our study (16 July) eventually hatched. The estimate of common murre hatching success at Cape Peirce is therefore a minimum value. Nevertheless, the fate of over half of the total eggs, and eggs of known status, were determined before the study ended and a large

Table 17. Productivity of black-legged **kittiwakes** at Cape **Peirce,** Alaska, 1970-1984.

	1970*	1976	1981	1984
X **clutch** size		10 43**	1.64	1.35
n = # nests with eggs			209	99
Hatching success (# chicks hatched/ # eggs laid)		.39+	.59	.01
Fledging success (# **chicks** alive at end of study/# chicks hatched)		.63	.16	.50
Reproductive Success (# chicks alive at end of study/# eggs . laid)		.46++	.14	<.01
Productivity (# chicks alive at" end of study/# nest attempts)	.15	.25	.16	<.01
95% Confidence Interval of Reproductive Success			.11- .18	.oo- .02
95% Confidence Interval of Productivity Estimate	.06- .24	.23- .27	.12- .20	.oo- .01
n (# of nest attempts) .	6 0	1986	308	275

*1970 data are from **Dick** and **Dick** (1971), 1976 data are from petersen and **Sigman** (1977), 1981 data are from D. Lloyd (unpub. data).

This value was calculated from a **subsample of 44 **nests** (with 63 eggs) in only two plots.

+This value is not directly comparable to other measures of hatching success; it is the proportion of nests (772; 38.9%) from which some eggs hatched.

++This value was calculated from a subsample of 50 nests with eggs (50 x 1.43 = 72 eggs) and 33 live chicks at the end of the study in only two plots. This value is not directly comparable to the 1981 and 1984 values, therefore it has not been included in Likelihood Ratio and Bonferroni comparisons in Appendix 7.

Table 18. **Breeding performance of common murres (*Uria aalge*) at Cape Peirce, Alaska, June-July, 1984.**

				Status at End of Study (16 July)					
				Eggs				Chicks	
Plot Name	$\bar{x}$ # Adults on Plots (A)	Total # Eggs (B)	# Eggs of Known Fate (C)	Hatched*	Failed	Still Unhatched	?*	Alive*	Dead
DUH	177	71	55	12 (3)	28	15	16	12(3)	0
HOKN	169	57	48	2	31	15	9	1	1
SPEC (L)	34	16	16	4	8	4	0	4	0
SPEC (R)	35	13	13	0	10	3	0	0	0
SPEC (M)	56	19	16	4 (1)	5	7	3	4 (1)	0
SPEC (B)	3	7	7	0	7	0	0	0	0
BKAN	13	7	6	0 (1)	5	1	1	0 (1)	0
ALL PLOTS	487	190	161	22 (5)	94	45	29	21 (5)	1

● Sites of unknown status. Chicks that hatched from eggs that were undetected are in parentheses in the 'Alive' column; these chicks were alive at the end of the study. The eggs (inferred) from which these chicks hatched are In parentheses in the 'Hatched' column.

'fable 19. Productivity **of common murres at Cape Peirce,** Alaska, 1976-1984*.

Measure of Productivity	1976	1981	8		
			A	L -	G -
Number of Eggs	4500	290-302	487	190	161
Hatching Success (# chicks hatched/ estimate of # eggs laid)		.44-*96	.06	.14	.14
Fledging Success (# chicks alive at end of study/# chicks hatched)		.18-.46		.95	.96
Reproductive Success (# chicks alive at end of study/# of eggs laid)		.17-.31	·	.14	.13
Productivity*** (# chicks alive at end of study/# of nest attempts)	.20	*I5	.05		
95% Confidence Interval of Productivity Estimate	.19- .21	.11- .19	.03- .07		
n = # of chicks alive at end of study			26	26	21

● 1976 data are from Petersen and Sigman (1977): 1981 data are from D. Lloyd (unpub. data).

● *Three different estimates based on different measures of productivity; see Table 18 for origin of A, B and C.

● **Studies ended after fledging in 1976 and 1981 and before fledging (mid-July) in 1984, therefore results are not directly comparable among years; see discussion in text.

Table 20. Schedule of first appearance of 190 common murre eggs on six productivity plots at Cape Peirce, Alaska, 9 June-16 July, 1984.

Sampling Interval			New Eggs (Seen for First Time)	
Interval	Date	Visit #	#	%
I	9-13 June	1	68	35.8
II	14-16 June	2	65	34.2
III	17-18 June	3	31	16.3
IV	1-16 July	4-6	26	13.7
I-IV	9 June-16 July	1-6	190	100.0

proportion of these (94 of 190 or 161; 49.5% or 58.4%, respectively) failed. Of 116 eggs whose status had been determined by 16 July, only 22 (19%) hatched. If this rate of hatch is applied to the 45 unhatched eggs, 31 of 161 eggs of known status (16% of the total 190 eggs) would hatch, and 6% of the 487 occupied sites would have chicks. Given this hatching scenario, one would expect the overall production of common murres at Cape Peirce to be somewhat less than 6% during 1984.

On 14 July, 185 randomly-selected murres were observed on nesting ledges at the tip of Cape Peirce (in the center of the mainland colony); 1 adult was seen incubating an egg, 8 adults were attending chicks, 125 adults appeared to be incubating (were standing in incubation posture), 49 adults clearly were not incubating, and 2 eggs appeared to be abandoned. Based on this ancillary information, the productivity of murres in the relatively inaccessible center of the colony, near the tip of Cape Peirce, is about the same (4%) as that computed from censuses of productivity plots at other locations.

DISCUSSION

Pribilof Islands

Likelihood Ratio Tests (LRT) indicate statistically significant differences in black-legged kittiwake hatching success and overall productivity among various years on both St. George and St. Paul islands (Table 21). More detailed comparisons of individual years indicate that 1984 was low on St. George Island. On St. Paul Island, both of these measures were significantly lower in 1984 than for any of the other five years when data were available for this species.

LRT analyses indicate a statistically significant difference among various years for hatching success of red-legged kittiwakes on St. George Island; no such difference (in hatching success) among years was found an St. Paul Island (Table 22). In contrast, statistically significant differences among years were detected for overall productivity on both St. George and St. Paul islands. More detailed inter-year comparisons of both St. George and St. Paul data indicate that 1984 was among the poorest years for overall productivity on both islands.

Table 21. Various estimates of black-legged **kittiwake** productivity on the **Pribilof** Islands, Alaska, 1975-1984, with results of Likelihood Ratio Tests and **Bonferroni** multiple comparisons. (See Appendix 7 for a similar statistical treatment and comparison of reproductive success for black-legged **kittiwakes** on St. George and St. Paul, and Cape **Peirce.**)

St. George Island

LRT Statistic for Hatching **Success*:** 25.1; **p<0.0001**

Year	1984	1981	1978	1976	1977
N	42	81	82	27	114
Estimate of Hatching Success	.19	.38	.57	.70	.73+

LRT Statistic for **Productivity**: 42.3; p<0.0001**

Year	1981	1984	1978	1980	1979	1977	1976
N	102	57	229	106	146	110	34
Estimate of Productivity	.07	.14	.22	.38	.40	.45	.62

St. Paul Island

LRT Statistic for Hatching Success: **18.5; p=0.002**

Year	1984	1977	1975	1976	1979	1978
N		155	121	104	128	146
Estimate of Hatching Success	.7;	.59	.60	.72	.73	.74

LRT Statistic for Productivity: 4"4.9; **p<0.001**

Year	1984	1978	1977	1975	1976	1979
N	106	203	157	185	127	158
Estimate of Productivity	.06	.36	.43	.44	.52	.54

***Hatching** success: # eggs hatched/# eggs laid.

**Productivity: # chicks alive at end of study/# nest attempts (platforms constructed).

+**Underscoring** designates estimates that are not significantly different from each other (p varies from 0.025 to 0.003).

Table 22. Various estimates of red-legged kittiwake productivity on the Pribilof Islands, Alaska, 1976-1984, with results of Likelihood Ratio Tests and Bonferroni multiple comparisons

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St. George Island

LRT Statistic for I-latching Success*: 42.2; $p<0.0001$

Year	1984	1981	1978	1977	1976
N	41	31	72	168	39
Estimate of Hatching Success	.07	.45	.57	.78	.79[+]

LRT Statistic for Overall Productivity*[a]: 68.8; $p<0.0001$

Year	1981	1984	1978	1979	1980	1976	1977
N	79	149	235	52	123	88	240
Estimate of Productivity	.11	*I3	.13	.18	.27	.30	.54

St. Paul Island

LRT Statistic for Hatching Success: 9.3; $p=0.0976$

Year	1984	1978	1979	1975	1977	1976
N	6	24	24	23		56
Estimate of Hatching Success	.33	.54	.63	.78	.;;	.88

LRT Statistic for Productivity: 43.7; $p<0.0001$

Year	1978	1984	1979	1975	1977	'1976
N	112	39	56	50	78	76
Estimate of Productivity	.09	.10	*34	.34	.54	.63

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*Hatching success: # eggs hatched/# eggs laid.

**Productivity: # chicks alive at end of study/# nest attempts (platforms constructed).

+Underscoring designates estimates that are not significantly different from each other (p varies from 0.025 to 0.003).

LRT analyses indicate a statistically significant difference among years in estimates of both hatching success and overall productivity of thick-billed murres on St. George Island (Table 23). More detailed inter-year comparisons indicate that the estimate of hatching success in 1984 was lower than had been recorded in the three years when similar studies had been conducted on this island. Although it was not statistically lower than during 1977, when hatching success also was very low, it was significantly lower than during both 1978 and 1981. Similarly, although the value for overall productivity of thick-billed murres on St. George was smeller than recorded in 1978, it was not significantly different from productivity values for any of the three other years when studies of thick-billed murres were conducted on St. George.

On St. Paul Island, LRT analyses and multi-year comparisons indicated that 1984 was by far the poorest of four years for which data exist on thick-billed murre hatching success and overall productivity (Table 23). Craighead and Oppenheim (1982) speculated that disturbance of nesting seabirds by human visitation on St. Paul may be responsible for depressed reproductive rates over the past several years there.

Cape Peirce

Likelihood Ratio Tests and multi-year comparisons of black-legged kittiwake hatching success and overall productivity indicated that 1984 was by far the poorest of the four years for which data exist at Cape Peirce (Table 24). The 1984 value for overall productivity was statistically" very much smaller than the very low value for 1970.

At Cape Peirce we were concerned that all of the black-legged kittiwake productivity plots may have been too far from the core of the colony, i.e., at the periphery of the colony where others working with kittiwakes (Coulson 1968) found the quality (productivity) of birds to be poor. Therefore, on 14 July we climbed to a difficult vantage point above Cape Peirce proper, and using a spotting scope, we examined the contents of 150 arbitrarily selected kittiwake nests. As mentioned in the 'RESULTS' section, this inspection revealed only 2 live chicks and no nests with eggs. Thus, ourkittiwake productivity plots appeared to be

Table 23. Various estimates of thick-billed murre productivity on the Pribilof Islands, Alaska, 1976-1984, with results of Likelihood Ratio Tests and Bonferroni multiple comparisons.

St. George Island

LRT Statistic for Hatching Success*: 13.8; p=0.001

Year	1984	1977	1978	1981
N	126	51	90	88
Estimate of Hatching Success	.60	.59	.61	.65
				+

LRT Statistic for Productivitys*: 12.5; p=0.002

Year	1981	1977	1984	1978
N	88	51	126	90
Estimate of Productivity	.15	.29	.31	.49

St. Paul Island

LRT Statistic for Hatching Success: 107.1; p<0.001

Year	1984	1977	1978	1976
N	146	102	114	47
Estimate of Hatching Success	.04	.66	.74	.85

LRT Statistic for Productivity: 77.0; p<0.0001

Year	1984	1977	1978	1976
N	146	102	114	47
Estimate of productivity	.03	.35	.61	.72

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*Hatching success: # chicks hatched/total # eggs laid ($\bar{x}$ # adults in plots during censuses).

**Productivity: #chicks alive at end of study/# breeding pairs ($\bar{x}$ # adults in plots during censuses).

+Underscoring designates estimates that are not significantly different from each other (p varies from 0.025 to 0.003).

Table 24. Various estimates of black-legged **kittiwake** and common murre productivity at Cape **Peirce,** Alaska, 1970-1984, with results of Likelihood Ratio Tests and **Bonferroni** multiple comparisons. (See Appendix 7 for a similar statistical treatment and comparison of reproductive success for black-legged **kittiwakes** at Cape **Peirce.).**

Black-legged Kittiwake

LRT Statistic for Hatching Success: 84.2; p<0.0001

Year	1984	**1981**
N	134	343
Estimate of Hatching Success	.01	.59

LRT Statistic for Productivity: 72.4; p<0.0001

Year	1984	1970	1981	1976
N	275	60	308	1986
Estimate of Productivity	<0.01	.15	.16	.25 +

Common Murre

LRT Statistic for Hatching Success: 13.9; p<0.0001

Year	1984	***1981***
N	487	***290***
Estimate of Hatching Success*	.06	***.44***

LRT Statistic for Productivity: 41.1; p<0.0001

Year	1984	1981	1976
N	487	302	4500
Estimate of Productivity**	.05	.15	.20

***Hatching success:** # chicks hatched/total # eggs laid.

**Productivity: #chicks alive at end of study/# breeding pairs ($\bar{x}$ # adults in plots during censuses).

+**Underscoring** designates estimates that are not significantly different from each other (p varies from 0.025 to 0.003).

representative of the colony; overall productivity in 1984 was nearly zero.

Although field work at Cape Peirce ended before the peak of hatching on at least one common murre productivity plot, results from other plots where the peak was observed indicated that murre productivity was low in 1984. More rigorous statistical analyses (Likelihood Ratio Tests) and multi-year comparisons (Bonferrani Tests) of common murre hatching success and overall productivity indicated that, as was the case with black-legged kittiwakes, 1984 was the poorest of the three years for which data are available (Table 24)

One of the major inefficiencies of any study of murre productivity is the amount of time spent watching birds on plots to determine whether or not a site is occupied by a breeding bird, e.g., whether an egg or chick is present at the site. Many investigators simply use the average number of adults present on the plot as an estimate of the number of occupied sites (Hunt et al. 1981). This approach biases productivity estimates downward because not all adults at sites breed. In this study we tested the usefulness of a detailed computer analysis of hourly attendance data collected by time-lapse 35-mm cameras at a common murre plot (DUH) at Cape Peirce. This procedure was found to be very useful, but our results were confounded by several problems. The most significant problem was caused by some birds obscuring others; when the images were digitized, the sites occupied by the birds in back were indistinguishable from those in front. The use of 35-mm time-lapse photography and digitized data analyses shows great promise, but great care needs to be exercised when setting up photographic equipment to monitor seabird plots so the type of occlusion described above does not occur. If the ledges are wide, as they often are where common murres nest, the camera should be mounted opposite and above the birds if possible.

At least four and possibly eight pairs of common ravens (Corvus corax) preyed heavily on eggs of common murres and black-legged kittiwakes at Cape Peirce in 1984. It was difficult to determine the impact of raven predation on a colony-wide basis, but they appeared to have a great impact on the birds nesting in productivity and population plots at Cape Peirce. . Recently fledged young ravens often accompanied adults to the colonies during feeding trips. During 10 hours of a 24-h count at several population plots on 7 June, 36 sightings were made of ravens carrying eggs away from the colony. Forty-six eggs eaten by ravens were picked up along a 500 m-long cliff-top transect over a 2-day period. Petersen and Sigman (1977) also saw ravens taking large numbers of seabird eggs at Cape Peirce; they calculated that three pairs of ravens "...could conceivably destroy 50 nests during one foraging effort." Although these estimates of predation are crude, they suggest that ravens may take large numbers of seabird eggs under certain circumstances at Cape Peirce. Hatching success was relatively high in 1981, and ravens, although present in numbers similar to 1984, appeared to be less successful at dislodging kittiwakes from nests. Also, kittiwakes mobbed ravens more and appeared to be more effective at detering ravens in 1981 (D. Herter, pers. ohs.).

On seven occasions during a 5-day period in early June, ravens were observed scaring large numbers of common murres and black-legged kittiwakes from census plots. On several occasions they pulled kittiwakes off their nests and dragged murres off ledges in order to take their eggs. Petersen and Sigman (1977) describe similar behavior by ravensat Cape Peirce in 1976. There is evidence that such raven predation may influence breeding site selection by murres (A.J. Gaston, CWS, pers. comm. 1984).

Seabird Productivity in Recent Years in the Bering/Chukchi Region

It is clear from the information gathered on the Pribilofs, at Cape Peirce and at St. Matthew Island that black-legged and red-legged kittiwake productivity in the southern Bering Sea was very poor in 1984. Black-legged and red-legged kittiwake productivity also was very poor on the Pribilofs in 1983 (Larry Merculief, pers. comm. to D.G. Roseneau 1984) and in 1982 (Craighead and Oppenheim 1982); black-legged kittiwake productivity was also near zero atSt. Matthew Island in 1982 and 1983 (Springer et al. 198.4a). The last year when kittiwakes were studied at Cape Peirce was 1981; productivity was also poor that year. The last year when good productivity was reported for red-legged and black-legged kittiwakes on the Pribilofs was 1977 and 1980, respectively; at Cape Peirce the last reported productive year for black-legged kittiwakes was 1976.

Very poor productivity was reported in 1984 at all black-legged kittiwake colonies in the Bering and Chukchi seas where data are available. No young were produced at Cape Lisburne (Chukchi Sea), at Bluff (Norton Bay) or at St. Lawrence Island (Springer et al. 1984a). No information is available on kittiwake productivity on St. Lawrence Island or Cape Thompson in 1983, but data from Bluff and Cape Lisburne (Springer et al. 1984a:25; Murphy and Springer, unpub. data) indicate fair to good productivity that year.

The small sample (4 birds) of thick-billed murres monitored on St. Paul Island in 1984 makes the very low productivity value (0.03) somewhat less reliable than that for nearby St. George Island, where more birds (40) were watched and productivity was greater (0.3 1). productivity was markedly higher on St. George in 1984 than what was recorded by Craighead and Oppenheim in 1982 (only 1 chick seen). Murre productivity was also poor on St. Lawrence Island in 1984 but has been good on St. Matthew Island since 1982, although thick-billed murres have apparently been less productive there than common murres, especially in 1983 (Springer et al. 1984a). Common murre productivity at Bluff also was apparently poor in 1984 (Murphy and Springer, unpub. data).

Productivity has frequently been estimated at seabird colonies as a way of comparing the general "health" of populations among years or, less commonly, as a tool in predicting change in population numbers. Attempts have frequently been made to correlate observed changes in productivity with causative mechanisms, and thus to isolate factors that ultimately control populations (Lid 1981, Fordet al. 1982). Some authors (Croxall and Prince 1970, Lid 1981) have blamed persisting changes in productivity caused by food supply changes (or other factors), for long-term population changes.

Springer et al. (1984b) suggest that long-term changes in weather and climate cause broad-scale changes in oceanographic conditions and in prey availability. They further suggest that such changes may affect the stability of regional, seabird populations in the Bering and Chukchi seas. The recent depressions in productivity of seabirds in the southern Bering Sea may be related to such meteorological and oceanographic events.

SUMMARY

Estimates of black-legged kittiwake productivity were very low in 1984 on St. George (0.14) and St. Paul (0.06) islands and at Cape Peirce (less than 0.01). Likelihood Ratio Tests indicated that 1984 was among the poorest of years for black-legged kittiwake productivity in the southern Bering Sea. Comparisons of productivity over recent years at other colonies in the southern Bering indicate that black-legged kittiwake productivity has been depressed for' three years at many important Bering Sea colonies (St. George, St. Paul, Cape Peirce, St. Matthew and possibly St. Lawrence).

Red-legged kittiwake productivity was very low (0.13 and 0.10) on St. George and St. Paul island in 1984. Likelihood Ratio Tests indicate that on St. George Island, where about 80% of the world population nests, productivity has been low for at least five years.

Estimates of productivity of thick-billed murres in 1984 were much higher on St. George Island (0.31) than on St. Paul (0.03), possibly because of human disturbance at St. Paul (Craighead and Oppenheim 1982). Productivity was markedly higher in 1984 on St. George than Craighead and Oppenheim recorded in 1982.

Productivity of common murres at Cape Peirce in 1984 was probably overestimated because observations ended too early; despite this, the maximum estimate of productivity in 1984 was only 0.05. Productivity also was relatively low (0.15) at Cape Peirce in 1981. During our study and the study by Petersen and Sigman (1977), common ravens preyed heavily on eggs of common murres and black-legged kittiwakes at Cape Peirce. During years when productivity is depressed (when breeding birds may be stressed), ravens may be more effective predators of eggs and chicks (D.G. Roseneau, pers. comm. 1984).

Future monitoring studies should measure productivity until most chicks are near fledging. Studies that terminate early (as ours did at Cape Peirce) will not provide accurate estimates of productivity in a year when many eggs hatch and many chicks survive.

We strongly recommend the use of 35-mm time-lapse photography and the digitization of imagery to monitor trends in diurnal and seasonal attendance of birds (especially murres) on study plots as a tool for determining their reproductive status. Cameras should be set up opposite and slightly above study plots to eliminate occlusion.

There were no significant differences in productivity among different elevational strata or among different plots for any key species of seabird studied in 1984 on either of the Pribilof Islands or at Cape Peirce.

Springer et al. (1984) suggest that long-term changes in weather and climate cause broad-scale changes in oceanographic conditions and in prey availability. They further suggest that such changes may affect the stability of regional seabird populations in the Bering and Chukchi seas.

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APPENDICES

Appendix 1. Technical description of procedures used to analyze digitized time-series data from time-lapse photographs.

Introduction

This technical appendix briefly describes the methods used and the analysis performed on the time-lapse photographic records collected at DUH plot at Cape Peirce in 1984. The most important tool used in the analysis of the photographs was a digitizer; it was used to convert the photographic (analog) record into a data-oriented (digital) record" Prior to the analysis we did the following:

(1) prepared the film,
(2) developed film projection methods,
(3) assembled and interfaced appropriate computer and optical hardware, and
(4) developed appropriate computer software.

In addition to the above, the following numerical and statistical procedures were developed: (1) numerical search methods (minimization procedures) that determine the location and number of nest sites, and (2) application of time series analysis in order to determine patterns in hourly abundance of birds on study plots.

Methods

To monitor hourly abundance and describe spatial patterns of the birds observed in the photograph% a HI-PAD digitizer was used to record the species, location and number of each bird. This required (1) the development of hardware to project the film onto the digitizing platen, and (2) computer hardware and software to drive the digitizer.

Each frame in the film strips (transparencies) were numbered consecutively (in the upper right corner), with a Permanent marker, beginning with the first frame of an hourly sequence. Poor quality and redundant photographs were not numbered (i.e., were eliminated).

A film projector and a two-sided mirror were used to reflect the image of each photograph onto the digitizing platen. The contents of each frame were then digitized. The digitized record contained the following quantitative measurements from each frame and bird observed:

1) time of the frame (0-24 hours),
2) date of the frame,
3) visibility of the colony, and
4) location and sample period of the frame.

The time of the initial photograph of a sample sequence was corroborated by observing cycles of night and day apparent in the photographs. For simplicity, the visibility of the colony was encoded using five ordinal levels (0-4), as follows:

0: complete visibility,
1: some shadowing--all birds visible,
2: overcast day and extensive shadowing--all birds visible,
3: visibility poor--not all birds visible, and
4: frame completely dark or overexposed--frame not digitizable.

The following information was recorded for each bird observed in each frame:

1) species code,
2) type of individual (adult, subadult, egg, nest, etc.),
3) vertical position of individual in the frame,
4) horizontal position of individual in the frame, and
5) occlusion index.

The occlusion index was an ordinal measure (1-3) of the degree to which the bird was hidden from view. For each bird that was not occluded, the horizontal and vertical measurement was taken by placing the crosshairs of the digitizing cursor on the center of the back and digitizing (recording) its position.

We used a Houston Instruments HI-PAD DT-1 14A Digitizer that was driven by an APPLE IIe computer using a serial interface card. The computer software that processed the digitized information was written and developed by LGL. Data were processed and stored on 5.25" floppy disks, and were transferred to the LGL data-management system where they were verified, edited and setup for analyses.

Analysis

The digitized photographic data were used in several different ways, depending on how the information was to be used. The following two types of data records were produced from the raw data files:

(1) spatial coordinates of each bird that was digitized, and
(2) frame or hourly counts of the number of birds of each species recorded at each location during each sample period.

The spatial coordinates of each bird were used to determine the number of nesting sites (breeding pairs) within the view of the camera (i.e., on the sample plot). An overall map of all the sites was constructed by accumulating the number of birds digitized for each pixtel (smallest resolved point) on the digitizing platen. Examples of these base maps are presented in Figures Al-1 to A1-3. Darker areas in Figure Al-1 indicate areas of high frequency of birds. Figure AI-2 and A1-3 show higher resolution plots of a section of Figure Al-1.

After the base map was constructed, the locations of discrete sites were determined through a numerical search procedure that defined the perimeters of each location in the plot where birds were recorded most frequently. These regions, or collections of coordinates, were then defined as discrete sites. The original spatial coordinates of each bird digitized on an hour by hour basis was used to determine residency characteristics for each site (for a description, see Ripley 1981).

Using this, procedure, we determined that about 330 sites at DUH study plot were occupied by common murres in the early part of the breeding season (7-20 June) and about 162 sites were occupied during the middle part of the breeding cycle (10-17 June). Comparable numbers for these same sampling periods but determined through visual counts are 487 and 161, respectively (see ‘RESULTS’ section, Table 19, under headings A and C, respectively).

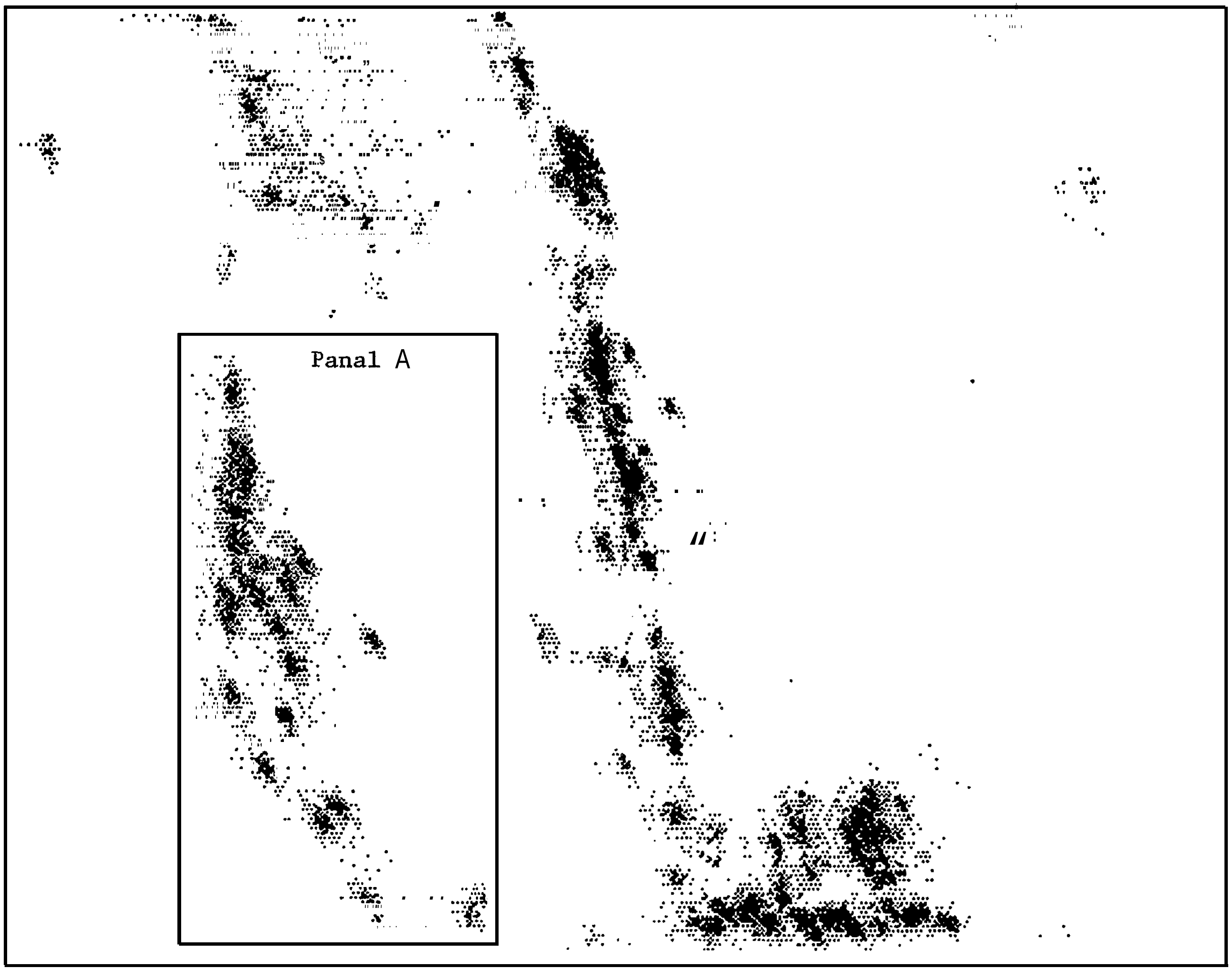

Figure Al-1. Base map showing the location (one dot) of each common murre digitized at DUH plot (Cape Peirce) during the early part of the nesting period (7-20 June 1984). A higher resolution map of Panel A is shown in Figure Al-2.

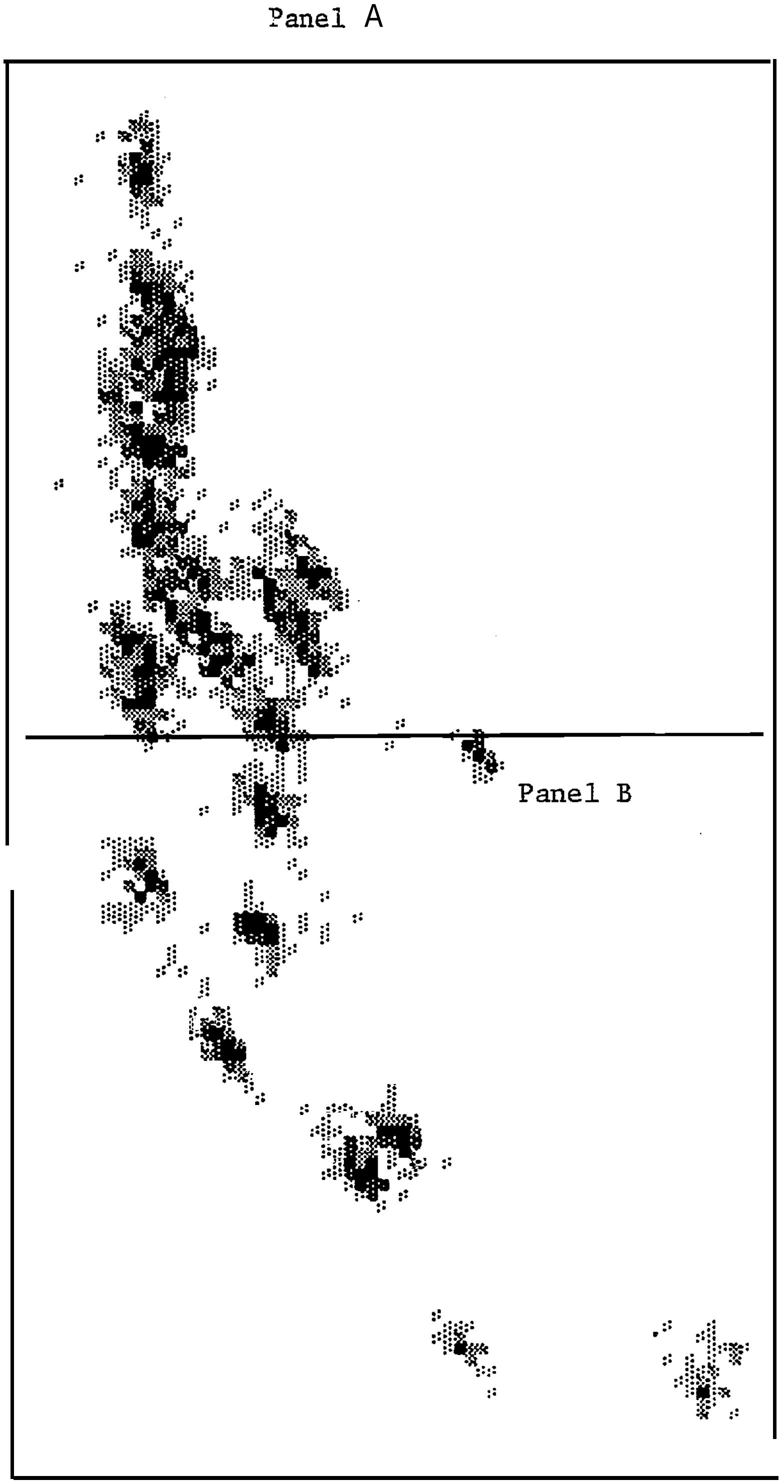

Figure Al-2. High resolution map of locations of common murres shown in Panel A, Figure Al-1. An even higher resolution, 3-dimensional graphic of the area designated Panel B in Figure Al-2, is shown in Figure Al-3.

Panel B in Panel A

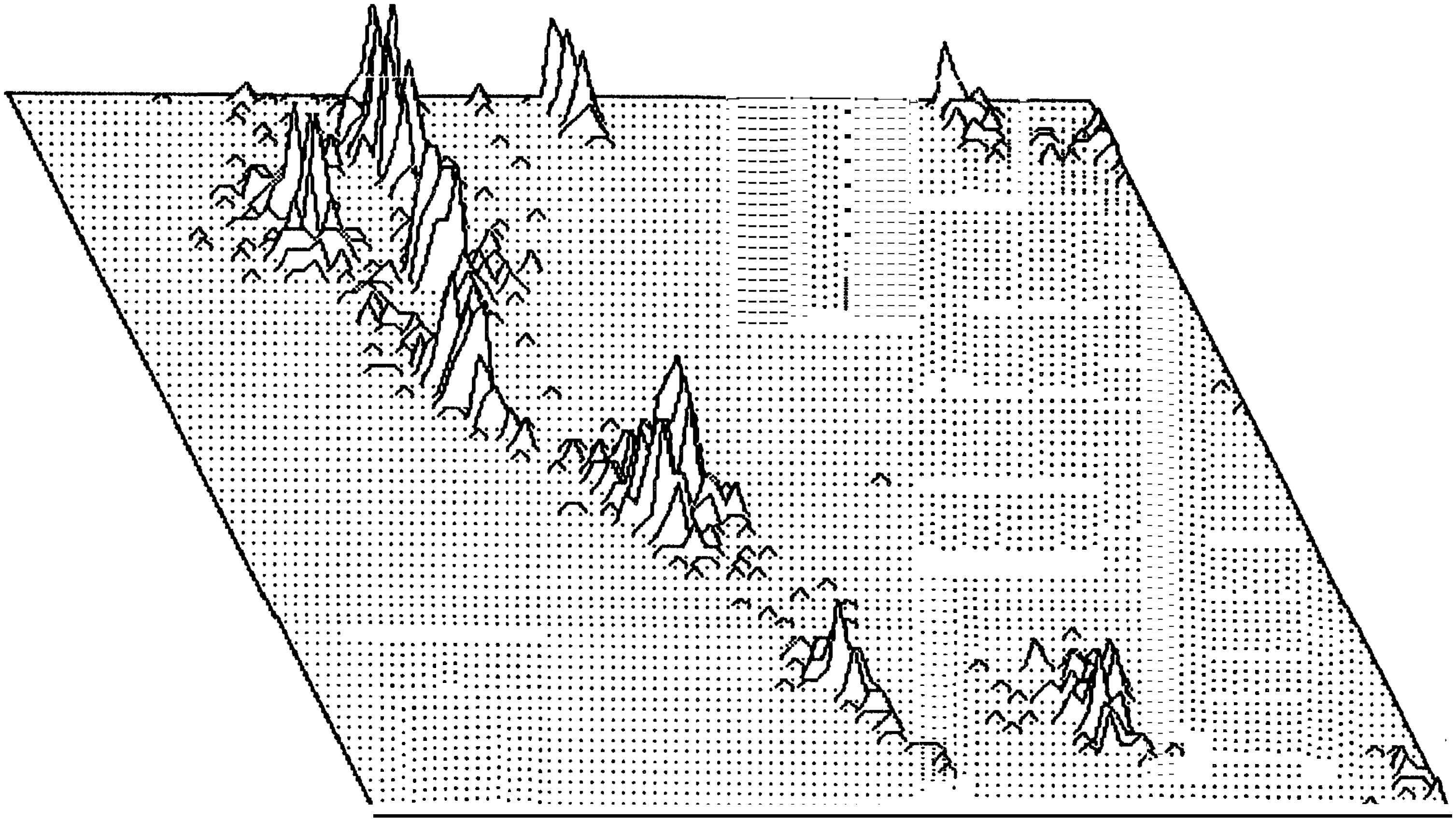

Figure A1-3. Frequency of occurrence of common at locations in Panel B of Figure A1-2.

Table Al-1. Estimates of the number of discrete nest sites (breeding pairs) of common murres at DUH study plot at Cape Peirce, Alaska. DUH 1= sampling period 7-20, June 1984; DUH 3= sampling period 10-17 July, 1984.

DUH1 - COMMON MURRES

0.1 - 9.9%	206
10.0 - 19.9%	26
20.0 - 29.9%	24
30.0 - 39.9%	16
40.0 - 49.9X	17
50,0 - 59.9%	5
60.0 - 69.9%	10
70.0 - 79.9%	15
80.0 - 89.9%	11
90,0 - 100.0%	0
0.1 - 100.0%	330

DUH3 - COMMON MURRES

0.1 - 9.9%	75
10.0 - 19.9%	22
20.0 - 29.9%	13
30.0 - 39.9%	7
40,0 - 49.9%	7
50.0 - 59.9%	3
60.0 - 69.9%	3
70.0 - 79.9%	9
80.0 - 89.9%	10
90.0 - 100.0%	13
0.1 - 100.0%	162

Appendix 2. A summary of weather information for the Pribilof Islands, Alaska, June-August, 1984.

	June				July			
	Wind		Temp (°C)		Wind		Temp (°C)	
Date	$\bar{x}$ spd **(km/h)**	**Dir**	**Min**	**Max**	$\bar{x}$ spd **(km/h)**	**Dir**	**Min**	**Max**
1	24	N	3	6	21	NE	3	10
2	27	N	4	8	19	NE	4	9
3	19	N	2	8	27	N	6	8
4	21	N	2	6	26	NE	7	10
5	6	NE	2	8	24	N	6	9
6	14	NE	2	9	29	NE	6	9
7	11	NE	0	6	18	NE	6	11
8	16	N	3	5	22	NE	7	8
9	22	N	3	7	24	NE	6	8
10	22	N	1	7	22	NE	4	9
11	14	N	0	8	30	NE	4	9
12	14	N	4	10	26	NE	6	8
13	14	NE	3	9	26	NE	6	12
14	13	N	1	9	27	NE	3	9
15	19	N	3	7	22	NE	5	8
16	21	N	3	10	30	NE	4	10
17	21	N	3	8	29	NE	7	10
18	14	N	4	11	32	NE	7	9
19	8	N	4	11	24	NE	7	11
20	14	N	6	9	14	N	6	10
21	24	N	6	8	13	N	2	10
22	22	N	4	9	11	N	7	10
23	21	N	4	9	14	N	7	11
24	24	N	5	10	11	N	8	11
25	21	N	4	12	13	N	8	10
26	24	NE	6	14	19	NE	7	9
27	18	NE	7	16	19	NE	6	11
28	26	N	6	8	34	NE	8	9
29	30	NE	6	8	19	NE	8	11
30	16	NE	6	12	29	N	8	9
31					16	N	8	12

Appendix 2 (cent'd)

	August			
	Wind		Temp (°C)	
Date	$\bar{x}$ spd (km/h)	Dir	Min	Max
1	32	N	8	10
2	24	N	8	10
3	11	N	8	11
4	10	N	10	14
5	10	N	9	12
6	11	NE	8	12
7	11	NE	8	13
8	24	NE	9	12
9	21	NE	8	11
10	24	NE	8	13
11	10	N	8	11
12	11	N	9	12
13	10	N	9	13
14	13	N	8	13
15	14	N	8	11
16	22	N	9	11
17	21	N	8	12
18	18	NE	8	11
19	19	N	8	10
20	27	N	9	11
21	29	NE	9	11
22	14	NE	8	11
23	24	N	9	11
24	37	N	9	11
25	14	NE	2	11
26	32	N	2	8
27	22	N	8	9
28	27	NE	4	11
29	19	NE	3	11
30	14	NE	7	9
31	21	NE	7	10

Appendix 3. A summary of weather information for the Cape Newenham-Cape Peirce area, Alaska, June-July 1984.

	June				July			
	Wind		Temp (°C)		Wind		Temp (°C)	
Date	Max-Min Speed (km/h)	Dir	Min	Max	Max-Min Speed (km/h)	Dir	Min	Max
1	0-18	N	7	15	0-21	NE	10	14
2	11-28	N	9	16	0-28	N	9	15
3	0-26	N	4	14	0-19	N	7	12
4	0-14	NE	2	9	0-18	NE	6	8
5	0-14	NE	1	7	0-21	N	6	12
6	0-11	N	2	11	5-37	NE	5	9
7	0-12	NE	2	7	0-11	NE	4	7
8	0-18	N	1	8	5-19	NE	4	7
9	0-30	N	3	12	0-25	NE	5	11
10	0-16	N	4	12	0-25	NE	6	8
11	0-12	N	4	8	0-12	N	6	12
12	0-9	N	2	9	0-7	N	8	14
13	0-7	N	7	12	0-14	N	7	16
14	0-18	N	5	9	0-25	N	9	16
15	0-9	N	6	15	0-19	N	8	12
16	0-11	N	8	12	0-18	NE	6	11
17	0-25	N	8	13	0-18	NE	5	8
18	0-16	N	9	13	0-19	NE	6	8
19	0-18	N	8	13	0-25	NE	7	9
20	0-12	N	5	14	0-21	N	7	12
21	0-18	N	7	13	0-33	N	6	14
22	9-35	N	7	9	0-25	N	11	14
23	12-20	N	4	12	0-16	N	10	13
24	0-28	N	8	12	0-18	N	9	12
25	0-21	N	8	14	0-9	N	9	11
26	0-23	N	10	16	0	N	9	13
27	0-9	N	7	12	0-14	NE	8	13
28	0-30	N	5	13	0-25	N	7	9
29	5-26	N	9	72	0-14	NE	7	9
30	0-18	N	8	15	7-33	N	7	12
31					11-25	N	8	11

Appendix 4. Results of Likelihood Ratio Tests (LRT) of differences in productivity estimates for seabirds nesting in different elevational strata on St. George Island, Pribilof Islands, Alaska, 1984.

Species	Stratum #	# Nest Attempts	# Chicks Alive at End of Study	Productivity Estimate	95% CI of Productivity Estimate
BLKI	1	55	4	0.07	0.00-0.14
	2	1	0	0	0.00-0.00
	5	1	0	0	0.00-0.00
	LRT Statistic = 0.15; P = 0.93				
RLKI	1	32	0	0	0.00-0.00
	5	117	3	0.03	0.00-0.05
	LRT Statistic = 0.73; P = 0.39				
TBMU	1	85	27	0.32	0.18-0.46
	2	41	13	0.32	0.22-0.42
	LRT Statistic = 0.00; P = 1.0				

Appendix 5. Results of Likelihood Ratio Tests (LRT) of differences in productivity estimates for seabirds nesting in different elevational strata on St. Paul Island, Pribilof Islands, Alaska, 1984.

Species	Stratum #	# Nest Attempts	# Chicks Alive at End of Study	Productivity Estimate	95% CI of Productivity Estimate
BLKI	1	50	1	0.02	0.00-0.06
	2	51	1	0.02	0.00-0.06
		LRT Statistic = 0.0001; P = 0.99			
RLKI	1	4	0	0	0.00-0.00
	2	35	0	0	0.00-0.00
		LRT Statistic = 0.00; P = 1.0			
TBMU	1	23	1	0.04	0.00-0.13
	2	123	3	0.02	0.00-0.05
		LRT Statistic = 0.11; P = 0.73			

Appendix 6. Results of Likelihood Ratio Tests (**LRT**) of differences in productivity estimates for seabirds nesting in different productivity plots on the **Pribilof** Islands and at Cape **Peirce,** Alaska, 1984.

Species	# Plots	LRT Statistic	P
St. George Island			
BLKI	6	1.49	0.91
RLKI	6	1.12	O*95
TBMU	3	0.15	0.93
St. Paul **Island**			
BLKI	5	1.78	0.78
RLKI	4	0.00	1.0
TBMU	5	2.06	0.73
Cape Peirce			
BLKI	11	3.26	O*97
COMU	7	9.83	0.13

Appendix 7. Various estimates of black-legged kittiwake reproductive success on the Pribilof Islands and at Cape Peirce, Alaska, 1975-1984, with results of Likelihood Ratio Tests and Bonferroni multiple comparisons.

St. George

LRT Statistic for Reproductive Success*: 40.3; p<0.0001

Year	1981	1984	1977	1978	1976
N	81	42	114	82	[illegible]
Estimate of' Reproductive Success	.09	.19	.44	.61	[illegible] S*

St. Paul

LRT Statistic for Reproductive Success: 17.0; p=0.004

Year	1984	1977	1978	1976	1979	1975
N	23	155	146	104	128	121
Estimate of' Reproductive success	.26	.44	.50	.63	*66	.67 **

Cape Peirce

LRT Statistic for Reproductive Success: 13.5; p<0.0001

Year	1981	1984
N	343	124
Estimate of Reproductive Success	.24	<0.01

● Reproductive success: # chicks alive at end of study/# eggs laid.

**Underscoring designates estimates that are not significantly different from each other (p varies from 0.025 to 0.003).

CHAPTER IV

FEEDING STUDIES

By

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INTRODUCTION

The data and analyses presented in this report are part of a monitoring program of seabirds at the Pribilof Islands and Cape Pierce funded by the Minerals Management Service, U.S. Department of the Interior. One of the specific objectives of this program is to develop estimates of the kinds and amounts of food consumed by the major seabird species in the Pribilof Island colonies.

Birds and (or) their food samples were collected at both St. George and St. Paul islands, although for logistical reasons most work was conducted at St. George. Food samples were collected from the following 11 species: northern fulmar (Fulmarus glacialis), red-faced cormorant (Phalacrocorax urile), black-legged kittiwake (Rissa tridactyla), red-legged kittiwake (Rissa brevirostris), common murre (Uris aalge), thick-billed murre (Uria lomvia), parakeet auklet (Cyclorrhyncus psittacula), least auklet (Aethia pusilla), crested auklet (Aethia cristatella), tufted puffin (Fratercula cirrhata) and horned puffin (Fratercula corniculata).

Five species (cormorant, both kittiwakes, thick-billed murre and least auklet) were to be studied in greater detail than the others, but too few red-faced cormorant samples were collected for detailed analyses. Detailed analyses of each of the remaining four species looked at diet differences between sexes of adult birds, between times of the breeding season, between adults and chicks, and between islands. No comparisons were made between different species of birds since differential digestion of food items among species may seriously bias such comparisons (Schneider and Hunt 1984). The results obtained are compared with the more intensive previous work conducted at the Pribilofs, mainly by George L. Hunt, Jr. and his co-workers (Hunt et al. 1981, Schneider and Hunt 1984).

METHODS

Field Methods

During field studies on the Pribilof Islands, 488 food samples were collected from 458 birds of 11 species (Table 1 and Appendix 1). Three types of samples were collected: stomachs from shot birds, regurgitations

Table 1. **Number** of **samples** collected for *feeding* studies, **Pribilof** Islands, 1984.

Species	Island	Type of Sample			Total No. Samples
		Stomach	Regurgitation	Food Load	
Northern fulmar	SP	o	0	0	o
	SG	15	0	0	15
Red-faced cormorant	SP	0	2	0	2
	SG	0	20	0	20
Black-legged kittiwake	SP	23	6	0	29
	SO	80	0	0	80
Red-legged kittiwake	SP	2	0	0	2
	SG	49	13	0	62
Common murre	SP	9	5	1	15
	SG	7	2	2	11
Thick-billed murre	SP	10	17	4	31
	SG	47	24	7	'78
Parakeet auklet	SP	o	0	o	0
	SG	13	o “	7	20
Least auklet	SP	10	0	8	18
	SG	13	0	40	53
Crested auklet	SP	o	0	0	0
	SG	13	0	13	26
Tufted puffin	SP	o	0	0	0
	SG	8	0	0	8
Horned puffin	SP	1	1	0	2
	SG	14	0	2	16
All Species		314	90	84	488

SP = St. 'Paul, SG . St. George

from chicks, and food loads brought to chicks by adult birds. Food loads were of two types-either one or a few items carried in the beaks of murres and puffins, or many items carried in the gular pouches of auklets.

Shot birds were taken either at sea or from vantage points along the coasts of St. Paul and St. George islands. Shortly after retrieval 5% formalin was injected down the throats and into the stomachs of shot birds to arrest digestion. Birds were dissected within 12 h of collection (usually sooner). Esophagi, proventriculi and gizzards were stored in 5% formalin for later analysis. Bird carcasses were frozen and most were later shipped to the Royal Ontario Museum, Toronto, Ontario, Canada, to be processed as study skins and skeletons. Food material is archived with LGL.

Some birds provided more than one food sample. This occurred when shot birds were carrying food for their chicks as well as for themselves. In such cases, items carried in food loads were processed separately from items in the digestive tracts.

Chick diet was studied by collecting two types of food samples: regurgitations and food loads. When handled, red-faced cormorant and kittiwake chicks occasionally regurgitated food. Murre and puffin chicks were neck-collared for several hours; then any food items the chicks had been fed were removed. Food loads contained in the gular pouches of auklets were taken from either shot or netted" birds, and murres occasionally dropped food items on chick ledges. Regurgitated samples and food loads were stored in 5% formalin for later analyses.

Laboratory Techniques

In the laboratory, food items were examined under low-power binocular microscopes and sorted and identified as precisely as possible given the condition of the food material. With whole items it was frequently possible to identify food to the species level but partial. items were usually identified to less precise levels (genus, family, order). In almost every sample there was some food material that could not be identified to any of the general taxonomic categories. Such material was recorded as 'other' and was treated as a separate food taxon throughout this report. Appropriate keys for the identification of invertebrates and fish of the Bering Sea were used (Bowman 1960, Akimushkin 1963, Boden et al. 1965, Brodskii 1967, Hart 19.73, Frost 1974, Morrow 1977, Frost 1981). Myctophid otoliths were identified by comparison with the otoliths of whole fish loaned by N. M. Harrison, Univ. Calif., Irvine.

Subsampling (by weight) was undertaken when large numbers of food items in a broad taxonomic grouping (e.g. copepods, euphausiids) were encountered. The lengths of whole items found in the samples or subsamples were measured.

Some stomachs contained fish material (bones, scales, entrails) that by itself could not be identified more precisely. When fish otoliths also were present and identified, it was assumed that the unidentified material was of the same taxa as were the fish otoliths. If two or more taxa of otoliths were present, the unidentified materiel was assigned (by weight) to each taxon in the same proportion as represented by each otolith taxon.

The amount of food in each stomach was assumed to be an accurate reflection of the amounts and kinds of food recently-ingested. Hard parts (e.g., otoliths, cephalopod beaks) remain in bird stomachs longer than does fleshy material, so a given wet weight of hard parts may overrepresent some prey species relative to a wet weight based solely on fleshy material.

Volumes Versus Wet Weights

I originally proposed to analyze the food samples with the methods employed by Hunt et al. (1981). These authors sorted, counted and identified food items at the lowest possible taxonomic level, and then measured displacement volumes or estimated them visually. I found the measurement of displacement volumes to be time-consuming and less precise than the measurement of wet weights. Volumes could be measured to plus-or-minus 1 ml (equivalent to about 1.0 g wet weight) whereas wet weights could be measured to plus-or-minus 0.1 g. In 60 randomly-selected stomachs (15 each from black-legged kittiwake, red-legged kittiwake, thick-billed murre, and least auklet) I investigated the reliability of volumetric measurements. The volumes and wet weight of three major food taxa (copepods, euphausiids and fish) in the stomachs were measured. Differences between these two measurements were compared statistically. Material from each taxon was categorized by wet weight (Table 2) and differences between volume and wet weight were compared. For two taxa (copepods and euphausiids), differences between volumes and wet weights were not consistent across the range of wet weight categories, indicating that volume may not have been measured consistently even within taxa. In this report, all statistical comparisons of the amounts of food eaten are based on standardized wet weight measurements. Standardization involved representing the wet weight of a given taxon as a percentage of the wet weight of all material in the stomach. This permitted comparisons of samples with differing amounts of food.

Statistical Comparisons

Mann-Whitney U-tests were conducted on standardized wet weights per sample for any prey taxon that comprised more than 5% of the diet in either of the groups being compared. If these tests were significant? G-tests were used to test for differences in the proportions of birds taking a given prey taxon. Criterion levels were set ata conservative level (P=0.01) since many comparisons were made. Parametric t-tests (P=0.01) were used to test for differences in the mean lengths of fish otoliths found in different groups of food samples.

RESULTS

Northern Fulmar (Fulmarus glacialis)

A small sample of northern fulmars (n=15) was collected for food habits studies (Table 3). Eight birds were collected on 9 July and seven were collected on 31 July--all were taken at sea near St. George. The major diet component of the collected birds was unidentified fish and many of the stomachs contained large pieces of fish flesh. Fulmars are well known to scavenge near fishing vessels and it is likely that most of the fish material in the stomachs was gathered in this way. One bird contained the otoliths of a walleye pollock (Theragra chalcogramma). Only

Table 2. Differences between volume (ml) and wet weight (g) measurements tor.different net weight categories of food found in 60 seabird stomachs (15 from each of black-legged kittiwake, ked-legged kittiwake, thick-billed murre and least auklet).

Food Taxa	Wet Weight Category					
	0.005 -0.5 g	t (P)	0.5 - 5.0 g	t (P)	+5.0 g	t (P)
Copepods[1]	0.16 ± 0.22 (12)[5]	2.52 <0.05	1.07 ± 0.69 (16)	4.01 <0.01	-- (o) .	1.94 <0.1
Euphausiids[2]	0.13 ± .20 (46)	4.41 <0.01	0.61 ± 0.74 (23)	3.95 <0.01	5.1 ± 8.3 (10)	3.23 <0.01
Fish[3]	-- (3)	- -	0.81 ± 0.65 (13)	4.49 <0.01	4.2 ± 6.1 (22)	

[1] Includes *Calanus marshallae*, *C. plumchris*, *C. cristatus*, *C. glacialis* and *C.* spp.
[2] Includes *Thysanoessa raschii*, *T. inermis*, *T. spinifera* and *T.* Spp.
[3] Includes *Ammodytes hexapterus*, Gadidae spp., Myctophidae spp., Pleuronectidae spp., and Osteichthyes spp.
[4] For copepods and fish, test statistic is Mann-Whitney U; for euphausiids, test statistic is Kruskal-Wallis H.
[5] Values in table are mean ± 1 ad. (n).

Table 3. Diet composition of northern fulmars collected at St. George Island, Alaska, 1984.

Food Taxa	Occurrence n	Occurrence %	Wet Weight (g) Mean	Wet Weight (g) %
Copepoda	1	6.7	<0.005	<0.005
Decapoda	1	6.7	0.01	0.1
Euphausiacea	2	13.3	0.01	0.1
Amphipoda	4	26.7	0.02	0.1
Squid	3	20.0	0.08	0.6
Gastropoda	1	6.7	<0.005	<0.005
Gadidae	1	6.7	2.79	19.6
Unid. fish	12	80.0	11.02	77.6
Other	14	93.3	0.28	2.0
n	15 samples		$\bar{x}$= 14.21 g	

small amounts of crustaceans were present in the stomachs examined. It is possible that these items were ingested incidentally to the capture of fish offal.

Red-faced Cormorant (Phalacrocorax urile)

Regurgitations were obtained from 22 red-faced cormorant chicks during the study--20 from St. George and 2 from St. Paul (Table 4). On St. George, sand lance (Ammodytes hexapterus) formed 52% of diet wet weight and occurred in half of the regurgitations. The mean length of the 25 Ammodytes otoliths occurring in the 10 stomachs was 5.35 mm. Two other fish taxa comprised more than 5% of diet wet weight: unidentified fish (16%) and gadids (walleye pollock and unidentified species--l 5%). Trichodon trichodon, the Pacific sandfish, occurred in two samples from St. George and in the two St. Paul samples. The only other fish identified to the species level was Pholis ornata, the saddleback gunnel. It occurred in one of the St. George samples.

Black-legged Kittiwake (Rissa tridactyla)

During the study, 102 adult black-legged kittiwakes were collected--80 at St. George and 22 at St. Paul. At both islands, adults of each sex were collected in both July and August.

At St. George there were no differences in diet composition between males and females in either month (Table 5; all Mann-Whitney probabilities >0.01). There did appear to be some change in the diets of all adult birds between July and August (Table 6). August birds took significantly greater amounts (standardized wet weights) ($P<0.01$) of gadids and Ammodytes than did July birds. Gadids were also taken by a larger proportion of the August birds than of the July birds ($G=11.86$, $P<0.001$). This was not the case with Ammodytes which was taken by similar proportions of birds in the two months ($G=1.05$, $P>0.01$).

At St. Paul, there were also no differences in diet composition between males and females in July or August (Table 7; all $P>0.01$). Again, however, there was some indication of diet change between July and August (Table 8). Polychaetes were taken in greater amounts and by

Table 4. Diet composition of red-faced cormorants at the Pribilof Islands, 1984.

	St. George Island				St. Paul Island			
	Occurrence		Weight Weight (g)		Occurrence		Wet Weight (g)	
Food Taxa	n	%	Mean	%	n	%	Mean	%
Decapoda	2	10.0	0.44	1.9		--	--	- -
Amphipoda	4	20.0	0.04	0.2'	1	50.0	0.04	O*1
Gastropod	2	10.0	<0.005	<0.005		--	--	- -
Gadidae	2	10.0	3.51	15.0	.	- -	--	- -
Cottidae	1	5.0	0.54	2.3		- -	- -	- -
Pleuronectidae	1	5.0	0.60	2.6		. .	- -	--
Ammodytidae	10	50.0	12.26	52.2		--	- -	- -
Pholidae	1	5.0	0.52	2.2		- -	--	--
Trichodontidae	2	10.0	1.13	4.8	2	100.0	47.09	92.1
Salmonidae	1	5*O	0.50	2.1		--	- -	--
Unid. fish	6	30.0	3*86	16.4		--	- -	--
Other	9	45*O	0.55	2.3	2	100.0	4.01	7.8
n	20 samples		x̄= 23.47 g		2 samples		x̄= 51.14 g	

Table 5. Diet composition of adult black-legged kittiwakes collected at St. George Island, Alaska, 1964.

Food Taxa	MALES - JULY				FEMALES - JULY				MALES - AUGU				FEMALE			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%	n	%	Mean	%	n	%	Mean	%
Copepoda	1	2.7	<0.005	<0.005	--	--	--	--		--	--	--	-	--	--	--
Decapoda	2	5.4	<0.005	<0.005	--	--	--	--	1	16.7	0.01	0.1		--	--	--
Euphausiacea	10	27.0	0.18	6.7	11	34.4	0.51	21.9		--	--	--		--	--	--
Amphipoda	3	8.1	<0.005	<0.005	1	3.1	<0.005	<0.005		--	--	--		--	--	--
Isopoda	1	2.7	<0.005	<0.005	--	--	--	--		--	--	--		--	--	--
Squid	4	10.8	0.03	1.1	6	18.8	0.01	0.4	1	16.7	0.29	4.0		--	--	--
Gastropoda	5	13.5	0.04	1.5	2	6.3	<0.005	<0.005		--	--	--		--	--	--
Polychaeta	1	2.7	<0.005	<0.005	1	3.1	<0.005	<0.005		--	--	--		--	--	--
Gadidae	--	--	--	--	1	3.1	0.26	11.2	3	50.0	6.14	84.9	1	50.0	0.13	26.0
Myctophidae	3	8.1	0.49	18.3	5	15.6	0.38	16.3		--	--	--	1	50.0	0.07	14.0
Pleuronectidae	--	--	--	--	2	6.3	0.16	6.9		--	--	--		--	--	--
Ammodytidae	--	--	--	--	--	--	--	--	1	16.7	0.65	9.0		--	--	--
Cyclopteridae	--	--	--	--	1	3.1	0.26	11.2		--	--	--		--	--	--
Unid. fish	18	48.6	1.70	63.4	12	37.5	0.57	24.5	3	50.0	0.11	1.5	1	50.0	0.11	22.0
Other	35	94.6	0.25	9.3	26	81.3	0.20	8.6	4	66.7	0.05	0.7	2	100.0	0.2	38.0
n	37 samples		$\bar{x}$= 2.68 g		32 samples		$\bar{x}$= 2.33 g		6 samples		$\bar{x}$= 7.23 g		2 samples		$\bar{x}$= 0.50 g	

Table 6. Diet composition of adult black-legged kittiwakes at St. George Island in July and August, 198410

Food Taxa	JULY				AUGUST			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%
Copepoda	1	1.4	<0.005	<0.005	--	--	--	--
Decapoda	2	2.8	<0.005	<0.005	1	12.5	0.01	0.2
Euphausiacea	22	30.6	0.33	13.5	--	--	--	--
Amphipoda	4	5.6	<0.005	<0.005		--	--	--
Isopoda	1	1.4	<0.005	<0.005		--	--	--
Squid	10	13.9	0.02	0.8	1	12.5	0.22	4.0
Gastropod	7	9.7	0.02	0.8		--	--	--
Polychaeta	2	2.8	<0.005	<0.005		--	--	--
Gadidae	1	1.4	0.11	0.45	4	50.0	4.64	83.6
Myctophidae	8	11.1	0.42	17.1	1	12.5	0.02	0.4
Pleuronectidae	2	2.8	0.07	2.9		--	--	--
Ammodytidae	--	--	--	--	1	12.5	0.48	8.6
Cyclopteridae	1	1.4	0.11	4.5		--	--	--
Unid. fish	31	43.1	1.12	45.7	4	50.0	0.11	2.0
Other	64	88.9	0.24	9.8	6	75.0	0.08	1.4
n	72 samples		$\bar{x}$= 2.45 g		8 samples		$\bar{x}$= 5.55 g	

[1] Includes samples from unsexed birds.

Table 7. Diet composition of adult black-legged kittiwakes collected at St. Paul Island, Alaska, 1984.

Food Taxa	MALES - JULY				FEMALES - JULY				MALES - AUGUST				FEMALES - AUGUST			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%	n	%	Mean	%	n	%	Mean	%
Copepoda	--	--	--	--	1	10.0	<0.005	<0.005		--	--	--		--	--	--
Decapoda	--	--	--	--	3	30.0	0.03	0.2	2	28.6	0.08	0.4		--	--	--
Euphausiacea	1	50.0	<0.005	<0.005	2	20.0	<0.005	<0.005		--	--	--		--	--	--
Amphipoda		--	--	--	4	40.0	0.02	0.1	2	28.6	0.02	0.1		--	--	--
Isopoda	--	--	--	--	--	--	--	--		--	--	--		--	--	--
Squid	1	50.0	0.01	<0.005	4	40.0	0.03	0.2		--	--	--		--	--	--
Gastropod		--	--	--	--	--	--	--		--	--	--		--	--	--
Polychaeta	--	--	--	--	1	10.0	<0.005	<0.005	5	71.4	3.27	16.1	2	100.0	4.14	48.4
Gadidae	--	--	--	--	--	--	--	--	2	28.6	1.73	8.5		--	--	--
Myctophidae	2	100.0	26.38	99.9	1	10.0	0.09	0.6	1	14.3	4.74	23.4		--	--	--
Pleuronectidae	--	--	--	--	--	--	--	--		--	--	--		--	--	--
Ammodytidae	--	--	--	--	2	20.0	8.59	55.2	2	28.6	10.05	49.6		--	--	--
Cyclopteridae	--	--	--	--	--	--	--	--		--	--	--		--	--	--
Unid. fish	--	--	--	--	8	80.0	6.02	38.7	2	28.6	0.30	1.5	1	50.0	4.00	46.7
Other	--	--	--	--	8	80.0	0.79	5.1	5	71.4	0.09	0.4	2	100.0	0.42	4.9
n	2 samples		$\bar{x}$= 26.39 g		10 samples		$\bar{x}$= 15.55 g		7 samples		$\bar{x}$= 20.28 g		2 samples		$\bar{x}$= 8.56 g	

Table 8. Diet composition of adult black-legged kittiwakes at St. Paul Island in July and August, 1984[1].

Food Taxa	JULY				AUGUST			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%
Copepoda	1	7.7	<0.005	<0.005		--	--	--
Decapoda	3	23.1	0.02	0.1	2	22.2	0.06	0.3
Euphausiacea	3	23.1	<0.005	<0.005		--	--	--
Amphipoda	4	30.8	0.02	0.1	2	22.2	0.01	0.1
Isopoda		--	--	--		--	--	--
Squid	5	38.5	0.02	0.1		--	--	--
Gastropod		--	--	--		--	--	--
Polychaeta	1	7.7	<0.005	<0.005	7	77.8	3.46	19.6
Gadidae		--	--	--	2	22.2	1.34	7.6
Myctophidae	3	23.1	4.12	24.4	1	11.1	3.69	20.9
Pleuronectidae		--	--	--		--	--	--
Ammodytidae	2	15.4	6.60	39.0	2	22.2	1.82	44.2
Cyclopteridae		--	--	--		--	--	
Unid. fish	9	69.2	5.32	31.5	3	33.3	1.12	6.3
Other	9	69.2	0.80	4.7	7	77.8	0.17	1.0
n	13 samples		$\bar{x}$= 16.91 g		9 samples		$\bar{x}$= 17.68 g	

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[1] Includes samples from unsexed birds.

proportionately more August birds than July birds (U=17.5, P< 0.02; G=8.91, P<0.0 l). There were no significant differences in the amounts of other food taxa in July vs. August diets.

Regurgitations from six black-legged kittiwake chicks were collected at St. Paul between 6 and 8 August. In descending order of importance by wet weight were myctophids (45%), walleye pollock (43%), unidentified fish (12%) and euphausiids (0.2%).

Three fish taxa (walleye pollock, myctophids and _Ammodytes_) were dominant in adult black-legged kittiwake diets. I compared the mean lengths of the otoliths found in the stomachs of adult birds from St. George and St. Paul islands (Table 9) but found no significant differences (all t-test probabilities >0.01).

Red-legged **Kittiwake** (_Rissa brevirostris_)

Adult red-legged kittiwakes were collected for food habits studies at St. George (n=49) and at St. Paul (n=2). I found no differences in the diet composition of 21 adult male and 27 adult female birds collected at St. George in July (Table 10; U-test probabilities >0.01 for those taxa comprising >5% wet weight). The diet of all adult birds (n = 51) was mainly myctophid fish (54% of diet wet weight), followed by unidentified fish (22$), euphausiids (11.3%), unidentified food material (10.5%); and small amounts (<l%) of copepods, decapods, amphipods, squid, polychaetes and gadid fish.

Thirteen regurgitations were obtained from neck-collared chicks at St. George between 25 July and 11 August. On average these regurgitations weighed 3.96 g and consisted of myctophids (62% of wet weight), unidentified fish (16%), squid (12%), unidentified food material (7.3%), crustaceans (2.3%) and gastropod (0.3%). The amountsof major tYPes of food eaten by adults and chicks at St. George were not significantly different (Table 11).

Myctophid otoliths were found in adult samples and chick regurgitations (Table 12). There were no differences in the mean lengths of otoliths in male vs. female or adult vs. chick samples (all t-test probabilities >0.01).

Table 9. Lengths of. selected taxa of otoliths taken from the stomachs of black-legged kittiwakes collected at the Pribilof Islands, 1984.

Food Taxa	Island	No. of Stomachs	No. of Otoliths	Otolith Length (mm) Mean	Otolith Length (mm) S.D.
Walleye pollock	St. George	4	35	2.15	0.69
	St. Paul	1	7	1.19	0.41
Myctophids	St. George	9	38	1.28	0.26
	St. Paul	4	15	1.43	0.28
Sand lance[1]	St. George	1	2	0.90	--
	St. Paul	4	15	2.03	0.38

[1] All otoliths identified to species were *Ammodytes hexapterus*, the only species of sand lance present in the southeastern Bering Sea (Hart 1973).

Table 10. Diet composition of adult red-legged kittiwakes collected at St. George Island, Alaska, July 1984.

					FEMALES			
Food Taxa	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%
Copepoda	4	19.0	<0.005	<0.005	5	18.5	<0.005	<0.005
Decapoda	3	14.3	<0.005	<0.005	6	22.2	0.08	0.8
Euphausiacea	6	28.6	0.98	3.7	10	37.0	1.32	12.8
Amphipoda	5	23.8	0.03	0.4	8	29.6	0.04	0.4
Squid	3	14.3	<0.005	<0.005	7	25.9	0.12	1.2
Polychaeta	1	4.8	<0.005	<0.005	--	--	--	--
Gadidae	--	--	--	--	2	7.4	0.08	0.8
Myctophidae	12	57.1	5.22	61.4	15	55.6	5.88	57.0
Unid. fish	8	38.1	1.18	13.9	7	25.9	1.84	17.8
Other	15	71.4	1.09	12.8	20	74.1	0.95	9.2
n	21 samples		$\bar{x}$= 0.50 g		27 samples		$\bar{x}$= 10.32 g	

Table 11. Standardized wet weights of food found in adult and chick samples of' red-legged kittiwakes at St. George Island, 1984.

Food Taxa	Standardized Wet Weight of Food 1 S.D. (n)		Mann-Whitney	
	Adults (n= 49)	Chicks (n=13)	Z	P
Crustacea	9.9 ± 24.4	5.0 ± 15.1	0.52	>0.1
Squid	0.7 ± 2.1	12.7 ± 30.6	1.20	>0.1
Gastropod	0.001 ± 0.005	1.8 ± 6.6	1.04	>0.1
Polychaeta	0.001*0.005	0.0 *6.6	0.52	>0.1
Fish	73*5 ± 35.3	72.0 ± 38.2	0.52	>001

Table 12. Lengths of' **myctophid otoliths** taken from adult and chick red-legged kittiwakes collected at St. George Island, 1984.

Group	No. of Stomachs	No. of Otoliths	Otolith Length (mm) Mean	Otolith Length (mm) S.D.
Adult males	21	70	1.31	0.27
Adult females	28	69	1.30	0.29
All adults "	49	139	1.30	0.28
Chicks	13	24	1.24	0.24

Common Murre (Uria aalge)

During the study, small numbers of adult food samples were collected at St. George (n=7) and St. Paul (n=9). I found no differences in the amounts of major food taxa taken by adults at the two islands (Table 13; all Mann-Whitney U-test probabilities >0.01). The only fish species that occurred in more than a single sample was walleye pollock. Twenty-eight otoliths of this species were found in three samples from St. Paul. These otoliths had a mean length of 1.96 mm.

Samples from seven neck-collared chicks at St. Paul and three at St. George were also obtained (Table 14). Squid, flatfish and lance occurred in two of the 10 samples; other taxa occurred in only single stomachs. Fishes identified to species level included Theragra chalcogramma (Gadidae), Hippoglossoides elassodon and Lepidopsetta bilineata (Pleuronectidae), Ammodytes hexapterus (Ammodytidae), and Lumpenus sagitta (Stichaeidae).

Thick-billed Murre (Uria lomvia)

During the study period, 57 adult thick-billed murres were collected--47 at St. George and 10 at St. Paul. AtSt. George, adults of each sex were collected in July and August (Table 15), but there were no significant differences in the diets of the birds in terms of the standardized amounts of major prey groups eaten (all Mann-Whitney U-test probabilities >0.01). There were, however, significant differences in the diets of the 47 St. George and 10 St. Paul birds (Table 16). In the 10 birds taken at St. Paul all identifiable food remains were Gadidae, whereas at St. George, cod occurred in only 30% of stomachs ($G = 15.54$, $P<0.001$) and account for only 5.6% of food ($z = 4.67$, $P<0.001$). Euphausiacea accounted for 62% of the food taken by birds collected at St. George on 15 August but for none of the food taken by 10 birds at St. Paul a week earlier. Squid, another important component of adult diet at St. George, especially in August, was also absent from St. Paul birds.

Gadids were the only identified fish that occurred in large numbers in the stomachs of adult thick-billed murres collected at both St. George and St. Paul islands. Two types of gadid otoliths were identified:

Table 13. Diet composition of adult common murres collected at the Pribilof Islands, 1984.

Food Taxa	ST. GEORGE				ST. PAUL			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	n	%	n	%	n	%
Decapoda	1	14.3	<0.005	<0.005		--	--	--
Euphausiacea	1	14.3	0.72	47.7	1	11.1	<0.005	<0.005
Amphipoda		--	--	--	1	11.1	<0.005	<0.005
Gadidae		--	--	--	3	33.3	1.36	86.6
Unid. fish	2	28.6	0.23	15.2		--	--	--
Other	7	100.0	0.57	37.7	8	88.9	0.21	13.4
n	7 samples		$\bar{x}$= 1.51 g		9 samples		$\bar{x}$= 1.57 g	

Table 14. Diet composition of common murre chicks at the Pribilof Islands, 1984.

Food Taxa	Occurrence		Wet Weight (g)	
	n	%	Mean	%
Squid	2	20.0	1.20	32.5
Gadidae	1	10.0	0.07	1.9
Cottidae	1	10.0	0.07	1.9
Pleuronectidae	2	20.0	0.43	11.7
Ammodytidae	2	20.0	0.32	8.7
Cyclopteridae	1	10.0	0.68	18.4
Stichaeidae	1	10.0	0.79	21.4
Agonidae	1	10.0	0.07	1.9
Unid. fish	1	10.0	0.07	1.9
n	10 samples		$\bar{x}$= 3.69 g	

Table 15. Diet composition of adult thick-billed murres collected at St. George Island, Alaska, 1984.

Food Taxa	MALES - JULY				FEMALES - JULY				MALES - AUGUST				FEMALES - AUGUST			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence				Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%	n	%			n	%	Mean	%
Copepoda	4	19.0	<0.005	<0.005	1	5.6	<0.005	<0.005	-	--	--	--	-	--	--	--
Decapoda	1	4.8	0.01	0.2	1	5.6	0.02	0.3	-	--	--	--	1	33.3	0.05	0.2
Euphausiacea	9	42.9	2.41	60.1	9	50.0	4.69	79.4	1	20.0	4.38	58.2	3	100.0	14.04	63.2
Amphipoda	--	--	--	--	1	5.6	<0.005	<0.005	-	--	--	--	.	--	--	
Squid	7	33.3	0.14	3.5	5	27.8	0.01	0.2	2	40.0	0.71	9.4	2	66.7	2.50	11.3
Gadidae	5	23.8	0.14	3.5	5	27.8	0.16	2.7	2	40.0	0.26	3.5	2	66.7	3.14	14.1
Pleuronectidae	1	4.8	0.14	3.5	--	--	--	--		--	--	--		--	--	--
Ammodytidae	--	--	--	--	--	--	--	--	1	20.0	0.51	6.8		--	--	--
Unid. fish	3	14.3	0.02	0.5	6	33.3	0.05	0.8	2	40.0	0.01	0.1	1	33.3	0.19	0.9
Other	21	100.0	1.14	28.4	17	94.4	0.99	15.2	5	100.0	1.65	21.9	3	100.0	2.28	10.3
n	21 samples		$\bar{x}$= 4.01 g		18 samples		$\bar{x}$= 5.91 g		5 samples		$\bar{x}$= 7.53 g		3 samples		$\bar{x}$= 22.20 g	

Table 16. Diet composition of adult thick-billed murres collected at the Pribilof Islands, 1984.

Food Taxa	St. George				St. Paul			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%
Copepoda	5	10.6	<0.005	<0.005	-			
Decapoda	3	6.4	0.01	0.2	-			
Euphausiacea	22	46.8	4.23	67.5	-			
Amphipoda	1	2.1	<0.005	<0.005	-			
Squid	16	34.0	0.30	4.8	-			
Gadidae	14	29.8	0.35	5.6	10	100.0	5.41	71.6
Pleuronectidae	1	2.1	0.06	1.00	-			
Ammodytidae	1	2.1	0.05	0.8				
Unid. fish	12	25.5	0.04	0.6	-			
Other	46	97.9	1.21	19.3	10	100.0	2.15	28.4
n	47 samples		$\bar{X}$=6.27 g		10 samples		$\bar{X}$=7.56 g	

walleye **pollock** and unidentified **Gadidae.** T-tests showed no differences (P>0.01) in the lengths of the two types of **otoliths** taken by adult birds on the two islands (Table 17).

The 21 meals collected from thick-billed **murrre** chicks at St. Paul were taken over a shorter time period (6 and 7 August) than were the 31 chick meals collected at St George (31 **July-15** August). **In addition, St** Paul samples were mainly from smaller chicks than were the St George samples. These two factors **must be** kept in mind when interpreting the observed differences in chick diet. At St. George, squid occurred **in** 23 of 31 samples and accounted for **82%** of food wet weight; identified fish (**Gadidae** and **Cottidae**) occurred in 5 of 31 samples and accounted for 9% of food wet weight (Table 18). Chick diet on St. Paul was very different. Squid were absent; fish occurred in 19 of 21 stomachs and accounted for 99% of food wet weight. The differences between the two islands in the occurrence and wet weights of squid and identified fish in chick meals were all significant (all G-test and U-test probabilities <0.001).

The amounts of fish eaten by adults versus chicks did not differ significantly either at St. George or at St. Paul (Table 19). At St. **Paul** adult and chick diet was largely fish. Not surprisingly, there were no differences in the amounts of crustaceans or squid eaten by the two age groups. At St. George, however, adult **murres** ate significantly greater amounts of **crustacea** (P<0.01) and significantly lesser **amounts of** squid (P<0.01) than they fed to their **chicks.**

Parakeet Auklet (*Cyclorrhyncus psittacula*)

A small number (n=15) of parakeet auklets was collected at St. George on 31 July and 15 August. Predominant in the wet weight diet of these birds were unidentified fish (73%), other unidentified food material (9%), and **copepods** and decapods (each comprising 6%) (Table 20). All of the above **taxa,** except **decapods,** occurred in more than half of the stomachs examined. Lesser amounts of amphipods, **euphausiids,** and especially squid and gastropod occurred in the samples.

Table 17. Lengths of gadid otoliths taken from the stomachs of thick-billed murres collected at the Pribilof Islands, 1984.

Food Taxa	Island	No. of Stomachs	No. of Otoliths	Otolith Length (mm)	
				Mean	S.D.
Walleye pollock	St. George	47	15	1.87	0.66
	St. Paul	10	47	2.03	0.42
Unid. Gadidae	St. George	47	41	1.12	0.36
	St. Paul	10	43	1.96	0.29

Table 18. Diet composition of thick-billed murre chicks at the Pribilof Islands, 1984.

	ST. GEORGE				ST. PAUL			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
Food Taxa	n	%	Mean	%	n	%	Mean	%
Copepoda	--	--	--	--	4	19.0	<0.005	<0.005
Decapoda	--	--	--	--	5	23.8	0.02	0.6
Amphipoda	1	3.2	<0.005	<0.005	2	9.5	<0.005	<0.005
Cumacea	--	--	--	--	1	4.8	<0.005	<0.005
Squid	23	74.2	4.44	82.4		--	--	--
Gadidae	3	9.7	0.08	1.5	6	28.6	0.97	27.2
Cottidae	2	6.5	0.42	7.8	1	4.8	0.35	9.8
Myctophidae	--	--	--	--	1	4.8	0.05	1.4
Pleuronectidae	--	--	--	--	1	4.8	0.07	2.0
Ammodytidae	--	--	--	--	4	19.0	0.82	23.0
Cyclopteridae	--	--	--	--	3	14.3	0.07	2.0
Stichaeidae	--	--	--	--	2	9.5	0.82	23.0
Agonidae	--	--	--	--	2	9.5	0.33	9.2
Unid. fish	5	16.1	0.47	7.6	2	9.5	0.06	1.7
Other	9	29.0	0.05	0.9	4	19.0	0.01	0.3
n	31 samples		$\bar{x}$= 5.39 g		21 samples		$\bar{x}$= 3.57 g	

Table 19. Standardized wet weights of food found in adult and chick samples of thick-billed murres at the Pribilof Islands, 1984.

Location	Food Taxa	Standardized Wet Weight of Food 1 S.D. (n) Adults	 Chicks	Mann-Whitney Z	p
St. George	Crustacea	41.6 *46.9 (47)	3.2 ± 18.0 (31)	4.07	<0.01
	Squid	15.1*34*0 (47)	74.2 ± 44.5 (31)	4.70	<0.01
	Identified fish	22.1 ± 40.0 (47)	16.1 *37.4 (31)	1.41	0.16
St. Paul	Crustacea	0.0 ± 0.0 (lo)	1.1*2*1 (21)	2.02	0.04
	Squid	0.0 ± 0.0 (lo)	0.0 ± 0.0 (21)	--	. .
	Identified fish	100.0*0.0 (10)	89.4 ± 29.8 (21)	2.37	0.02
Both islands	Crustacea	34.3 *45.4 (57)	2.3 ± 13.9 (52)	3.33	<0.01
	Squid	12.4 *31.3 (57)	44.2 ± 50.2 (52)	2.62	<0.ol
	Identified fish	35.8 ± 47.0 (57)	45.7 *49.9 (52)	0.33	>0.05

Table 20. Diet composition of adult parakeet auklets collected at St. George Island, 1984.

Food Taxa	Occurrence		Wet Weight (g)	
	n	%	Mean	%
Copepoda	9	69.2	0.05	6.2
Decapoda	6	46.2	0.05	6.2
Euphausiacea	5	38.5	0.02	2.5
Amphipoda	3	23.1	0.03	3.7
Squid	1	7.7	<0.005	<0.005
Gastropoda	1	7.7	<0.005	<0.005
Unid. fish	10	76.9	0.59	72.8
Other	10	76.9	0.07	8.6
n	13 samples		$\bar{x}$= 0.81 g	

Least Auklet (Aethia pusilla)

During the 1984 study, 49 food loads brought to least auklet chicks by adults were collected--41 at St. George and eight at St. Paul. Most samples were obtained by netting birds as they flew into nesting areas and collecting any food material that they dropped. At St. George, samples were collected during July and August; at St. Paul, only during July (Table 21).

There were no significant differences in the composition of food loads collected at St. George in July and August (all U-test probabilities >0.01), nor were there any significant differences between the dietsof St. George and St. Paul birds (all test probabilities >0.01). The diet in all 49 food loads combined was primarily copepods (89% of wet weight) followed by equal amounts of decapods, amphipods and unidentified material (each 3% of weight), euphausiids (2%), unidentified fish (1.1%) and traces (<0.005%) of gastropod and oligochaetes.

Fifteen samples were selected at random from the 25 food loads with the highest gross weights. These samples were analyzed in detail (Table 22). Three species of calanoid copepods dominated the dietof these 15 birds. In descending order of abundance were Calanus plumchris, C. marshallae and C. cristatus. C. cristatus, however, was about twice the size of its congeners and hence dominated diet by wet weight, followed by C. plumchris and C. marshallae. Since many calanoid copepods were too digested to be identified to species, the taxon Calanus spp. was also an important dietary item (18% of items and diet wet weight). Least auklets brought food items to their chicks that ranged in average length from 3.6 to 13.0 mm.

Crested Auklet (Aethia cristatella)

Thirteen crested auklets were collected near St. George for food habits studies (Table 23). In this small sample of birds, wet weight diet was predominantly unidentified material (55%) and euphausiids(43%). Squid and copepods were taken in trace (<0.005%) amounts.

Table 21. Diet composition of adult least auklets collected at the Pribilof Islands, 1984.

Food Taxa	St. George, July				St. George, August				St. Paul, July			
	Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)		Occurrence		Wet Weight (g)	
	n	%	Mean	%	n	%	Mean	%	n	%	Mean	
Calanoida	8	38.1	0.95	40.9	4	20.0	0.27	22.5	3	37.5	0.92	36.4
Other Copepoda	13	61.9	1.12	48.3	16	80.0	0.76	63.3	5	62.5	1.38	54.5
Decapoda	17	81.0	0.06	2.6	13	65.0	0.02	1*7	7	&7.5	0.13	5.1
Euphausiacea	9	42.9	0.01	0.4	8	40.0	0.07	5.8	1	12.5	<0.005	<0.005
Amphipoda	16	76.2	0.07	3.0	14	70.0	0.04	3*3	2	25.0	<0.005	<0.005
Gastropoda	3	14.3	<0.005	<0.005	1	5.0	<0.005	<0.005	2	25.0	0.01	0.4
Oligochaeta	1	4.8	<0.005	<0.005	1	5.0	<0.005	<0.005	-	--	.-	--
Unid. fish	5	23.8	0.04	1.7	2	10.0	<0.005	<0.005	1	12.5	0.03	1.2
Other	20	95.2	0.06	2.6	7	35.0	0.03	2.5	4	50.0	0.06	2.4
n	21 samples $\bar{x}$= 2.32 g				20 samples $\bar{x}$= 1.20 g				8 samples $\bar{x}$= 2.53 g			

Table 22. Detailed diet composition in 15 least auklet samples chosen at random.

Food Taxa	Occurrence		Frequency		Wet Weight (g)			Length (mm)		
	n	%	n	%	Mean	S.D.	%	Mean	S J L	-9
Calanus marshallae	4	26.7	2,990	27.3	0.39	0.9	16.7	4.1	0.6	81
C. plumchris	6	40.0	4,221	38.5	0.58	1.0	24.8	4.6	0.7	150
C. cristatus	9	60.0	1,390	12.7	0.78	0.9	33.3	8.6	0.6	142
C. glacialis	1	6.7	50	0.5	0.03	0.1	1.3	8.2	0.5	25
C. Spp.	4	26.7	2,004	18.3	0.41	0.9	17.5	4.3	0.6	100
All Copepoda	15	100.0	10,655	97.3	2.18	1.3	93.2	6.1	0.6	498
Lithodidae spp.	2	13.3	79	0.7	0.03	0.1	1.3	6.4	0.9	30
Reptantia spp. (crabs)	7	46.7	43	0.4	0.01	0.0	0.4	7.9	1.4	30
Natantia spp. (shrimps)	9	60.0	72	0.7	0.02	0.0	0.9	11.3	2.8	38
Decapoda spp.	1	6.7	6	0.1	<0.005	<0 .005	+*	9.2	0.5	5
All Decapoda	13	86,7	200	1.8	0.06	0.1	2.6	9.5	1.9	103
Thysanoessa inermis	3	20.0	9	0.1	<0.005	<0.005	+	8.8	0.9	5
T. raschii	3	20.0	6	0.1	<0.005	<0.005	+	13.0	12.7	4
T. spinifera	1	6.7	7	0.1	<0.005	<0.005	+	?*5	0.6	. 4
T. spp.	5	33.3	4	<0.005	0.01	0.0	0.4	--	--	.-
All Eusphausiacea	8	53.3	26	0.2	0.01	0.0	0.4	10.4	5.2	13
Parathemisto Spp.	10	66.7	51	0.5	0.02	0.0	0.9	6.9	2.5	40
All Amphipoda	10	66.7	51	0.5	0.02	0.0	0.9	6.9	2.5	40
Limacina helicina	4	26.7	5	<0.005	<0.005	<0.005	+	3.6	0.4	3
All Gastropod	4	26.7	5	<0.005	<0.005	<0.005	4	3.6	0.4	3
Osteichthyes spp. (fish)	1	6.7	17	0.2	0.03	0.1	1.3	--	--	--
Other	11	73.3	--	--	0.02	0.0	0.9	--	--	--
n	15 samples		10,954 items		x̄= 2.34 g			657 Items		

*'+' denotes <0.1%.

Table 23. Diet of adult crested auklets collected at St. George Island, Alaska, 1984.

Food Taxa	Occurrence		Wet Weight (g)	
	n	%	Mean	%
Copepoda	2	15.4	<0.005	<0.005
Euphausiacea	10	76.9	0.17	42.5
Squid	1	?.7	<0.005	<0.005
Other	10	76.9	0.22	55.0
n	13 samples		$\bar{x}$= 0.40 g	

Tufted Puffin (*Fratercula cirrhata*)

In the eight tufted puffins collected near St. George, gadids comprised 85% of diet wet weight and occurred in five stomachs (Table 24)0 The diet of these birds was mostly fish (89%) with much smaller amounts of copepods, squid and unidentified material. .

Horned Puffin (*Fratercula corniculata*)

Fifteen adult horned puffins were collected during the study--one at St Paul and 14 at St. George. The diet of these adults was primarily squid, gadids and unidentified fish, although trace amounts (<0.005% of wet weight) of several kinds of crustacea and polychaetes were also eaten (Table 25). In three chick samples, *Hippoglossoides elassodon* (Pleuronectidae), *Ammodytes hexapterus* (Ammodytidae) and unidentified Gadidae were the fish species present.

DISCUSSION

Northern Fulmar

Hunt et al. (1981) collected five fulmar stomachs from the Pribilofs and five from elsewhere in the Bering Sea. The diet of those fulmars was somewhat different than that observed in 1984. In 1984, invertebrates comprised only about 3$ of diet wet weight but in the birds analyzed by Hunt et al., about 25% of diet volume. Like Hunt et al., I was unable to . determine whether the fish present in the fulmars were caught by the birds or scavenged from fishing operations. Pollock comprised most of the fish taken by Hunt's birds. In this study most of the fish remains present could not be identified to species.

Red-faced Cormorant

Compared to previous efforts by Hunt et al. (1981) over a four year period, few food samples were collected from red-faced cormorants in this study. Hunt et al. collected 169 samples, of which 127 were

Table 24. Diet composition of adult tufted puffins collected at St. George Island, Alaska, 1984.

Food Taxa	**Occurrence**		**Wet Weight (g)**	
	n	**%**	**Mean**	**%**
Copepoda	1	12.5	0.01	0.6
Squid	2	25.0	<0.005	<0.005
Gadidae	5	62.5	1.39 ,	84.8
Myctophidae	1	12.5	0.03	1.8
Unid. fish	1	12.5	0.04	2.4
Other	8	100.0	0.17	10.4
n	8 samples		$\bar{x}$= 1.64 g	

Table 25. Diet composition of horned puffins collected at the Pribilof Islands, 1984.

Food Taxa	ADULTS Occurrence n	%	Wet Weight (g) Mean	%	CHICKS Occurrence n	%	Wet Weight (g) Mean	%
Copepoda	5	33.3	<0.005	<0.005	1	33.3	<0.005	<0.005
Decapoda	3	20.0	<0.005	<0.005	-	--	--	. .
Euphausiacea	1	6.7	<0.005	<0.005	-	. .	--	. .
Amphipoda	1	6.7	<0.005	<0.005	-	--	--	. .
Squid	6	40.0	1.04	45.0	-	--	- -	- -
Polychaeta	1	6.7	<0.005	<0.005	-	- -	. -	--
Gadidae	7	46.7	0.60	26.0	1	33.3	0.03	1.3
Pleuronectidae		- -	--	- -	-	--	--	--
Ammodytidae		. .	- -	--	1	33.3	0.84	37.7
Unid. fish	7	46.7	0.54	23.4	1	33.3	1.36	61.0
Other	12	80.0	0.12	5.2	1	33.3	<0.005	<0.005
n	15 samples		$\bar{x}$= 2.31 g		3 samples		$\bar{x}$= 2.23 g	

regurgitations (according to Schneider and Hunt 1984), compared to the 22 taken during this study. Hunt et al. and Schneider and Hunt found more invertebrates and cottids in their regurgitations than did I. On the other hand, I found *Ammodytes* to be present in a larger proportion of, stomachs and in greater amounts than they did. Most of my samples were collected from a small section of cliff near Starya on St. George, and it can't be ruled out that the preponderance of *Ammodytes* was a local phenomenon. Too few cormorant samples were collected by me to make many generalizations about the birds' diets. I did, however, find some fish species not previously noted by Hunt et al. (*Trichodon trichodon* and *Pholis ornata*). Hunt et al. found significant differences in the diets of adults (stomachs) and chicks (regurgitations).

Black-legged Kittiwake

In the 80 black-legged kittiwakes collected at St. George, I was unable to detect sex-related differences in diet "but I did note some changes in diet from July to August, with the use of gadids and *Ammodytes* increasing over time. I detected similar time, but not sex, differences in the diets of St. Paul birds with a significant increased use of polychaetes from July to August. The time-trends I noted were only over a two month period but the trends observed generally agreed with those observed by Hunt et al. (1981) over a longer period (June to September) and with larger sample sizes (n=579). Unlike these authors, however, I found an increased use of polychaetes from July to August at St. Paul. In combining samples from both islands, Hunt et al. noted a general decrease in the use of polychaetes between these two months. Given the observed differences in adult diet between July and August, I did not combine all samples to look for differences between the diets of St. George and St. Paul birds. Schneider and Hunt (1984), however, did find such inter-island differences in the occurrence of nereids, euphausiids and pollock.

Red-legged Kittiwake

As noted by Hunt et al. (1981) and Schneider and Hunt (1984) red-legged kittiwakes feed largelyon myctophid fish which they apparently find at the shelf break at night. In this study, myctophids formed 54% of the wet weight diet of adult birds and 62$ of that of chicks. Hunt et al. (1981) noted some seasonal changes in diet but these were not statistically significant. I was unable to test for time-trends in diet because of the small number of August samples. The similarity in diet between adults and chicks noted in this study suggests that combining samples from adults and chicks (as was done by Hunt et al.) does not negate inferences made about time-trends in diet.

Commom Murre

Only small numbers of common murre food samples were collected during this study. Although some of the differences in diet composition between adults collected at the two islands were large, none was significant. Schneider and Hunt (1984) found that St. George birds contained greater numbers and volumes of euphausiids than did St. Paul birds, a finding corroborated by my meagre results.

Thick-billed Murre

In this study I found differences in the diets of adults as well as chicks between St. George and St. Paul islands. I also found significant differences indict between adults and chicks at St. George. Schneider and Hunt (1984) found few differences in adult diet between the two islands other thanan increased occurrence of euphausiids in St. George birds. Hunt et al. (1981) noted some non-significant seasonal trends in diet (decreased use of invertebrates over time concomitant with an increased use of fish). I was unable to detect such differences with the samples available to me.

Parakeet Auklet

In the small number of samples collected (n=15), unidentified fish were the dominant food taxon, representing 73% of wet weight. By contrast, Hunt et al. (1981), using 55 samples collected over four years, found invertebrates to be dominant (almost 75% of diet volume). In addition to the invertebrates recorded by Hunt et al., I also recorded decapods in the diets of parakeet auklets. They and copepods were the dominant invertebrates in the diet (each 6% of wet weight).

Least Auklet

The results from this study indicate that calanoid copepods, and especially Calnus plumchris, C. marshallae and C. cristatus dominate the diet of breeding least auklets. Hunt et al. (1981) reached a similar conclusion on the importance of copepods. Indeed, the overall composition of auklet diets in the two studies was quite similar.

Crested Auklet

Euphausiids comprised nearly all of the identifiable food material in the 13 crested auklet samples collected in 1984. Hunt et al. (1981) found that euphausiids and amphipods were major diet components in the 20 samples they analyzed.

Tufted Puffin

Gadids dominated the diet of the small number of tufted puffins collected in 1984 (85% of diet wet weight in eight birds). In 23 samples collected by Hunt et al. (1981), similar results were obtained.

Horned Puffin ,

In the 15 adults collected in 1984, squid comprised 45% of diet wet weight but squid comprised none of the food volume in 39 samples collected by Huntet al. (1981) from 1975 to 1978. Huntet al. also recorded many more fish species than I did but this may have been due to the tendency of these authors to combine adult stomachs and chick regurgitations.

Implications for the Monitoring of Seabird Diets

There are two main topics to be addressed in designing a monitoring system for seabird diets: What should be monitored? How should samples be collected and results be reported?

This study and those by Hunt et al. (1981) and Schneider and Hunt (1984) have shown differences in the diets of (1) birds of the same species collected at the same time on adjacent islands, (2) adults and chicks of the same species, and (3) the same species and age-classes of birds at different times during the breeding season. Obviously for a monitoring scheme to be successful, information must be gathered on the same kinds of birds from year to year. At the Pribilofs it would do no good to collect samples at St. Paul in one year and at St. George the next if diet varied by island and within year in the species being monitored. In some circumstances it would be reasonable to combine food samples collected in different ways. For example there were no differences in adult vs. chick diets in red-legged kittiwakes, so a collection of samples from adults and chicks would be a reasonable way to look at seasonal changes in diet. A similar approach would not be appropriate for thick-billed murres because adult and chick diets are dissimilar. Collections must be carefully controlled so that differences detected in the monitoring program reflect changes in diet and not changes in the kinds of birds being investigated, or in the methods being used to investigate such differences. Unfortunately, different bird species behave indifferent ways so it will probably always be necessary in diverse colonies like the Pribilofs to select representative species to be monitored. One consideration in the selection of such species should be the degree to which collections of samples can be controlled.

It is also important to recognize that certain methods of diet analysis are inherently more precise and can be demonstrated to be more consistently applied than others. As demonstrated in the 'Methods' section, weights measured on a quality digital balance are more precise, consistent and rapid than volumetric measurements. I recommend that wet weights be used as the standard method of reporting food studies results. Non-parametric statistical testing of weight and occurrence data. also seem to be more appropriate than parametric tests with their associated assumptions about normality.

SUMMARY

Food samples were collected from adults of 10 of the 11 species studied (not red-faced cormorant). The diets of these 10 species are summarized in Table 26. In 5 species (northern fulmar, both kittiwakes, parakeet auklet, tufted puffin) fish comprised greater than 80% of wet weight diet. In these other species (common murre, thick-billed murre, horned puffin) fish comprised 25-70% of diet wet weight, with the remainder being primarily crustaceans (in murres) or squid (in horned puffins). In the remaining two species (least and crested auklets), fish comprised less than 2% of diet wet weight, whereas crustaceans comprised greater than 94%. Based on these results, I conclude that, in general, adults of the 5 species in the first group are typically fish eaters; the murres and horned puffins take a varied combination of fish, crustaceans and squid; and least and crested auklets feed primarily on crustaceans. The diet composition of the 22 red-faced cormorant regurgitations was primarily fish.

The generality of these statements must be borne in mind. Differences in the diets of birds grouped by age, time, or island were found in 3 of the 4 species studied in detail. Only in least auklets was the diet similar between months and islands. Hence, when monitoring the diets of seabirds, it is important to control collections for various attributes of the birds' ages, collection locations and times of sampling.

I also found that wet weight measurements of food samples were more rapid, more precise and more consistent than were volumetric measurements. Wet weights are recommended as the preferred method of measuring the amounts of food eaten by seabirds. Generally, non-parametric statistical methods are more appropriate for analyzing differences in the amount of food eaten than are parametric methods.

Table 26. Summary of food habits of 10 species of seabirds at the Pribilof Islands, 1984, based on adult collection.

Species (No. of Samples)	% of Diet Wet Weight*				
	Crustaceans	Squid	Gastropods	Polychaetes	Fish
Northern fulmar (15)	0.3	0.6	+**		99.2
Black-legged kittiwake (102)	4.3	0.5	0.2	5.6	89.3
Red-legged kittiwake (51)	13.5	0.7		0.6	85.1
Common murre (16)	31.3				69.1
Thick-billed murre (57)	68.3	4.9			26.5
Parakeet auklet (13)	13.7	+	+		80.0
Least auklet (49)	98.3		+		1.1
Crested auklet (13)	94.4	+			--
Tufted puffin (8)	0.7	+			99.3
Horned puffin (15)	0.4	47.5		+	52.1

*The wet weight of the food taxon 'other' was assigned to major groups in a proportional fashion,

**+ designates taxon was present in trace amounts.

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APPENDIX

Appendix 1. Food samples collected from seabirds at the Pribilof Islands, Alaska, 1984.

Date	Island	Species	No. Birds Sampled	Types of Samples
1 July	St. George	Least auklet	12	12 AdS
9 July	St. George	Northern fulmar	8	8 AdS
		Black-legged kittiwake	28	28 AdS
		Red-legged kittiwake	3	3 AdS
		Common murre	5	5 AdS
		Thick-billed murre	9	9 AdS
		Horned puffin	2	2 AdS
18 July	St. Paul	Black-legged kittiwake	13	13 AdS
		Red-legged kittiwake	1	1 AdS
		Common murre	5	5 AdS
		Lesat auklet	11	10 AdS, 8 ChF
23 July	St. George	Leeet auklet	10	1 0ChF
24 July	St. George	Red-faced cormorant	1	1 ChR
25 July	St. George	Red-faced cormorant	1	1 ChR
		Red-legged kittiwake	3	3 ChR
26 July	St. George	Red-faced cormorant	4	4 ChR
		Red-legged kittiwake	3	3 ChR
27 July	St. George	Thick-billed murre	12	12 AdS
		Parakeet auklet	1	1 AdS
		Crested auklet	11	11 AdS, 11 ChF
28 July	St. George	Red-faced cormorant	5	5 ChR
		Black-legged kittiwake	14	14 AdS
		Red-legged kittiwake	31	29 AdS, 2 ChR
29 July	St. George	Red-faced cormorant	2	2 ChR
		Red-legged kittiwake	1	1 ChR
30 July	St. George	Black-legged kittiwake	30	30 AdS
		Red-legged kittiwake	16	15 AdS, 1 ImS
31 July	St. George	Northern fulmar	7	7 AdS
		Red-faced cormorant	5	5 ChR
		Red-legged kittiwake	1	1 ChR
		Common murre	2	1 AdS, 1 ChF
		Thick-billed murre	18	18 AdS, 1 ChF
		Parakeet auklet	2	2AdS, 1 ChF
		Least auklet	12	11 ChF, 1 ChS
		Crested auklet	2	2 AdS, 2 ChF
		Tufted puffin	6	6 AdS
		Horned puffin	7	7 AdS

Appendix 1 (cont.)

Date	Island	Species	No. Birds Sampled	Types of Samples
6 August	St. Paul	Black-legged kittiwake	2	2 ChR
		Common murre	4	4 ChR
		Thick-billed murre	12	11 ChR, 1 ChF
		Horned puffin	1	1 ChR
7 August	St. Paul	Black-legged kittiwake	1	1 ChR
		Common murre	2	1 ChR, 1 ChF
		Thick-billed murre	9	6 ChR, 3 ChF
8 August	St. Paul	Red-faced cormorant	2	2 ChR
		Black-legged kittiwake	13	9 AdS, 1 ImS, 3 ChR
		Red-legged kittiwake	1	1 AdS
		Common murre	4	4 AdS
		Thick-billed murre	10	10 AdS
		Horned puffin	1	1 AdS
10 August	St. George	Least auklet	19	19 ChF
11 August	St. George	Red-faced cormorant	2	2 ChR
		Red-legged kittiwake	2	2 ChR
		Thick-billed murre	10	7 ChR, 3 ChF
13 August	St. George	Common murre	1	1 ChR
		Thick-billed murre	11	9 ChR, 2 ChF
15 August	St. George	Black-legged kittiwake	8	8 AdS
		Red-legged kittiwake	2	1 ChR, 1 AdS
		Common murre	3	1 AdS, 1 ChR, 1 ChF
		Thick-billed murre	17	8 AdS, 8 ChR, 1 ChF
		Parakeet auklet	10	10 AdS, 6 ChF
		Tufted puffin	2	2 AdS
		Horned puffin	5	5 AdS, 2 ChF

(In this table Ad. adult, Im = immature, Ch = chick, S = stomach, R = regurgitation, and F = food load.)

CHAPTER V

A PROPOSED SEABIRD MONITORING STRATEGY, BERING SEA*

By

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INTRODUCTION

The United States OCS Lands Act Amendments of 1978 (92 Stat. 629) requires the monitoring of marine and coastal environments following oil and gas lease sales. This monitoring shall 'provide time-series and data trend information which can be used for identifying any significant changes in the quality and productivity of the environments, for establishing trends in the areas studied and monitored, and for designing experiments to identify the causes of such changes." The data provided by monitoring are also needed for inclusion in lease sale environmental statements.

The U.S. Minerals Management Service (MMS) has designated seabirds in the Bering Sea and Arctic Ocean breeding colonies as one environmental component that should be monitored in Alaska OCS areas, because these seabirds are (1) highly visible and major components of marine ecosystems, (2) protected by international treaties between the U. S. A., the U. S. S. R., Japan, and Canada, and (3) may be vulnerable to adverse effects of OCS lease development. Colonies at Cape Peirce and on the Pribilof Islands have been selected for monitoring studies in 1984.

Monitoring of seabirds, as defined herein, has two main purposes, as the OCS Lands Act Amendments make clear:

(1) To repeatedly measure bird populations over time so that population changes can be detected, and
(2) To identify the causes of such changes.

It is implied by the Lands Act Amendments that the causes of change should be sorted at least into those related to OCS leasing and those independent of OCS leasing activities.

The attributes of seabird colonies that should be monitored would logically be those valued by society. The most important variable thus seems to be bird abundance! though factors such as productivity that are known to regulate abundance may logically also be candidates for monitoring.

This chapter discusses concepts and principles of seabird monitoring in view of the legal mandates and needs of MMS in Alaska. Information from the literature and from studies conducted in 1984 at Cape Peirce and the Pribilof Islands are used to develop these discussions On the basis of the discussions, recommendations are made for the continuation of seabird monitoring programs in the Alaskan Bering Sea.

The following section provides a brief review of observed changes in seabird abundance at colonies and causes of those changes, with particular reference to the effects of OCS activities. Other sections use this information to evaluate strategies for measuring change in Alaskan seabird colonies and for determining whether OCS activities are implicated.

BACKGROUND: SEABIRD POPULATION CHANGES AND CAUSES OF CHANGE

It is clearly possible to measure changes in numbers and productivity of some seabird species at colonies. Bourne (1972) reported surveys of auk colonies in Britain that detected changes in guillemot (= common murre) numbers of about 50 percent and in razorbill (Alca torda) populations of about 20 percent. Lid (1981) documented relatively drastic changes in annual productivity of Atlantic puffins (Fratercula arctica) in the Lofoten Islands, Norway. Wanless et al. (1982) detected annual changes in murres and black-legged kittiwakes (nests and individuals) and northern fulmars (individuals) of ± 30 percent in Scotland. Gaston et al. (1983) were able, by intensive observation of breeding birds, to estimate total eggs laid by thick-billed murres within about 5 percent of the true numbers in N.W.T., Canada, colonies. Richardson et al. (1981) indicated that small changes (as low as 2-4 percent) in numbers of apparently occupied kittiwake nests could be detected between years in Shetland.

Causes of changes observed are more difficult to document, though many workers have observed what they believe are food-caused changes in abundance or productivity of many of the species that are found in Alaska. Bourne (1972) notes the deaths, suspected of being caused by starvation? of many guillemots in the Irish Sea in 1969. Gaston and Nettleship (1982) believed that numbers of thick-billed murres observed at a colony in Canada declined when food became scarce, simply because food scarity caused the birds to spend more time foraging at sea away from the colony.

Lid (1981) found high chick mortality in puffins in Norway to be caused by food shortages. Bourne (1976) suspected that an instance of mass mortality observed among common murres in the Irish Sea might have been caused by food shortages. Richardson et al. (1981) believed that declines in populations of some seabirds in the North Sea might have been caused by depletion of their food supplies by fishing fleets. Bailey and Davenport (1972) believed that a die-off of Common murres on the Alaska Peninsula and Unimak Island resulted from starvation precipitated by severe weather that prevented normal access to food. Hunt et al. (1981b) state that decreases in productivity of kittiwakes and other species in the Bering Sea are probably caused by changes in food supply. Springer et al. (1984) correlated changes in the reproductive success of murres and kittiwakes in the northern Bering and eastern Chukchi seas with apparent changes in stocks of fish prey possibly caused by alteration of meteorologic and oceanographic conditions.

The phenomenon of population regulation by food availability is widespread also among species of seabirds not common in the Bering Sea, lending additional support to the idea that birds in the Bering Sea might be regulated by food. Croxall and Prince (1979) note the large increases in several krill-eating penguin species in Antarctica after other krill (Euphausia superba) predators (whales) declined. Anderson and Gress (1984) found breeding success and winter populations of brown pelicans (Pelecanus occidentalis) to rise or fall with the abundance of their dominant prey, northern anchovies (Engraulis mordax). Burger and Cooper (1984) and Furness (1984) reported changes in the abundance of penguins, gannets and cormorants in South and Southwest Africa, and of most seabirds in Scotland, in response to changing food abundance caused by commercial fisheries.

Other causes of declines in seabird populations have been suspected, but none have been implicated to the extent that food shortages have. Bourne (1972) suggested several other possible reasons for observed declines of guillemots in the Irish Sea (i.e. poisoning from toxic chemicals, predation by gulls, oil pollution), but none of the possibilities was supported by evidence. Bourne (1983) mentioned some possible causes of change in seabird populations in general, including climatic fluctuations, mortality of birds in fishermen’s nets, introduction of predators to breeding colonies, and human exploitation. Cairns (1980) correlated locally decreased chick productivity with higher levels of human activity in the vicinity of a black guillemot colony in the St." Lawrence River estuary.

Several kinds of activities related to OCS development (e.g. oil spills, human activity or aircraft or boat traffic near feeding areas or colonies) are thought to be potential causes for declines in seabird abundance (Hood and Calder 1981a, Hameedi 1981). Of these, only spilled oil has been demonstrated to have appreciable effects, and in most cases the effects have been observed at spill sites but not at colonies. A series of oil spills in the North Sea at Orkney, Shetland, and north. eastern Scotland in late 1978 and early 1979 killed at least 4000 birds, mostly murres and razorbills (Richardson et al. 1981, 1982). One of these spills, that of the Esso Bernica, apparently caused declines in nearby colonies. In 1977 an oil spill at Bempton Cliffs, Humberside, British Isles affected over 1400 murres, and may have caused a substantial drop the following summer in numbers of murres in a nearby colony (Stowe 1982).

Efforts to model the effects of oil spills have been made, but the validity of model results is uncertain. Simulations of seabird damage and recovery from oil spills by Samuels and Ladino (1984) and by Samuels and Lanfear (1982) suggest generally higher levels of damage and much longer population recovery rates of seabirds from worst-case incidents than have been observed to occur. Ford et al. (1982) modeled the responses of murres and kittiwakes to three oil spill scenarios near breeding colonies at St. George Island in the Bering Sea, Alaska. Their models suggested that mortality might come indirectly from food-web impacts as well as directly by oiling of birds, but the literature reviewed does not report actual cases of oil-caused mortality on food-webs that have affected birds.

Several summary points about population change in seabirds, causes of this change, and effects of OCS activities appear relevant to development of a monitoring strategy. First, it is clear that changes in seabird populations and productivity are readily detectable in some species and in some situations, at sometimes quite low levels of change. Second, most observed changes in seabird numbers or productivity at colonies have been attributed to food shortages caused by natural or human-related phenomena (e.g., climate, weather, commercial fishing, elimination of competitors for food, etc.) that change the abundance of (or prevent access to) prey over broad areas. Third, the only OCS-related activities documented to appreciably affect seabird populations are oil spills; these effects have generally been observed as direct mortality near spill sites and only infrequently have resulted in measured changes at colonies. Modeling efforts have projected potentially larger and longer-lasting effects from large-scale oil releases than have been observed; models have also suggested that oil contamination might affect seabirds by reducing food supplies. The relationship between predicted and observed effects from oil spills and other OCS-related activities is perhaps best summarized by Bourne (1983):

> ". ..serious damage is seldom caused except on a purely temporary and local scale due to inexcusable carelessness (which still requires severe punishment). Otherwise the damage seldom appears to exceed that which occurs at intervals from other more natural causes, and, far from showing the delayed recovery expected from their low normal reproductive rate, the birds have been found to recover unexpectedly rapidly, presumably due to a relaxation of density-dependent population-limiting mechanisms."

PROPOSED MONITORING PLAN

Implications of the above discussions to the design of an effective seabird monitoring program that measures changes at colonies and sorts development-caused change from that caused by. other factors are several. It is clear that annual change in both numbers and productivity of seabirds frequently occurs, independently of OCS development, and that development-caused change is likely to be small in comparison. The only development activities that are likely to cause detectable changes at most colonies (given existing restrictions on chronic discharges of pollutants and on development activities near colonies) are probably those related to large oil spills; But even should large spills occur, their measurable effects on seabirds will almost certainly be localized, and" not distinguishable over large areas from natural variation. This "implies that (1) any monitoring measurements made over broad areas must be accompanied by measurements at sites of OCS activity while there is much hope of sorting consequences of oil-and-gas-related activities from consequences of other variables that affect seabird populations, and (2) broad-scale measurement schemes would best be oriented to detecting the kinds of changes that would be caused by oil pollution.

It is thus proposed that a useful monitoring program should include annually (or bi-annually) repeated measurements at selected colonies in the general regions of expected OCS activities, supplemented by experimental studies at specific sites (perhaps including places where oil has been recently spilled) to quantify effects of selected activities. On the basis of these considerations, detailed discussions of the strategies proposed for monitoring seabirds in the Bering Sea follow. First we discuss which variables should be measured and why. Then we recommend programs for detecting population changes and for determining whether changes are caused by OCS development.

Selection of Variables to Measure

Three characteristics of seabird populations commonly suggested as variables tobe measured in seabird monitoring programs are population numbers, productivity, and food habits (see solicitation and proposal for this project; Wiens et al. 1984). The main variable of interest to society, in terms of impact, is population numbers. Productivity data are collected to help interpret or predict changes in population numbers. Food habits data are collected to help interpret or predict changes in productivity and population numbers. Each of these variables needs to be evaluated for its usefulness to MMS for monitoring seabird populations.

The speciffic monitoring objectives determine which variables should be measured. In the following discussions we assume that the objectives are twofold--(1) to measure trends (look for long-term changes) in abundance of birds at colonies, and (2) to determine whether any changes observed are caused by OCS leasing and development. The second objective includes attributing cause of change to specific OCS activities such as oil spills, drilling operations, shore-based operations, and disturbance by aircraft, boats, or people near colonies.

There is potentially a third objective of monitoring, which we do not address in this report--to determine the ultimate causes of population changes that are attributable to other than OCS development activities. These causes might include such factors as changes in oceanic currents or water temperatures, climatic changes, or changes in commercial fishing pressures. Such an objective seems beyond the mandate of MMS, and a reasonable response to it is probably beyond the normal fiscal scope of monitoring programs. It would entail ecosystem process-oriented studies involving many disciplines, much time, and large sums of money. Further, it might not appreciably improve the ability of MMS to measure or predict the effects of leasing.

Population Numbers

The usefulness of this variable is immediately obvious. It is the major population characteristic by which society judges the value of seabird colonies. Relative to production, it is easier to measure in most species and tends to fluctuate less from year to year (see Ford et al. 1982, Hunt et al. 1981b). Most seabird monitoring programs use variation in number of presumed breeding adults as the primary measure of change in most species (e.g., Gaston et al. 1983, Wanless et al. 1982, Richardson et al. 1981). The best application of counting numbers of adults is in programs that measure the same colonies in a systematic manner over many years.

Productivity

Productivity has frequently been estimated at seabird colonies (usually as some measure of young produced per breeding pair) as a way of comparing the general 'health" of populations among years or, less commonly, as a tool in predicting change in population numbers. Attempts have frequently been made to correlate observed changes in productivity with causative mechanisms, and thus to isolate factors that ultimately control populations (see Lid 1981, Ford et al. 1982). Some authors (Lid

1981, Croxall and Prince 1979) have blamed persisting changes in productivity (caused by food supply changes or other factors) for long-term population changes.

Repeated measurements of productivity unselected colonies are of questionable value for establishing trends in populations. Because variability among years, and among locations within years, is frequently great under normal circumstances (Hunt et al. 1981b), productivity measures lend themselves poorly to discrimination of "abnormal" levels of productivity on a regional basis. Further, the effects of short-term variations in productivity on long-term breeding population levels is uncertain, and may be minimal (see Samuels and Lanfear 1981, Stowe 1982).

But productivity measurements may lend themselves well to assessing whether selected OCS activities have the potential to ultimately affect population numbers. Adult seabirds would not normally suffer mortality from such activities as increased noise, disturbance and people or predators near colonies, but their eggs and young might (see Cairns 1980). Further, because such activities tend to be spatially restricted (i.e. effects extending a few km or less from the source of disturbance), rigorous experiments with spatial controls could be readily conducted to determine whether OCS activities were the cause of observed productivity changes. At some sites existing activities (e.g., aircraft, boat, or human activity near colonies) might simulate what would be expected to occur with development, and experiments could be conducted prior to development.

Food Habits

In theory, because seabird populations are frequently regulated by food, food habits data would appear to help establish whether the causes of population changes are related to OCS development. That is, correlations found between food habits changes and population or productivity changes might suggest a prey-mediated effect of OCS development.

But in fact, food habits studies at colonies do not appear very useful either for regional long-term monitoring to examine population trends or for site-specific experiments. First, prey selection within species is frequently different among colonies, often for reasons that are not clear, and within-species diets may change within colonies between years and as the season progresses, sometimes for likewise unclear reasons (Hunt et al. 1981a). To further confuse attempts to correlate dietary variables with OCS activities, it is highly unlikely that OCS activities could affect seabird diets to nearly the extent that diets are affected by other forces that cause changes in food supply (e.g. weather, climate, ocean circulation, commercial fishing--see Springer et al. 1984, Furness 1984, and earlier discussions in this chapter under "BACKGROUND"). These natural forces commonly alter distribution, abundance, or accessibility of seabird prey over wide areas; OCS activities have not been found to have such widespread effects, nor does it seem likely that they in fact will have such extensive effects. Perhaps most important of all, seabirds are probably much more vulnerable to oil spills (the only industrial action that appreciably threatens prey) than is their prey. However, catastrophic diet changes have been linked to major population changes in some species of seabirds (see Lid 1981). If diets of seabirds are not monitored systematically in similar situations (e.g., Bering Sea), similar changes could be attributed arbitrarily to nearby OCS activities. There is some justification, therefore, for including feeding studies in seabird monitoring programs, especially if such studies are interdisciplinary and relevant information on prey availability is also being collected.

Given these considerations, it appears that (1) measured changes in the seabird diet, or in the seabird prey base, would be almost impossible to attribute to OCS-related activities, given the uncertainties about causes of dietary change and about the many natural forces that affect prey base availability, and (2) oil spills, the only conceivable OCS activity that might affect appreciable proportions of seabird prey, would probably affect the seabirds much more drastically by oiling their feathers than by killing or contaminating their prey.

Summary

Population numbers and productivity of seabirds, and in some cases possibly food habits, appear to be useful variables to measure in a monitoring program. Repeated measures of breeding bird population levels would be useful for monitoring long-term population trend in several key locations over a number of years. Measures of′ productivity are most useful for controlled, site-specific experiments to determine short-term consequences to seabird populations of selected OCS activities. Measures of population levels alone will not be able to establish whether change has been caused by OCS development; localized experiments alone probably cannot determine whether changes found to result from OCS activities will have regional or long-term population effects. Both methods used in combination, and possibly combined with food habit studies, is the only reasonable way to measure population trend and validly examine whether changes in trend are development-related.

Monitoring for Population Trend

Attributes of Monitored Species

Reliable estimation of regional changes in seabird numbers requires an initial selection of species appropriate for monitoring. These species should be abundant with a relatively widespread breeding distribution over the area of interest (i.e., Bering Sea) (see Richardson et al. 1981, 1982; Croxall and Prince 19799, and should have population parameters that are relatively easy to sample, e.g., habitats are relatively easy to sample; breeding adults, subadults, nests, eggs, and feeding young are relatively easy to count. The group of species selected should include representatives of all the important foraging types (e.g., those that feed on the benthos, at the sea surface, in nearshore environments, etc.--see Croxall and Prince 1979). Additionally, some information should be available on the history of the population (size of colony, number of breeding pairs, previous disturbances, etc. in earlier years). Ideally, the species" should be relatively sensitive to perturbations from activities expected to accompany oil and gas development. Any species whose distribution is restricted to the area of interest should also be considered in any regional monitoring program (e.g., an auklet, or the red-legged kittiwake in the Bering Sea), because large proportions of world populations of such species may be at risk. We used these attributes as criteria for selecting key or important species for investigation in a regional type of monitoring program, as discussed in the following section.

Species to be Monitored

Initially, we have identified 14 species that occur over a reasonably wide area in the Bering Sea (exclusive of the Aleutian Islands) in appreciable numbers (thousands of individuals). All of these are of interest, but all need not be monitored. In general, most previous studies have concentrated on the cliff-nesting species (murres, kittiwakes, cormorants) and neglected the hole- or cavity-nesting species (auklets, puffins), because the cliff-nesting species are most easily sampled and several species frequently can be monitored simultaneously. The cavity-nesting species require more intensive study effort, usually individual attention to each species.

We arranged the initial 14 species and the selection criteria (attributes discussed earlier) in a matrix (Table 1). A score of 0-3 was assigned to each cell in the matrix for each species. Although feeding characteristics are an important attribute and a necessary criterion in, any consideration of seabird monitoring, they were not included in the matrix because of the complexity in assigning a score on the basis of how birds foraged. Nevertheless, the top five species (red-legged kittiwake, thick-billed murre, black-legged kittiwake, least auklet and red-faced cormorant) selected for monitoring (Table 1) provide a good cross-section of species with different food habits and feeding strategies in the Bering Sea (Hunt et al. 1981a, Bedard 1969a, Searing 1977, Wehle 1980). As well, each of these species has all or most of the other attributes considered desirable for monitoring.

Colonies to be" Monitored

We identified 11 colonies in the Bering Sea (exclusive of the Aleutian Islands) most of which support appreciable numbers (thousands) of seabirds. All of these (plus others) may be of interest, but all. need not be monitored. An evaluation of the 11 colonies is given in Table 2. We

Table 1. An example of a possible scheme for evaluating seabirds for monitoring in the Bering Sea, Alaska.

Attributes	Murres		Puffins		Auklets			Cormorants		Kittiwakes/Gulls			Pigeon	Northern
Selection Criteria	TB	CO	HO	TU	LE	CR	PA	RF	PE	BL	RL	GWGU	Guillemot	Fulmar
A. Abundant and Widespread	3	2	1	2	3	2	2	2	2	3	1.5	2	0.5	2
B. Monitoring Parameters Quantifiable	3	2	0.5	1	1	1	1	3	3	3	3	2.5	0	2
C. Historical Data	3	3	0.5	0.5	2	1	2	1	1	3	3	1	0.5	2
D. Especially	0	0	2	1	2	2	1	2	1	0	3	1	0	0.5
Score*	9	7	4	4.5	8	6	6	8	7	9	10.5	6.5	1	6.5
Rank	2.5	6.5	13	12	4.5	10.5	10.5	4.5	6.5	2.5	1	8.5	14	8.5

● Scores were separately and independently assigned by two biologists. No major differences in ranks occurred; minor differences were resolved through compromise (e.g., scores of 0.5, 1.5, 2.5, 3.5, 4.5 and 5.5).

Table 2. An example of a possible scheme for evaluating seabird colonies for monitoring in the Bering Sea, Alaska.

Attributes/ Selection Criteria	Pribilof Is.	St. Matthew/ Hall Is.	Nunivak Is.	Cape Seniavin	St. Lawrence	Amak Is.	Cape Peirce/ Shaiak Is.	Bluff	Cape Newenham	King Is.	Little Diomede Is.
A. Appreciable # of Key Species Present at Colony	3	2	1	0.5	2	0.5	1	1	1	1	1.5
B. Amenable for Study	3	1.5	2	1.5	3	1.5	2	2.5	2	1	1
C. Historical Data	3	2	1.5	0.5	3	1	2	2.5	1	1	1
Score*	9	5.5	4.5	2.5	8	3	5	6	4	3	3.5
Rank	1	4	6	11	2	9.5	5	3	7	9.5	8

* Scores were separately and independently assigned by two biologists. No major differences In ranks occurred; minor differences were resolved through compromise (e.g., scores of 0.5, 1.5, 2.5, 3.5, 4.5 and 5.5).

used the same evaluation procedures for the colonies as we did for seabird species in Table 1.

An additional important attribute of a colony, when one considers a region-wide monitoring program in the Bering Sea, is its location relative to different development basins (Fig. 1) and/or major oceanographic and physiographic features (e.g., shelf breaks, water masses, straits, gyres; . see Hood and Calder 1981b). We have not listed this as an attribute in the matrix, "again because of the complexity in assigning a single score. Nevertheless, the top five colonies (Pribilof Islands, St. Lawrence Island, Bluff, St. Matthew Island, Cape Peirce; see Table 2) selected for monitoring on the basis of the other attributes, provide a good cross-section of different locations (northern and southern mainland, northern and southern offshore)? different development areas, and different oceanographic and physiographic features.

Monitoring for Effects of OCS Development

As noted earlier, site-specific experiments are recommended to evaluate whether specific OCS development activities will cause changes in populations. These experiments should be conducted when OCS activities take place near seabird aggregations (e.g., where onshore or nearshore activities occur near colonies or where offshore activities occur in feeding areas). Because accidentally spilled oil is the most likelyof activities to cause large adverse effects, it would be very useful to site experiments at an oil spill. Unfortunately, because sites of accidental spills cannot be predicted, and because many effects of a spill may not still be evident by the time experiments can be mobilized, the most that can be done in such cases may be to count oiled or dead birds as quickly as possible after a spill occurs to acquire a mortality estimate. But it should be relatively easy to test the effects of planned activities that persist for relatively long periods.

Except for oil spills, OCS activities would not be expected to cause appreciable mortality to adults, but they have the potential to locally alter production of young (see Roseneau and Herter 1984), which over the long term could alter adult numbers. Thus, measures of productivity seem the most logical approach to testing for the effects of development. (See

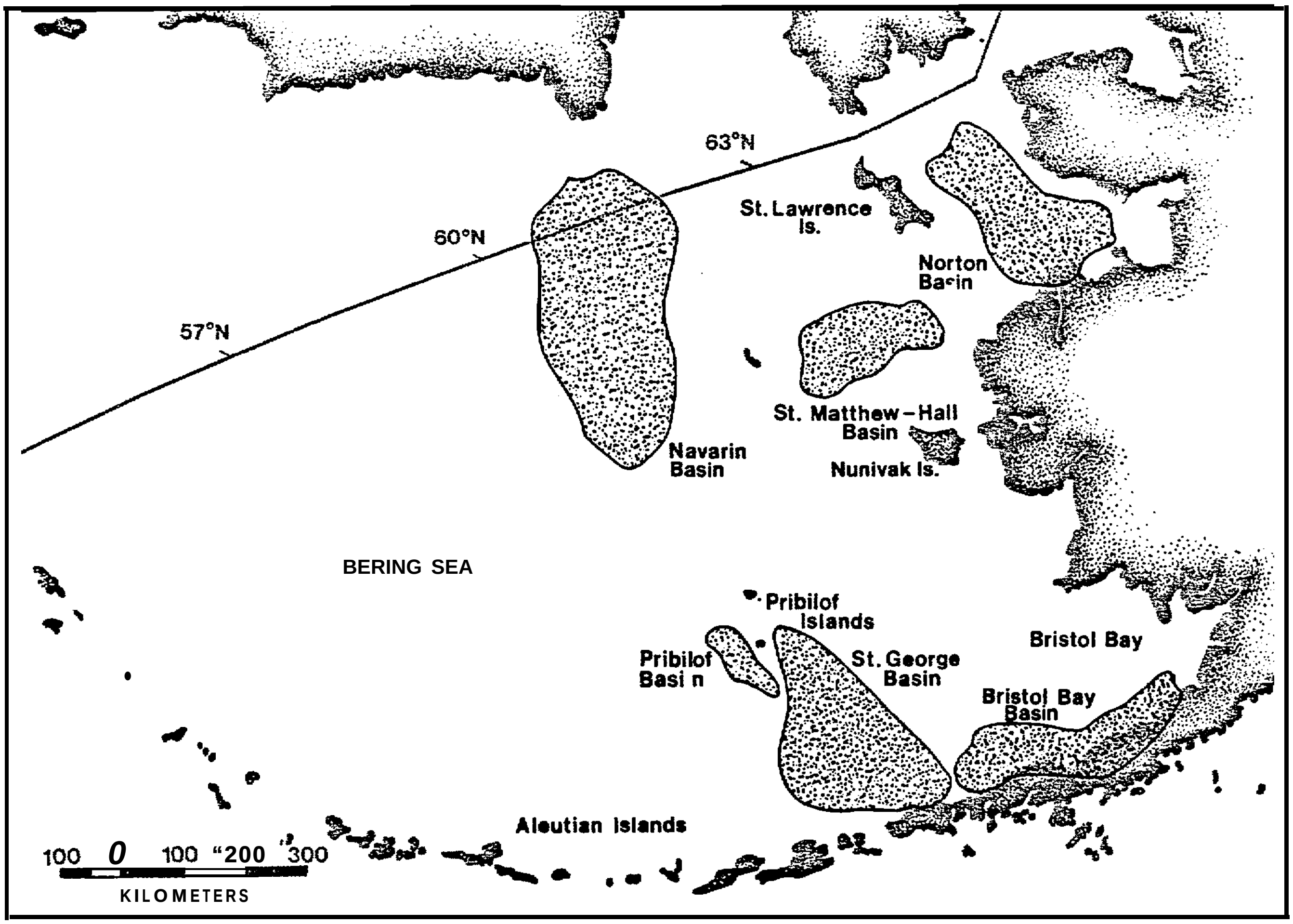

Figure 1. Development basins in the Bering Sea (from Lewbel (cd.] 1983).

also discussions in the previous section "Selection of Variables to Measure".)

Rather than basing a productivity monitoring program on species and colonies whose attributes are best for monitoring, the program would be based on hypotheses and experiments designed to investigate the cause-and-effect relationship between a specific OCS activity and the seabirds most likely to be affected (i.e., those nearby). This approach to monitoring has the best chance of establishing cause-and-effect relationship between OCS oil and gas activities and seabirds. Coupled with a region-wide monitoring program (to place the experimental results in a broader perspective), this site-specific approach to monitoring also has the best chance of predicting the consequences to regional populations of specific OCS oil and gas activities.

OCS oil and gas activities that could have impacts on seabirds in the Bering Sea have been described in several recent documents (Hameedi 1981, Roseneau and Herter 1984, Truett 1984), and generally fall into the following eight categories: 1) large oil spill, 2) small pollutant release, 3) chronic operational discharges 4) seismic testing, 5) vessel traffic, 6) aircraft traffic, 7) onshore construction, and 8) dredging and pipeline construction. All of these activities? depending on their timing and location, could have negative consequences on seabirds.

We have not attempted to formulate hypotheses or to design experiments to test these hypotheses. These activities are best done where participants from a variety of disciplines and affiliations can interact and make contributions (see LGL et al. 1984). We simply describe a reasonable generic productivity sampling design to detect changes that might lead to long-term population effects. Proposed methods follow.

SUMMARY

Legislative mandate requires that MMS conduct monitoring programs following oil and gas lease sales on Alaskats continental shelf to examine long-term trends in environmental quality-and productivity and to determine whether any changes observed in such trends might have resulted from OCS oil and gas development. MMS has decided that seabird populations should be one of the ecosystem components to be monitored in the Bering Sea. The objectives of a seabird monitoring program would be to measure trend in populations and to determine if observed changes in trend are development-related. Potential items to be monitored include population numbers and productivity. Measures of seabird diet may help interpret observed productivity and population changes.

Past research has demonstrated that small to moderate changes in numbers and annual production of seabirds at colonies can be documented. Causes of change are more difficult to determine, though changes in food availability, resulting from such things as fishing by man, large-scale shifts in ocean circulation or climatic changes, have been implicated. There is no indication from the literature that any activities related to OCS development, except for oil spills, have caused population changes to seabirds.

A monitoring plan must measure both long-term trends at bird colonies and determine whether OCS activities cause population changes. A combination of two approaches seems desirable to meet these requirements-- (1) repeated measures of population numbers over time at selected colonies to determine trends, and (2) experiments at sites of OCS activity to determine whether the activities affect annual productivity. Trend measurements alone cannot isolate causes of change, and results of experiments at sites of OCS activities cannot, without trend measurements, be readily translated into regional population-level effects. It does not appear that food habits studies would contribute a great deal to determining whether bird populations change or to establishing whether OCS activities caused the changes.

For measuring regional trends in population “numbers over time, monitoring should focus on species that are abundant, widespread, and easily sampled. Species that are unique or endemic to the area are of particular interest. At least one species from each major foraging type (e.g., benthic, surface, nearshore, offshore) should be included if possible. In the Bering Sea, the five most suitable species are, in approximate order of suitability: red-legged kittiwake, black-legged kittiwake, thick-billed murre, least auklet, and red-faced cormorant. Colonies that would be most suitable as trend monitoring sites, based on the number and diversity of seabird species present, ease of study, and amount of historical data available are those on the Pribilof Islands, St.

Lawrence Island, Bluff, St. Matthew/Hall islands, and Cape Peirce/Shaiak Island. Other colonies are considered less suitable.

The primary variable of interest for trend monitoring is population numbers, and several considerations apply. Two parameters need to be estimated: 1) the number of birds in attendance and 2) the number of nests or breeding birds. Distributional characteristics of most seabirds in colonies suggest the best enumeration techniques involve stratifying cliff faces on which birds occur, counting of birds on sample plots, and accounting for clustering of birds in statistical treatment of data. Patterns of temporal variability in bird attendance at colonies suggest that at least five replicate counts should be made. Time-lapse photography is a useful tool to acquire important time-series information Counts should be designed (e.g., collapsible into simpler forms) so that data collected can be readily compared with data from previous studies.

For determining whether OCS activities contribute to seabird population changes, site-specific studies of the effects of selected activities on productivity are recommended. Studies with experimental controls in space should be designed around specific activities that occur near seabird colonies or feeding areas. The measured effects of these activities on colony productivity should be translated into potential long-term effects on regional population numbers so that correlations may be made with results of the trend monitoring studies (see above). Unfortunately, the activity most likely to affect population numbers is probably an accidental oil spill, effects of which would be difficult to experimentally evaluate because locations of spills are not predictable. The most that canbe hoped for in such a case wouldbe to quantify oil-caused mortality to the extent possible and attempt to relate mortality level to observations at trend monitoring stations (e.g., at Colonies).

Productivity data collected on test and control sites should be amenable to rigorous statistical tests for differences among locations and years. Passive methods for determining productivity (e.g., observations from a distance) are recommended to prevent reduced productivity as a consequence of the research activity. Automatically-controlled camera systems to regularly photograph sample plots offer promise in both population and productivity studies.

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