APPENDIX E

APEX: 96163E

Exxon Valdez Oil Spill
Restoration Project Annual Report

KITTIWAKES AS INDICATORS OF FORAGE FISH AVAILABILITY

Restoration Project 96163E
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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STUDY HISTORY

Field work for project 95163E began during the summer of 1995 and consisted of detailed studies of the reproductive biology and foraging ecology of Black-Legged Kittiwakes in Prince William Sound (PWS), Alaska. In 1995, studies were conducted at one colony in northeastern (Shoup Bay) and two colonies (Eleanor Island and Seal Island) in central PWS. Research at Shoup Bay was conducted in conjunction with ongoing studies funded by the U.S. Fish and Wildlife Service (USFWS). In 1996, we expanded the study to include North Icy Bay rather than Seal Island, thereby having sites representing northeastern (Shoup Bay), central (Eleanor Island), and southwestern (North Icy Bay) PWS. Additionally, we can make comparisons with long-term demographic (Shoup Bay) and population studies (all of PWS) conducted by the USFWS. This allows us to more accurately address relationships of variation in prey and decadal trends in populations.

ABSTRACT

The distribution of Black-legged Kittiwakes (*Rissa tridactyla)* nesting in Prince William Sound (PWS), Alaska has changed dramatically since the early 1970's. Sixty-three percent of the population now nests in northern PWS compared to 30% in 1972. Population analyses indicated that between 1984 and 1996, productivity at five northern colonies ($n = 9$) was sufficient to maintain a stable or net population increase (fledgling production $\geq$ adult mortality) while productivity at all southern colonies ($n = 18$) was insufficient to maintain the population (fledgling production $<$ adult mortality). These changes and trends corresponded with a decrease in the availability of high quality forage fishes in the Gulf of Alaska (GOA). We hypothesize that these changes in the GOA primarily affected kittiwakes in the southern PWS where oceanographic conditions and prey associated with the Alaska Coastal Current are more similar to those found at colonies in the GOA. This resulted in a shift of the nesting population to the north where local forage fish production (primarily Pacific herring, *Clupea pallasi*, and Pacific sand lance, *Ammodytes hexapterus*) allowed high kittiwake productivity in PWS compared to the GOA. As part of the APEX project we are conducting detailed studies of three kittiwake colonies located in northeastern (Shoup Bay), central (Eleanor Island), and southwestern (North Icy Bay) PWS. Based on the above hypothesis, we would expect the Shoup Bay colony to be most successful followed by Eleanor Island and North Icy Bay. Our results for 1996 partially support this hypothesis and, in cooperation with other APEX components, will allow us to further examine the relationship between PWS and GOA ecosystems. Additionally, results of these studies will help determine factors limiting the productivity of kittiwakes in portions of PWS.

In 1990, the year following the *T/V Exxon Valdez* oil spill, productivity of Black-legged Kittiwakes in Prince William Sound (PWS) decreased and had not recovered as of 1995. Studies during this period indicated the decline in productivity resulted from decreased food availability and increased predation. Data collected in 1996 provided the first evidence that food availability may have been similar to conditions prior to 1990.

Data collected during this study and Irons (1992) will allow us to model relationships of reproductive success, chick diets, chick growth rates, and foraging effort, as indicators of relative prey quality and availability. By working with other APEX components and the SEA project (EVOS project #320), the above parameters can be used to predict the effects of changes in oceanographic conditions and forage fish availability on population dynamics of kittiwakes in PWS.

INTRODUCTION

Seabirds have been recognized as potentially useful indicators of marine resources by many authors (Ashmole 1971, Boersma 1978, Crawford and Shelton 1978, Anderson and Gress 1984, Ricklefs et al. 1984, Cairns 1987, Croxall et al. 1988, Monaghan et al. 1989, Harris and Wanless 1990, Furness and Barrett 1991, Furness and Nettleship 1991, Hamer et al. 1991, Hunt et al. 1991). Availability of food resources affect foraging success, which in turn affects reproductive output. Several reproductive parameters have been proposed as useful indicators: breeding phenology, clutch size, breeding success, chick diets, chick growth rates, adult colony attendance, adult activity budgets, foraging trip duration, and adult mass (Cairns 1987, Croxall et al. 1988).

Although foraging behavior partially determines reproductive output, the nature of this relationship may be complex. Optimal foraging models predict precise behaviors that are assumed to maximize fitness (Schoener 1971, 1987, Pyke 1984, Stephens and Krebs 1986). In contrast to the idea of optimality, evidence indicates there is a range of foraging effort over which reproductive output is not affected (Costa and Gentry 1986, Burger and Piatt 1990, Irons 1992). For example, Cairns (1987) suggested that adult survivorship changes only when food is in very short supply while activity budgets change only during medium and high levels of food availability. The phenomenon responsible for this uncoupling of foraging effort and reproductive output above threshold levels of food abundance has been termed a "buffer" (Cairns 1987, Burger and Piatt 1990). A buffer can be defined as the surplus capacity to forage. Buffers can be used to compensate for periods of low food availability so that reproductive output is maintained even though food is less available. Cairns (1987) also pointed out that activity budgets may be better than reproductive parameters as indicators of changes in food supply; the effects that changes in food supply have on reproductive output may be reduced by parents altering their foraging behavior to compensate for shortages. Burger and Piatt (1990) and Irons (1992) found evidence of this in common murres (*Uria aalge*) and black-legged kittiwakes, respectively.

In addition to understanding how food shortages affect productivity of seabirds, it is important to understand how seabirds find their food in order to identify which processes break down during a food shortage. Many species of seabirds, including black-legged kittiwakes and marbled murrelets (*Brachyramphus marmoratus*), forage in flocks (Sealy 1973, Hoffman et al. 1981, Duffy 1983, Harrison et al. 1991) which apparently increase foraging efficiency (Lack 1968, Morse 1970, Sealy 1973, Hoffman et al. 1981, Wittenburger and Hunt 1985, Gotmark et al. 1986, Harrison et al. 1991). The formation of seabird feeding flocks is enhanced by a form of information transfer termed "network foraging" (Wittenburger and Hunt 1985), which results in seabirds learning of and joining feeding flocks by observing the flight of other seabirds as they fly toward a feeding flock (Gould 1971, Sealy 1973, Hoffman et al. 1981). However, the importance of flock foraging has been questioned by Irons (1992), who found that much foraging by breeding kittiwakes occurred outside of foraging flocks.

During the 1995 and 1996 nesting season, productivity, chick diets, and foraging of kittiwakes were monitored at three colonies in PWS. We addressed three of the ten APEX project hypotheses:

1) Seabird diet reflects changes in relative abundance and distribution of forage fishes around colonies.
2) Changes in seabird productivity reflect changes in availability of forage fishes as measured in foraging trips, chick meal size, and chick provisioning rates.
3) Seabird species within a community react predictably to different prey bases.

METHODS

Study Area

This study was conducted in Prince William Sound (PWS), a 10,000 km^2 inland marine/estuarine waterway located along the north coast of the Gulf of Alaska (Fig. 1). The abundant fjords, bays, and islands in PWS provide shoreline habitat in excess of 4000 km. This area is also characterized by heterogeneous bathymetry and large tide height variation causing eddies and upwelling which likely affect the distribution of forage fishes and availability to seabirds (Irons 1992).

Population Dynamics

Estimates of the nesting population of Black-legged Kittiwakes in PWS were first conducted in 1972 by Isleib and Kessel (1973). In 1984, David Irons (1996) began collecting annual population (nest counts in mid June) and productivity (chick counts in early August) data from all colonies (n = 27) in PWS (total of 13 years including 1996). Additionally, an intensive banding effort was initiated at Shoup Bay in 1988. This consisted of color-banding 500 kittiwake chicks each year. In 1991, about 850 were captured and color-banded for individual identification and annual resighting efforts (1991 to 1996) have been conducted to estimate adult survival rates (Golet et al. in review). By using these data and treating individual colonies (initially) and PWS (secondarily) as closed populations (assuming no immigration or emigration) we addressed the working hypothesis:

1) Demographic parameters can be used to explain observed changes in populations at individual colonies and PWS as a whole.

Recruitment required to maintain a population at equilibrium is defined by :

$$fecundity = \frac{1 - FSR_{adult}}{FSR_{juv}}$$

where fecundity is the number of female offspring/female/year, FSR_{adult} is the finite survival rate of adults and FSR_{juv} is the finite survival rate of juveniles (Ricklefs 1973). Estimates of adult survival were obtained from kittiwakes at Shoup Bay, PWS (mean = 0.922; Golet et al. in review). We are in the process of calculating juvenile survival and mean age at first breeding for kittiwakes at Shoup Bay. For these analyses, however, we used first year survival (0.79; Coulson and White 1959) and mean age at first breeding (4 to 5 years; Wooler and Coulson 1977; Porter and Coulson 1987) from studies at the North Shields colony in Scotland. We used adult survival rate as a conservative estimate for juvenile survival from age 1 to breeding age and a fledgling sex ratio of 50:50. Given these demographic parameters, a population would have to produce 0.24 to 0.27 young per nest (or female) for the population to replace itself. Therefore, a productivity (fledglings/nest) of > 0.27 produced a net population increase, < 0.24 produced a net decrease, and 0.24 to 0.27 was considered a stable population.

Treating each colony as a closed population, we determined if immigration or emigration occurred by comparing projected colony sizes to actual counts between 1984 and 1996. Estimated colony sizes were determined by using a population projection matrix (birth pulse model for a post-breeding census; Leslie 1945, 1948) with the above demographic parameters, and number of fledglings produced each year. For initial analyses we assumed a probability of breeding of 100%.

Colony Studies

Primary Black-legged Kittiwake colonies studied during the 1996 nesting season in PWS were located near Shoup Bay, Eleanor Island, and North Icy Bay. In 1996, Shoup Bay was the largest kittiwake colony (6537 nests, an increase of 5106 nests since 1984) in PWS, Eleanor Island was a relatively small colony (268 nests, relatively stable since 1984), and North Icy Bay was of moderate size (1877 nests, an increase of 1680 nests since 1984).

Between 2 June and 16 August, the contents of Black-legged Kittiwake nests were recorded every three to seven days at colonies near Shoup Bay (206 nests in 12 plots), Eleanor Island (286 nests, entire colony), and North Icy Bay (162 nests; 11 plots). Only nests built before 20 June were included in the plots.

To determine growth rates, measurements of chicks were recorded every four (Shoup Bay and Eleanor Island) to eight days (North Icy Bay) from hatching to fledgling. Recorded measurements included head plus bill (± 0.1 mm), tarsus (± 0.1 mm), wingchord (±1 mm), tenth primary (±1 mm), and total mass (±1 g) of bird. Growth was calculated as mass gain per day during the near-linear growth phase of 60 to 300 g; producing results that are virtually identical to

Ricklef's (1967) maximum instantaneous growth rates (Galbraith 1983). Additional measures of growth will be evaluated during further data analyses.

Chick diet samples (regurgitations) were collected while handling chicks, weighed to the nearest 0.01 g on an Ohaus top-loading balance, and frozen. Typically, no more than one sample was collected per chick. Prey were identified using otoliths (all species) and scales (Pacific herring).

Adult Black-legged Kittiwakes were captured at their nests using a noose pole or leg noose and radio transmitters (Advanced Telemetry Systems, Inc (ATS), 166 - 167 MHZ, 10 g) were attached to 38 birds at Shoup Bay, 24 birds at Eleanor Island, and 20 birds at North Icy Bay. At Shoup Bay and Eleanor Island, each transmitter had a unique frequency. At North Icy Bay, three transmitters for each frequency were differentiated by pulse widths of 145, 185, and 195 milliseconds. Transmitters were attached (using two plastic cable ties and Loctite 494 instant adhesive) to the ventral surface at the base of tail feathers (Anderson and Ricklefs 1987; Irons 1992). Head, breast, tail and underwings of radio-tagged kittiwakes were dyed (Nyanzol D and Rhodomine B) one of three unique color combinations. The dye permitted easy identification of kittiwakes during tracking.

A remote receiving station (RRS) recorded the presence of radio-transmittered kittiwakes at Shoup Bay, Eleanor Island, and North Icy Bay colonies. A RRS consisted of an ATS data collection computer (DCC) connected to an ATS receiver and a dipole (Shoup Bay and Eleanor Island) or two element "H" antenna (North Icy Bay). A reference transmitter was placed on the colony to verify continuous operation of the DCC. Frequencies beyond the range of transmitters ("dummy frequencies") were input into the DCC to test for radio interference. The RRS was powered by an 80 amp/hr deep cycle, lead-acid battery, which was charged by a three amp solar panel. The DCC's at Shoup Bay and Eleanor Island continuously scanned each frequency (including high/low brackets $\pm$ 2 KHz, reference transmitter, and three dummy frequencies) for approximately twenty seconds every ten minutes. DCC's at North Icy Bay continuously scanned each frequency for approximately one minute every ten minutes. The DCC at Shoup Bay required a little less than 45 min for a complete scan of all frequencies (including high/low brackets, allowing three opportunities to receive each frequency). A kittiwake was, therefore, considered absent from the nest if the transmitter signal was not received for > 45 min.

Foraging trip duration, distance, location, and behavior were determined while tracking radio-tagged kittiwakes from a 7.3 m Boston Whaler with an ATS receiver and a four element yagi antenna. Kittiwakes rearing chicks were selected for tracking. Observers waited near the colony until a radio-tagged bird left, then attempted to keep the kittiwake in view until it returned to the colony. Behaviors recorded included traveling (straight flight), searching for prey (back and forth flight), foraging (surface plunge or surface seize; Ashmole 1971), resting, and lost (bird out of view) . Since duration of pursuit and handling of prey for kittiwakes is negligible compared to search time (Irons 1992), foraging was combined with searching in final analyses. Observers also recorded locations of foraging flocks and whether the radio-tagged kittiwake joined or passed the foraging flock. Foraging flocks included any seabird species and were divided into three categories; 1) foraging flock ($\geq$ 2 birds flying back and forth with at least two surface plunge or surface seize locations less than 10 m apart), 2) dispersed foraging flock ($\geq$ 2 birds foraging in an area > 10 m and < 500 m), and 3) potential foraging flock ($\geq$ 2 birds flying back and forth with < 2 foraging attempts within a 500 m diameter). Locations of foraging kittiwakes, foraging flocks, and flight paths of radio-tagged kittiwakes were determined using a Lowrance LMS-350A geographic positioning system receiver (GPS). The computer program Atlas GIS was used to plot foraging trip locations and measure distance to shore for foraging kittiwakes, maximum foraging distance from colony (shortest distance without intersecting land), and total trip distance.

In addition to tracking efforts at Shoup Bay and North Icy Bay colonies, we also used a series of telemetry surveys to obtain at-sea locations of birds from these colonies. The telemetry surveys consisted of traveling by boat along a designated route encompassing expected foraging ranges and monitoring radio frequencies for presence or absence of radio-tagged birds.

In addition to adult kittiwakes captured for radio-tagging, adults were also captured during the late chick rearing period at the three colonies. Morphometrics obtained from these birds were used to compare body condition between incubation and chick rearing and among sites. Principal components analysis (SAS 1988) was used to calculate body size indices which were plotted against corresponding masses. A regression of body size index versus mass was calculated to compare mean residual mass between early and late season and among sites.

RESULTS

Analyses of data collected are not complete and considered preliminary. Final results will be subjected to additional statistical analyses.

Population Dynamics

There are 27 colonies of Black-legged Kittiwakes located throughout PWS (Fig 1). Colony size ranges from < 20 to over 6500 nests. Since 1972, the nesting population at certain colonies has greatly increased while others have greatly decreased or been abandoned. Overall, distribution of the nesting population in PWS has changed dramatically since the early 1970's. Sixty-three percent of the population now nests in northern PWS compared to 55% in 1985 and 30% in 1972. For this comparison, northern and southern PWS are divided by a line intersecting Port Nellie Juan in western, Naked Island in central, and Bligh Island in eastern PWS (northern PWS comprises those colonies with foraging ranges more likely associated with oceanographic conditions specific to PWS waters vs. GOA influences in southern PWS; Fig 1). Population analyses indicated that between 1984 and 1996, productivity at five northern colonies (n = 9) was sufficient to maintain a stable or net population increase at those colonies (fledgling production $\geq$ adult mortality) while productivity at all southern colonies (n = 18) was insufficient to compensate adult mortality (fledgling production < adult mortality; Fig 2). For PWS as a whole, productivity was sufficient to maintain a net population increase between 1984 and 1989. Decreased productivity, however, between 1990 and 1995 was insufficient to maintain the population. When evaluated by regions during 1984 through 1996, however, it was only the northern colonies that maintained sufficient productivity to compensate adult mortality. Whereas, productivity at the southern colonies was insufficient to maintain populations during this period (Table 1).

There was evidence of immigration at 44% of northern (n = 9) and only 28% (n = 18) of southern colonies (Fig 3). Suprisingly, these included colonies where fledgling production was ≥ adult mortality and where fledgling production was < adult mortality. Passage Canal was the only colony that had evidence of juvenile emigration (projected population was > actual counts). Six colonies in southern PWS had evidence of emigration of adults (population declined at a rate greater than what could be explained by adult mortality alone). There was evidence for immigration into PWS during several years. Based on demographic parameters, the kittiwake population in PWS should decline over the next couple of years if immigration is not occurring.

Colony Studies

In 1996, productivity (fledglings/nest) was greatest at Shoup Bay (0.73) followed by Eleanor Island (0.53) and North Icy Bay (0.28). Compared to 1995, productivity was less at Shoup Bay and greater at Eleanor Island in 1996. Laying success (≥ 0.87 of nest structures having ≥ 1 egg) and mean clutch size (≥ 1.73 eggs) was relatively high at all three sites. Therefore, low productivity at North Icy Bay resulted from loss of eggs and chicks over the nesting period. Overall productivity for kittiwakes in PWS was the greatest (0.35 fledglings/nest) since 1989; in contrast to the last six years (1990 to 1995) of reduced productivity.

Chick growth rates were greatest at Shoup Bay and least at North Icy Bay, although these differences were smaller than anticipated (< 0.6 g/day). Chick growth rates at Eleanor Island and North Icy Bay were slightly greater in 1996 compared to 1995.

When reproductive and foraging parameters were compared with previous years, some interesting trends became apparent. At Shoup Bay, foraging trip distance, chick growth, productivity, and chick diets were similar during three of four years (Fig 4). In 1990, however, a dramatic change in diet (significantly less herring, and more walleye pollock, *Theragra chalcograma*) resulted in greater foraging trip distances, reduced chick growth, and decreased productivity. These data indicated the additional time and energy required to obtain food was beyond the adults ability to buffer their chicks against variability in prey resources. At Eleanor Island, two of three years were similar among these measurements. In this case, a significant change was observed in 1996 with a dramatic change in diet (markedly less herring and more capelin, *Mallotus villosus*) and corresponding increase in foraging trip distance (Fig 5). This increased effort, however, did not result in decreased productivity or chick growth, indicating that the adults were able to obtain sufficient quantities of good quality food and that the increased effort was within the limits for the adults to buffer their young. The relatively few adult kittiwakes at North Icy Bay that were able to obtain sufficient quantities of high quality food (herring, sand lance, and capelin) produced chicks with good growth rates (Fig 6). Their estimated foraging trip distances, however, were long; approaching the limit observed for kittiwakes at Shoup Bay in 1990 and may have contributed to reduced productivity. This increased effort at North Icy Bay corresponded with adults being slightly lighter (1.5 - 4%) than those at Eleanor Island and Shoup Bay. These differences were not as great as expected, but may reflect increased energetic requirements of adults at North Icy Bay and reduced abundance of good quality prey.

At-sea locations of kittiwakes from Shoup Bay in 1996 were similar to locations obtained in 1995 (Fig 7c). The only exception appears to be more locations around Glacier Island in 1996, west of the entrance to Valdez Arm. These are consistent with similar foraging trip durations and diets between the two years. In contrast, there was a change in foraging areas used by kittiwakes from Eleanor Island. In 1996, the significantly greater foraging trip durations and distances and change in diet corresponded with more trips to Green Island where large schools of capelin were observed (Fig 7a). One kittiwake from North Icy Bay was tracked south to Pt. Elrington (Fig 7b) where it was observed foraging on a large school of capelin. Foraging flocks associated with the capelin schools were much larger (100's to 1000's of birds) than those typically found in PWS. Although foraging flocks were commonly encountered while tracking, adult kittiwakes that successfully raised young were observed foraging alone > 50% of the time when foraging flocks were present. Distance to shore of foraging locations was on average within 1 km of shore, consistent with data from previous years.

Data from continuous monitoring by the DCCs indicated mean daily trip duration changed over the chick rearing period (Fig 8a,b). At Shoup Bay and Eleanor Island, mean trip duration increased markedly and became more variable around the third week in July. The increased trip duration was observed for adults with chicks of various ages and for one adult without chicks; indicating potential responses to variation in prey availability. Trip duration among adults raising chicks at North Icy Bay was considerably more variable (Fig 8c) and may reflect limited or unpredictable food resources.

Using these measures of reproductive and foraging effort obtained over years with variable prey diversity and abundance, we can build theoretical frameworks for estimating quality and relative abundance of prey as outlined in Table 2. These estimations could then be compared to data collected by the fisheries investigators (APEX component A).

DISCUSSION

Morrison (1986) and Temple and Wiens (1989) argued that avian population measures are not useful to monitor environmental change because of the difficulties involved in establishing direct cause-and-effect relationships. Also, the appearance of the effects may be buffered by time-lags caused by intermediate stages in the cause-effect relationship or the site-fidelity of breeding birds (Temple and Wiens 1989). This is a reasonable conclusion when addressing change over time periods that are short in relation to life hisories of seabirds, which are typically long-lived species that experience delayed maturity, low reproductive rates (Lack 1967), and breeding site-fidelity. However, when considering environmental change on the decadal scale, such as that described in the GOA (Piatt and Anderson 1996), changes in seabird populations would likely reflect these conditions. Until recently, there has been little information on the relationship of oceanographic processes in PWS and the GOA. Because of this, it is not known how changes in the GOA since the late-1970's may have affected oceanographic conditions in PWS. Researchers from the SEA project (EVOS project 320) are in the process of collecting data to model the Alaska Coastal Current and its effect on the oceanography of PWS. Long term monitoring of kittiwake populations and demography in PWS may provide valuable information for correlating population trends with environmental changes. Between 1984 and 1989, kittiwake productivity in the GOA was at a low of 0.19 fledglings/nest (Hatch et al.1992), similar to those colonies in southern PWS. In contrast, productivity at colonies in northern PWS were significantly greater, indicating availability of prey resources to maintain productivity. Diets of kittiwake chicks in the GOA consist of primarily capelin and sand lance, in contrast to northern PWS where herring and sand lance are the dominant prey items. Reduced productivity of kittiwakes and other piscivorous seabirds in the GOA are likely related to changes in oceanographic conditions and subsequent decline in abundance of capelin and, potentially, sand lance since the late 1970's. We hypothesize that the proposed regime shift in the GOA primarily affected kittiwakes in southern PWS where oceangraphic conditions and prey associated with the Alaska Coastal Current are more similar to those found at colonies in the GOA. This resulted in a shift of the nesting population to the north where local forage fish production (primarily herring and sand lance) allowed greater kittiwake productivity in PWS compared to the GOA.

Cairns (1987) described relationships between population and behavioral parameters of a generalized seabird and its food supply. These parameters--adult survivorship, breeding success, chick growth, colony attendance, and activity budgets--are sensitive to different ranges of food availability and indicate responses on the order of hours (time budgets) to years (survivorship). A confounding factor is the ability of an adult to buffer their chick(s) from variability in food supply (Burger and Piatt 1990). As food supply decreases, however, a maximum limit of foraging effort is reached at which point adults can no longer buffer their chicks from reduced prey availability (Irons 1992). Therefore, to use seabirds as indicators of food availability requires integration of measures from all parameters and a standard by which to compare; as can only be obtained from long-term studies.

For example, based on the above parameters for data acquired for kittiwakes in PWS, we would estimate relative prey quality and availability as depicted in Table 2. If reproductive parameters, diet quality, and chick growth are good and foraging trip effort (distance/duration) is within limits of the buffer, we conclude that available prey is of high quality and availability (as for Shoup Bay in 1989, '95, '96, and Eleanor Island 1996). If measurements of parameters were all poor, then prey quality and availability is presumed low, as with Shoup Bay in 1990. If all parameters were good except productivity (Eleanor 1989, '95) we would conclude that factors other than food quality and availability limited productivity (e.g. predation, weather, anthropogenic influences). If, however, foraging effort was unusually high in association with low productivity, as with North Icy Bay in 1996, this indicates that relative abundance of prey may have been low (Table 2). With sufficient data, theoretical relationships (such as proposed in Table 2) can be developed into predictive models.

Further development of these relationships (conceptually and numerically) in conjuction with other APEX components will provide powerful tools for future monitoring of factors affecting reproductive success and foraging effort.

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Table 1. Productivity (fledglings/nest) of kittiwakes nesting at colonies in northern vs. southern PWS from 1984 to 1989.

	1984	1985	1986	1987	1988	1989
North	0.44	0.47	0.48	0.45	0.46	0.54
South	0.09	0.03	0.13	0.19	0.16	0.09

Table 2. Conceptual framework for estimating quality and abundance of prey available to kittiwakes based on measures (+:good, -: poor, =: average) of productivity, diet quality, chick growth, and trip distance (+:within estimated buffer, -:at or near limit of buffering ability).

	Shoup '89, '95, '96 Eleanor '96	Eleanor '89, '95	North Icy Bay '96	Shoup '90
Productivity	+	-	-	-
Diet Quality	+	+	+	= -
Chick growth	+	+	+	-
Trip Distance	+	+	-	-
Estimated Prey Availability				
Quality	high	high	high	mod / low
Abundance	high	high	low	low
Comments		Not Food Related		

LIST OF FIGURES

Figure 1. Locations of 27 kittiwake colonies (○ = study colonies) within Prince William Sound (PWS), Alaska. Line divides northern and southern PWS; northern PWS comprises those colonies with foraging ranges more likely associated with oceanographic conditions specific to PWS waters vs. GOA influences in southern PWS.

Figure 2. Kittiwake colonies with productivity sufficient for a net population increase (reproduction > adult mortality), one colony where productivity was sufficient to maintain a stable population (reproduction = adult mortality), and colonies with insufficient productivity to maintain the population (reproduction < adult mortality) between 1984 and 1996. Arrows depict approximate summer flow of the Alaska Coastal Current.

Figure 3. Kittiwake colonies with consistent evidence of immigration or emigration among years, 1984 to 1996.

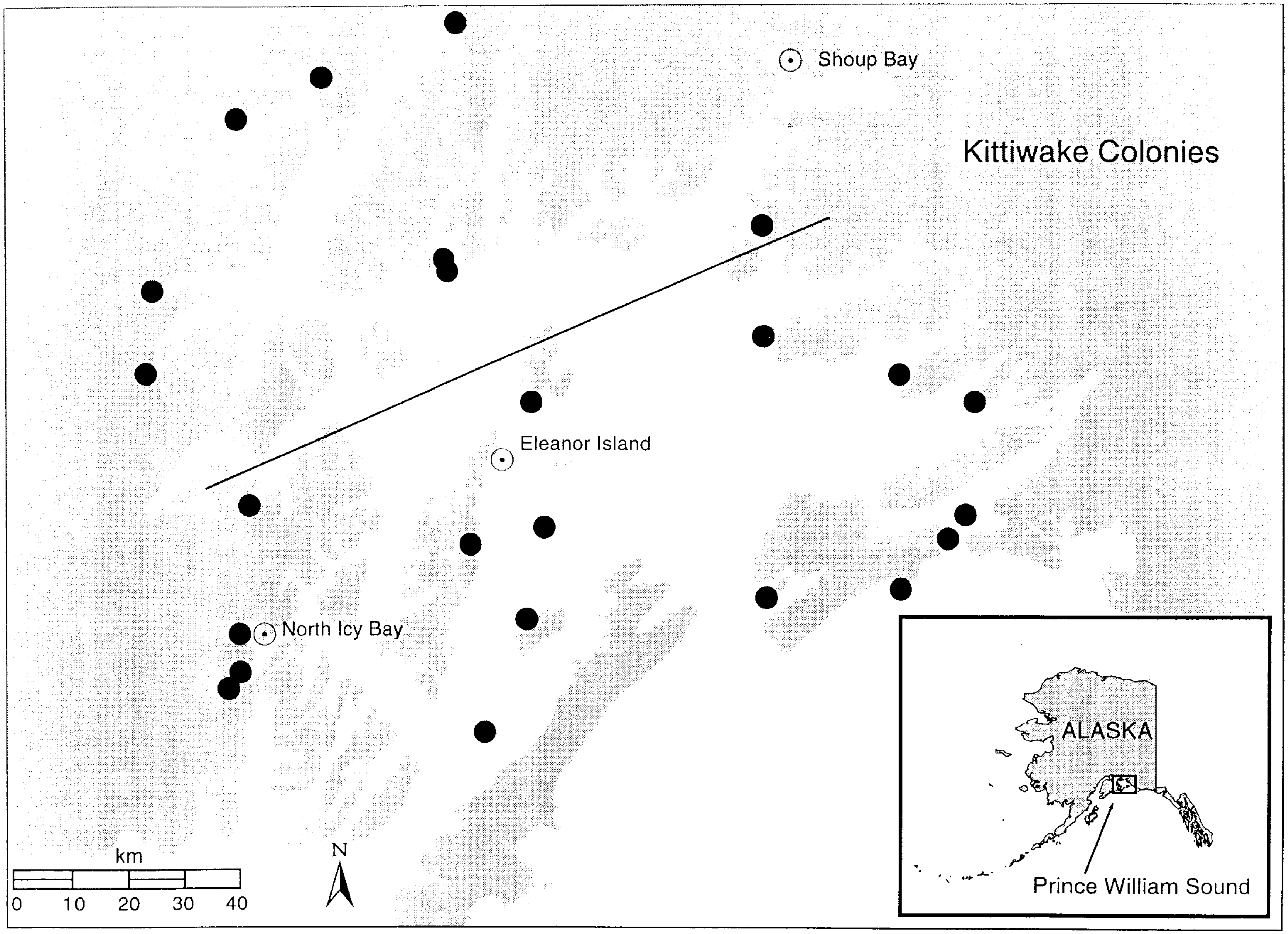
Figure 4. Mean foraging trip distance (straight line distance without hitting land to the furthest foraging location from colony), chick growth rates (60 - 300 g linear), productivity (fledglings/nest), and diet composition of chicks (% occurrence) for kittiwakes at the Shoup Bay colony, 1989 - 1996.

Figure 5. Mean foraging trip distance (straight line distance without hitting land to the furthest foraging location from colony), chick growth rates (60 - 300 g linear), productivity (fledglings/nest), and diet composition of chicks (% occurrence) for kittiwakes at the Eleanor Island colony, 1989 - 1996.

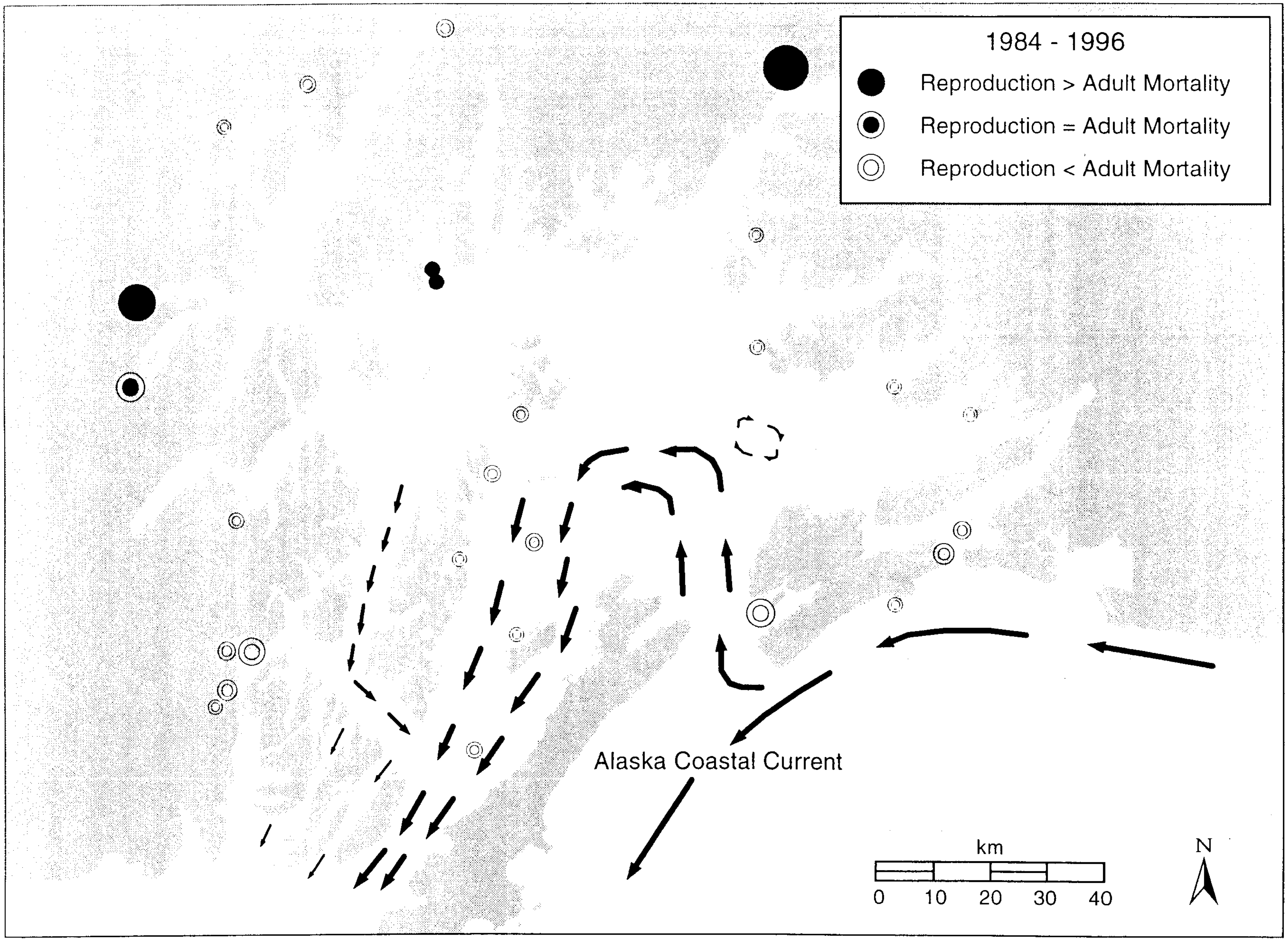
Figure 6. Mean foraging trip distance (straight line distance without hitting land to the furthest foraging location from colony), chick growth rates (60 - 300 g linear), productivity (fledglings/nest), and diet composition of chicks (% occurrence) for kittiwakes at the North Icy Bay (1996) and Shoup Bay colonies (1990, a year of poor food availability).

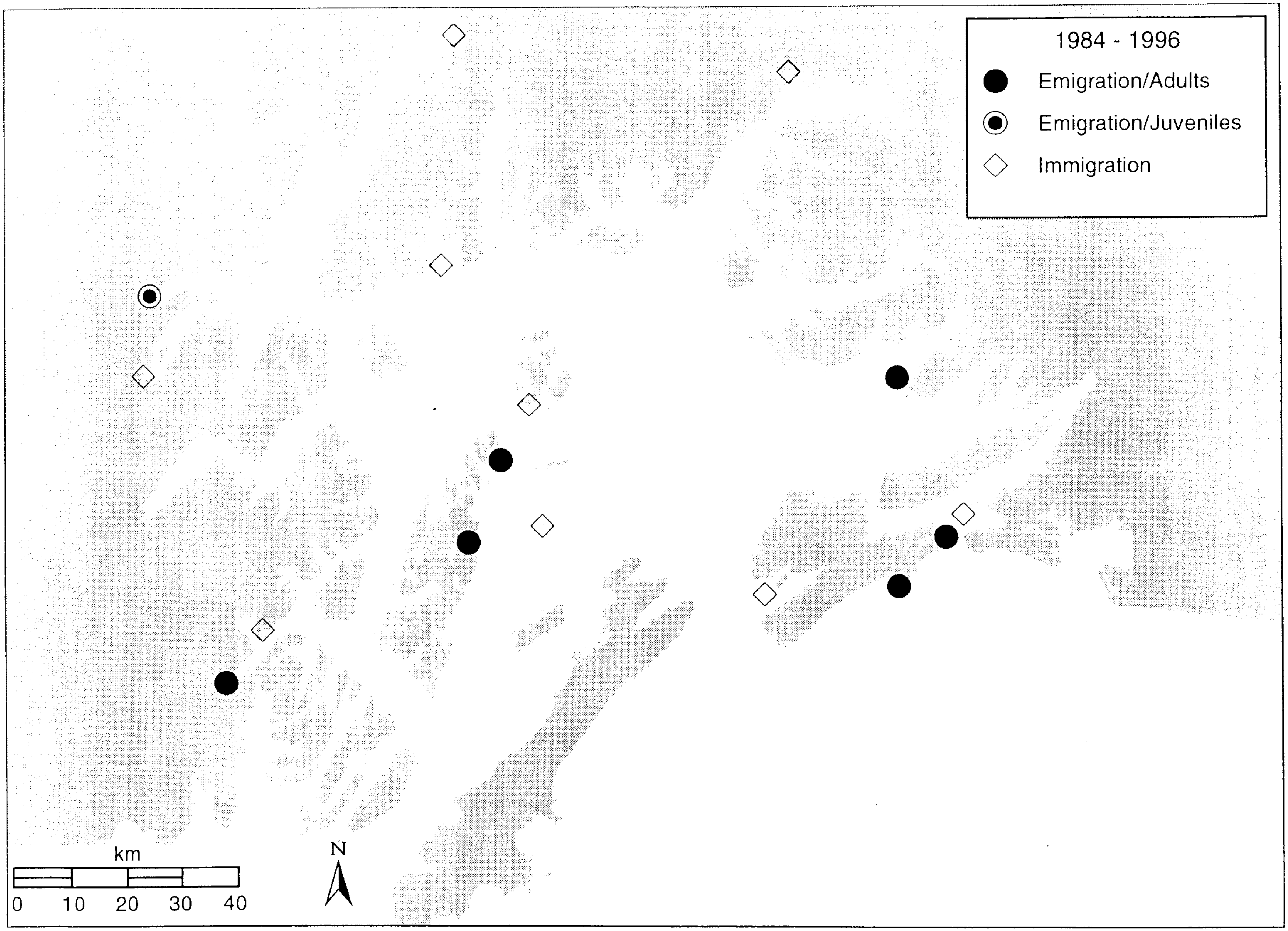
Figure 7. Foraging locations obtained by radio-tracking kittiwakes from Eleanor Island (a), North Icy Bay (b) and Shoup Bay (c) in 1995 (+) and 1996 (●). Also, approximate locations of unknown activites of kittiwakes from North Icy Bay (b) and Shoup Bay (c) in 1996, determined by telemetry surveys.

Figure 8. Mean daily foraging trip durations during July for kittiwakes raising chicks (< 32 days old) at Shoup Bay, Eleanor Island, and North Icy Bay colonies in 1996.



Shoup Bay
Kittiwake Colonies
Eleanor Island
North Icy Bay
ALASKA
Prince William Sound
km
0 10 20 30 40
N


1984 - 1996
Reproduction > Adult Mortality
Reproduction = Adult Mortality
Reproduction < Adult Mortality
Alaska Coastal Current
km
0
10
20
30
40
N


1984 - 1996
Emigration/Adults
Emigration/Juveniles
Immigration
km
0
10
20
30
40
N

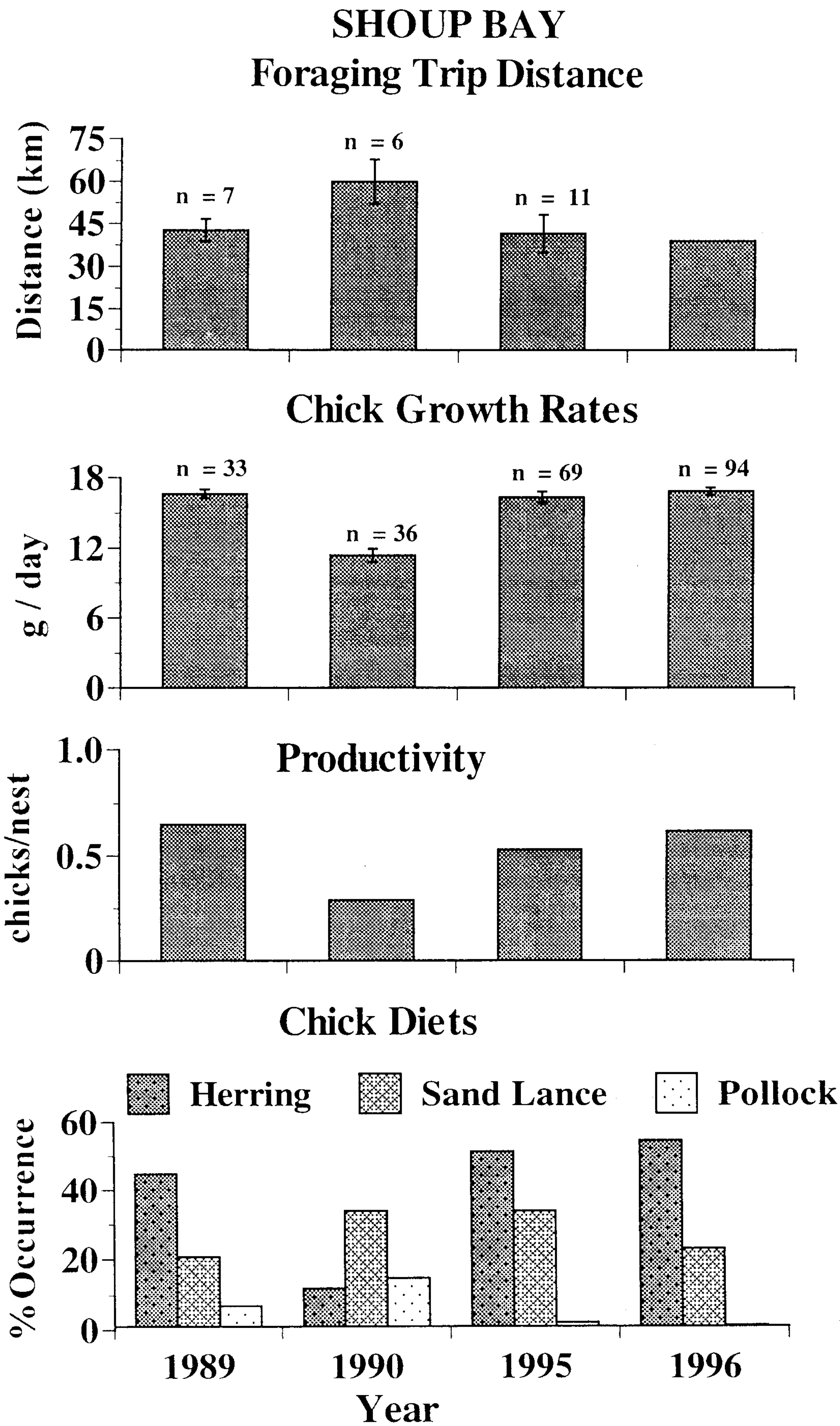

SHOUP BAY
Foraging Trip Distance
Distance (km)
75
60
45
30
15
0
n = 7
n = 6
n = 11
Chick Growth Rates
g / day
18
12
6
0
n = 33
n = 36
n = 69
n = 94
Productivity
chicks/nest
1.0
0.5
0
Chick Diets
Herring
Sand Lance
Pollock
% Occurrence
60
40
20
0
1989
1990
1995
1996
Year

Figure 4.

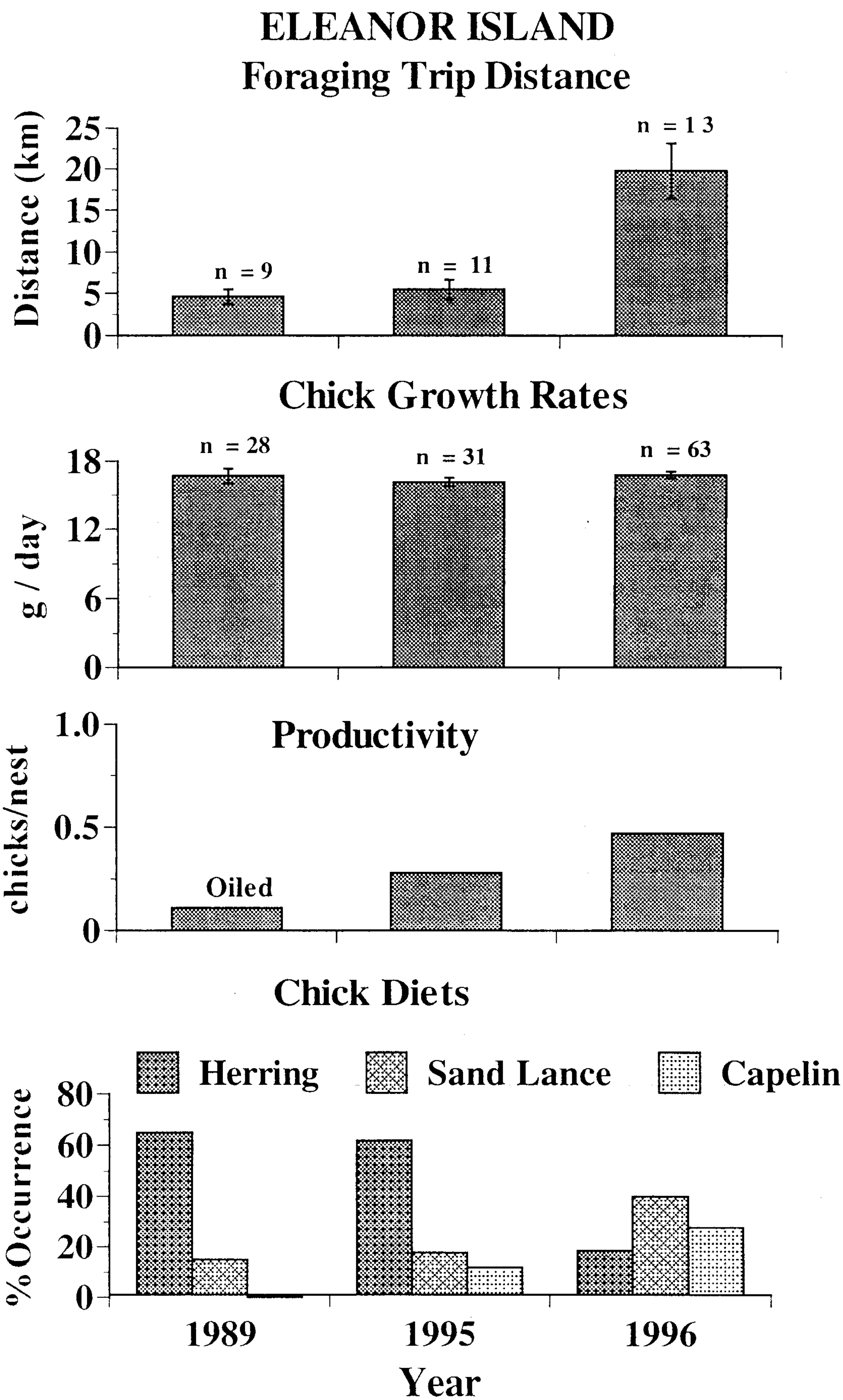

ELEANOR ISLAND
Foraging Trip Distance
Distance (km)
25
20
15
10
5
0
n = 9
n = 11
n = 1 3
Chick Growth Rates
g / day
18
12
6
0
n = 28
n = 31
n = 63
Productivity
chicks/nest
1.0
0.5
0
Oiled
Chick Diets
Herring
Sand Lance
Capelin
% Occurrence
80
60
40
20
0
1989
1995
1996
Year

Figure 5.

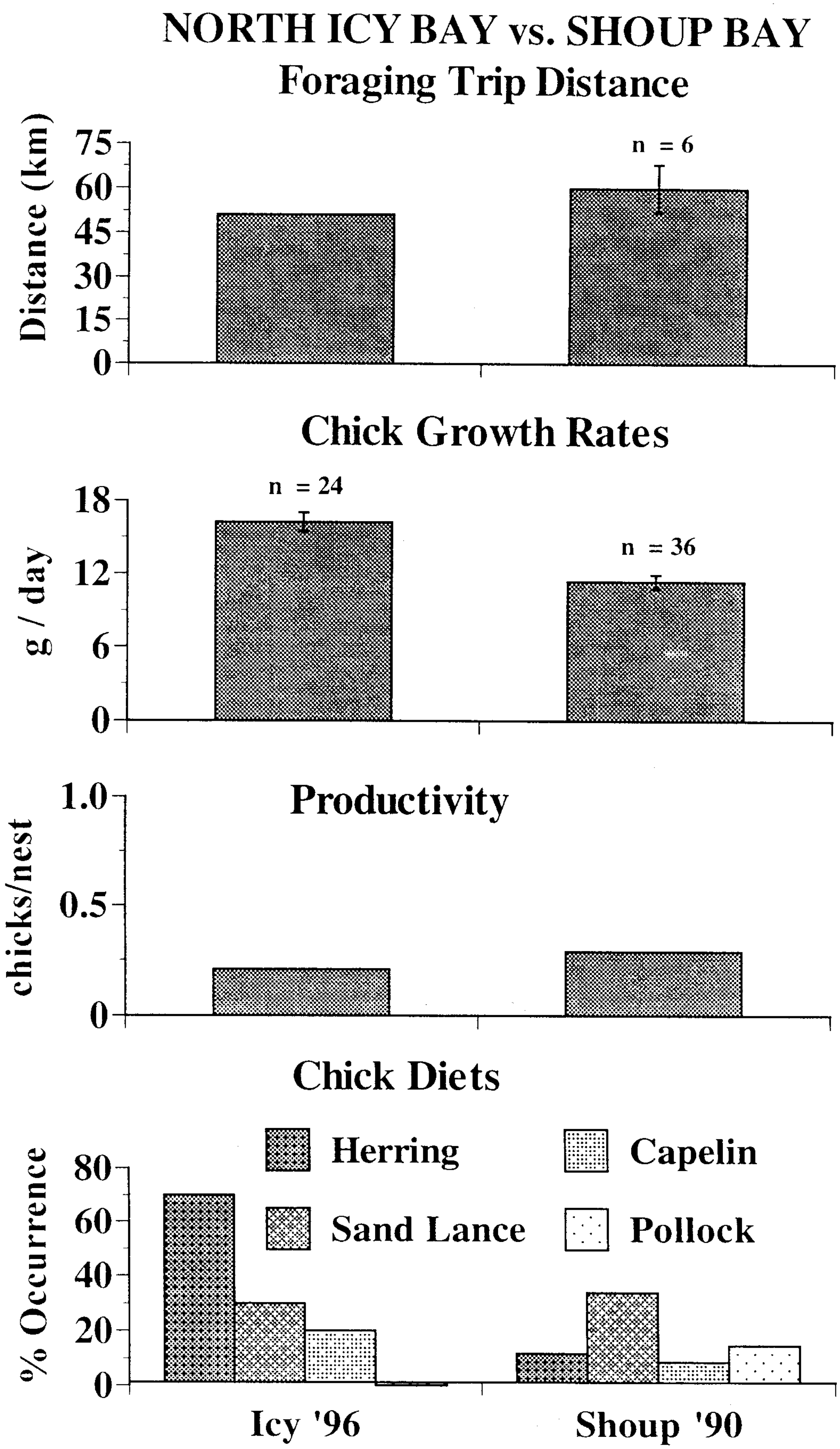
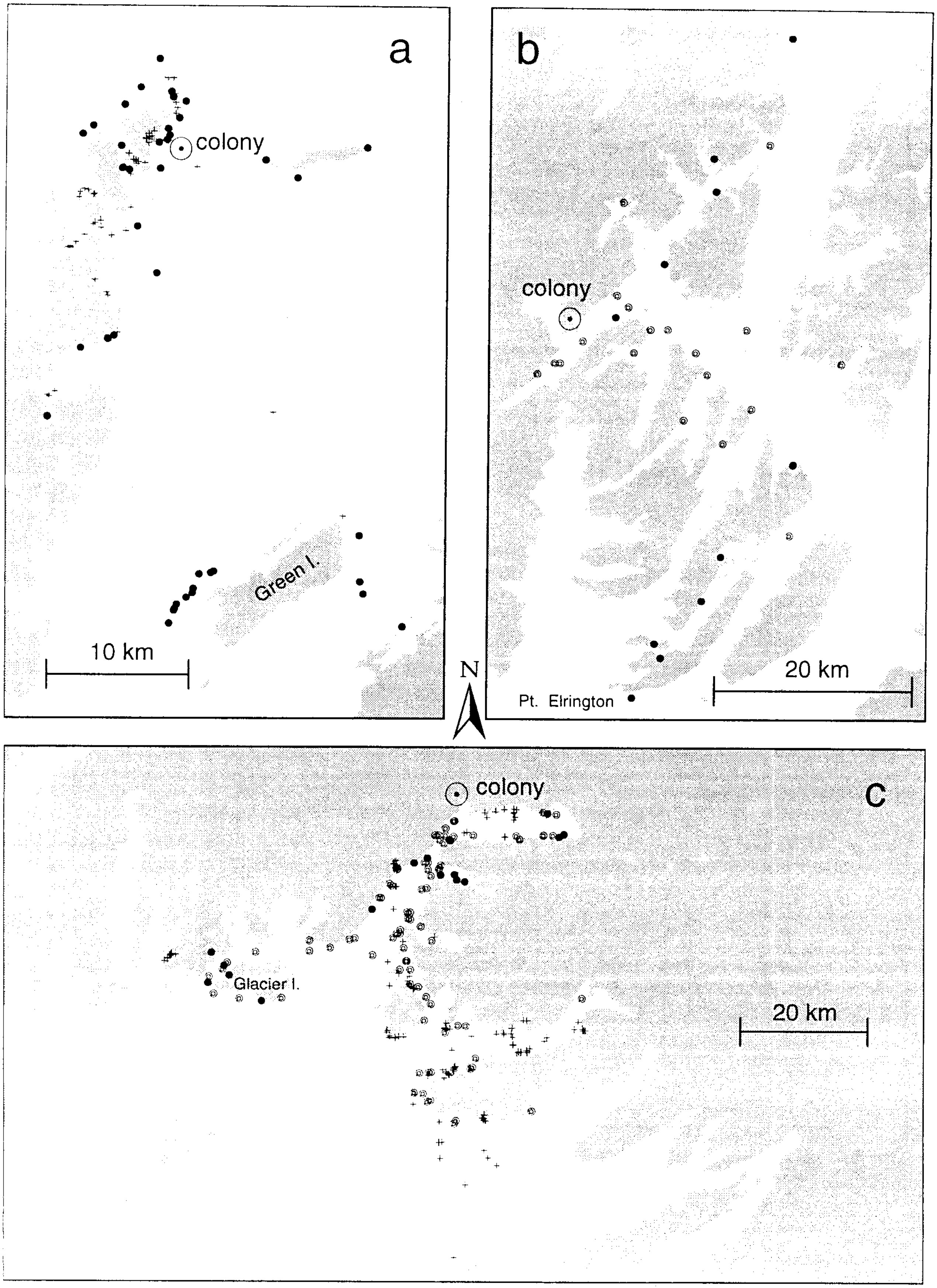
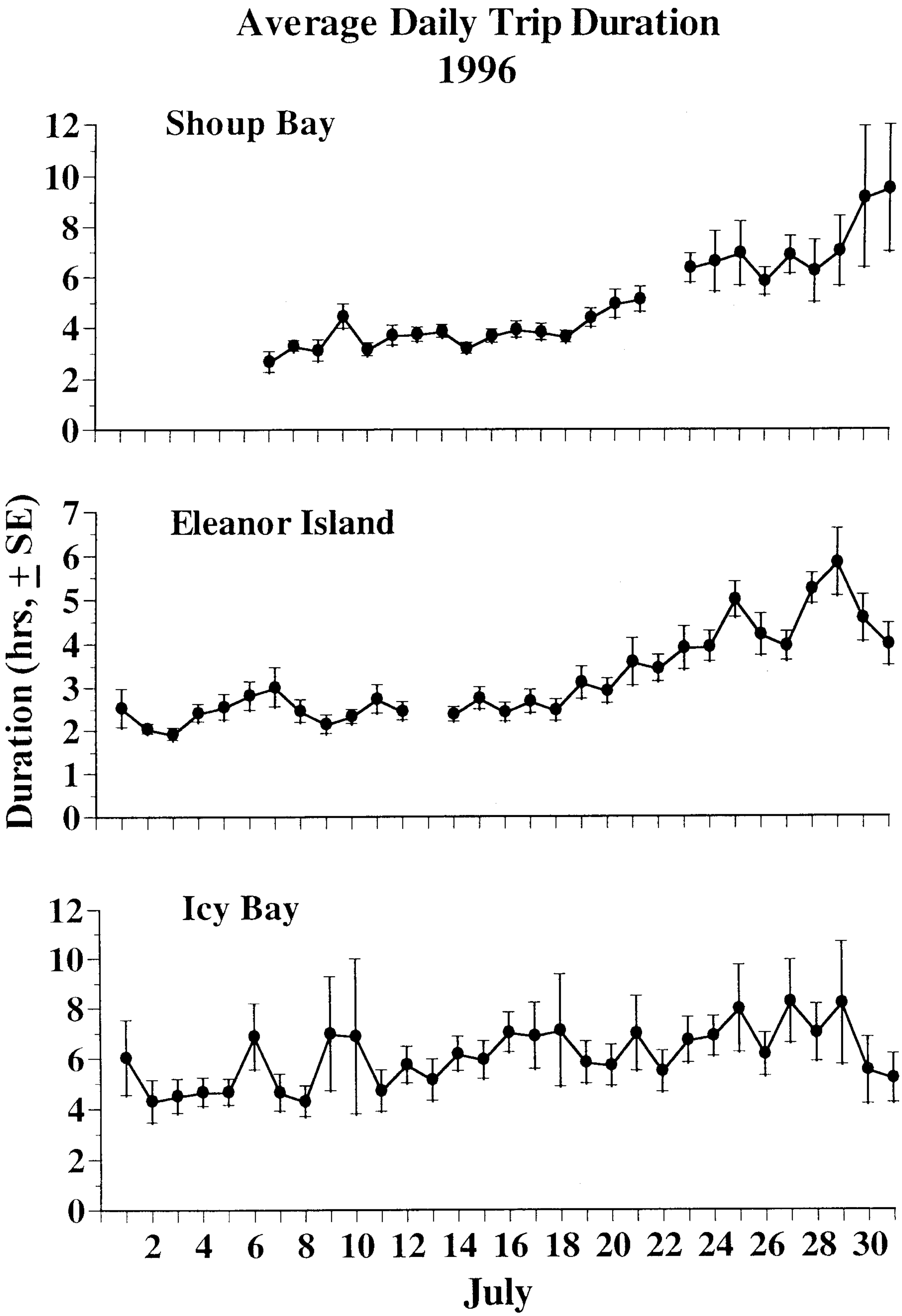

NORTH ICY BAY vs. SHOUP BAY
Foraging Trip Distance
Distance (km)
75
60
45
30
15
0
n = 6
Chick Growth Rates
g / day
18
12
6
0
n = 24
n = 36
Productivity
chicks/nest
1.0
0.5
0
Chick Diets
% Occurrence
80
60
40
20
0
Herring
Capelin
Sand Lance
Pollock
Icy '96
Shoup '90

Figure 6.


a
colony
Green I.
10 km
b
colony
20 km
Pt. Elrington
N
c
colony
Glacier I.
20 km



Average Daily Trip Duration
1996
Shoup Bay
Eleanor Island
Icy Bay
Duration (hrs, ± SE)
12
10
8
6
4
2
0
7
6
5
4
3
2
1
0
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
July

Figure 8.

Completed and Proposed Publication List for Irons and Suryan March 15, 1997

Completed

1. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. (revision of diss. chapter). Revised for Ecology, Irons, March 1997

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5. Monitoring activities associated with other EVOS species or habitats. in, Recommendations to the EVOS trustee Council, in EVOS Restoration Workshop Final Report (Project 95038) and planned book

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