Exxon Valdez Oil Spill
Restoration Project Annual Report

APEX: Alaska Predator Ecosystem Experiment

Restoration Project 95163
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: This research project, APEX: the Alaska Predator Ecosystem Experiment, was initiated under Restoration Project 95163, merging together a group of existing projects and proposals to provide an integrated research approach that examined the interactions of seabirds and their prey, the reasons that changes in prey might have occurred, and the consequences for seabirds, to test the hypothesis that several seabird species have failed to recover from the oil spill of the *Exxon Valdez* because of shifts that may have occurred independently in the marine ecosystems of Prince William Sound and the northern Gulf of Alaska.

The year being reported, 1995, was a pilot year. A review in December 1995 by the Trustee Council approved a three-year project to continue this project. Additional details of methodology for the individual projects may be found in the detailed project descriptions for 1995 and 1996.

Abstract:

This study, the Alaska Predator Ecosystem Experiment, uses seabirds as probes of the trophic (foraging) environment of Prince William Sound and compares their reproductive and foraging biologies, including diet, with similar measurements from Cook Inlet, an area with an apparently more suitable food environment. These measurements are compared with hydroacoustic and net samples of fish to calibrate seabird performance with fish distribution and abundance. This will allow us to determine the extent to which food limits the recovery of seabirds from the *Exxon Valdez* oil spill. We are sampling fish to compare diet, energetics and reproductive parameters of the different forage-fish species, to determine whether competitive and predatory interactions or different responses to the environment may be favoring the abundance of one fish species over another.

Key Words: *Ammodytes, Cepphus, Clupea,* Cook Inlet, forage fish, foraging, population trends, predation, Prince William Sound, reproductive success, schooling, *Theragra, Exxon Valdez, Rissa,*

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Executive Summary

APEX (the Alaska Ecosystem Predator Experiment) is designed to test the role of food in limiting the recovery of seabird species following the spill of the Exxon Valdez oil spill in Prince William Sound and Lower Cook Inlet, Alaska. The project attempts to measure the degree of variability of food food resources, their effects on birds, and the reasons for such variability.

For APEX, 1995 was a pilot year of a multi-year project. Initial analysis of results indicates that that food affected seabird reproduction in Prince William Sound and Lower Cook Inlet, Alaska, setting the stage for further tests of more detailed hypotheses concerning the relation between food and avian population demography.

In work at sea, researchers found differences in prey distribution between sample areas in the northern, central, and southwestern parts of Prince William Sound and between the Barren Islands, Kachemak Bay and the Chisik Islands of Lower Cook Inlet, based on acoustic surveys and net samples. In Prince William Sound, a clear pattern emerged of an abundance of pollock (*Theragra chalcogramma*) in offshore, deeper waters, with herring (*Clupea pallasi*) and capelin (*Mallotus villosus*) closer inshore in upper layers. In Lower Cook Inlet, sand lance (*Ammodytes hexapterus*) dominated in Kachemak Bay and capelin in the waters surrounding the Barrens. In contrast, fish were scarce around the Chisik Islands.

Studies of diet of these species suggested a great deal of overlap in diet. Sampling was not systematic, so we do not know if the overlap reflects competition or foraging on superabundant food resources. Future work will measure fish food resources and diet simultaneously.

Seabird foraging at sea reflected these differences. Black-legged Kittiwakes (*Rissa tridactyla*) and Marbled Murrelets (*Brachyramphus marmoratus*) tended to feed on inshore, surface fish schools, with Tufted Puffins (*Lunda cirrhata*) and Glaucous-winged Gulls (*Larus glaucescens*) feeding on deep schools. Pigeon Guillemots were confined to very near shore where they fed on benthic fish or inshore schools of sand lance, herring, or other forage fish. Common Murres (*Uria aalge*), dependent on larger patches of prey, were almost absent in Prince William Sound, but common in Cook Inlet where they fed predominantly on capelin.

Fish varied in abundance but also in terms of energetic content, reflected by their percent of fat which varied from 3 to 50% of dry mass. The energy value of fresh fish varied five-fold between species.

Kittiwakes varied in distance traveled, duration of foraging, and meal sizes and energetic content between colonies. Growth rate, which reflects these various foraging factors, did not differ for kittiwake young between colonies in Prince William Sound, but was greater in the Barrens. Overall nesting productivity was similar at the Barrens and at one of the two colonies studied in Prince William Sound.

For Pigeon Guillemots, Kachemak Bay and Jackpot Island in southwestern Prince William Sound had more schooling fish and higher growth rates, but productively was similar.

The results from kittiwakes and guillemots indicate that numerous factors contribute to reproductive success. These may differ between colonies but balance each other out. We need to understand the relative importance of such factors in reproduction and their variability, a task for future years.

Finally, analysis of historical fish sampling data demonstrated major changes in relative species abundance at the decadal scale, with relative stability at shorter intervals. This suggests that seabird reproduction and populations may be relatively stable for years, then shift suddenly as a major changeover occurs in the ecosystem. Long-term monitoring is essential to document this, but there is some evidence, such as the resurgence of capelin in the Barrens, that such a shift may already be underway.

Introduction

The spill from the oil tanker Exxon Valdez resulted in significant mortality of several seabirds and in acute massive damage to Prince William Sound (PWS) and the Gulf of Alaska (GOA) (Piatt et al. 1990). Five years following the spill, several species have not recovered (Agler et al. 1994 a,b; Klosiewski and Laing 1994). This may be the result of lingering effects of the oil spill (toxicity of prey, sublethal effects of oil exposure to organisms, or enduring changes to ecosystem structure). On the other hand, other non-oil factors may be involved, such as predation, climate-driven ecosystem changes, or even 'random' perturbations (cf. Piatt and Anderson 1995).

Both to aid in the recovery of injured resources and to safeguard the long-term health of Prince William Sound, we need to understand the ecological processes that control the ecosystem. This project focuses on the trophic interactions of seabirds and the forage species they feed on. We chose food as the focus because: 1) much of seabird population theory (Ashmole 1963) and several empirical field tests (e.g. Furness and Birkhead 1984; Birt et al. 1987) have identified food as an important limiting factor; 2) seabird/fish researchers in the PWS/GOA complex have concluded that major changes in food have occurred during the period (e.g. Hatch et al. 1993; Springer 1993); 3) other factors such as oil toxicity and climate change might express themselves through the food supply (e.g. Duffy 1993); and 4) a knowledge of the forage food base is critical for other apex predators, such as marine mammals and predatory fish, as well as for any larger effort to manage Prince William Sound's marine resources in a sustainable manner.

In addition, testing the importance of abiotic factors such as El Niño/Southern Oscillation (Duffy 1993) or 18.6 year nodal tides (Royer 1993) requires data sets at least as long as the expected frequencies. In testing biotic factors first, we also acquire time-series that can be used for subsequent tests of abiotic factors.

We studied the distribution and abundance of prey species through acoustic sampling in relation to food, environmental conditions and possible competitors, to examine the physical, behavioral and competitive limits to access to these forage species for seabirds. We examined the reproductive consequences of such limitations for pigeon guillemots *Cepphus columba* and black-legged kittiwakes *Rissa tridactyla,* with pilot components to determine if we could extend the examination to tufted puffins *Lunda cirrhata* , common murres *Uria aalge* and predatory fish. By examining the diet and reproductive consequences for a surface-feeder (kittiwake), a benthic diver (pigeon guillemot), two pelagic divers (puffin and murre), and large fish, we should be able to build up a picture of the forage base for the entire seabird community, setting the stage for a long-term, low-cost monitoring program.

Seabird Species

Prince William Sound has large populations of seabirds, although these are not as numerous or diverse as populations elsewhere in the Gulf of Alaska region (Sowls et al. 1978; DeGange and Sanger 1987).

The main breeding species within the Sound are marbled murrelets *Brachyramphus marmoratus* , black-legged kittiwakes , glaucous-winged gulls *Larus glaucescens*, and pigeon guillemots, with smaller numbers of double-crested cormorants *Phalacrocorax auritus*, mew gulls *Larus canus*, Arctic terns *Sterna paradisaea,* and horned *Lunda corniculata* and tufted puffins (Isleib and Kessel 1973; Sowls et al. 1987). Kittlitz's murrelets *Brachyramphus brevirostre* are also frequent in the Sound, presumably breeding (Isleib and Kessel 1973; Klosiewski and Laing 1994).

In contrast, northern fulmars *Fulmarus glacialis,* and Leach's storm-petrels *O. leucorhoa* are absent from the Sound. Fork-tailed storm-petrels *Oceanodroma furcata* are known from only a single colony (Isleib and Kessel 1973). Absence of appropriate cliff-nesting habitat in much of the Sound may restrict breeding by common murres (D. Roseneau, pers. observ.) and, to a lesser extent, by kittiwakes. The same may be true for pelagic *Phalacrocorax pelagicus* and red-faced cormorants *P. urile* which use cliff ledges (Sowls et al. 1978).

Population Trends: Numerous species have declined between surveys in the 1970's and the 1990's in Prince William Sound: cormorant spp., kittiwake, glaucous-winged gull, Arctic tern, Kittlitz's and marbled murrelets, tufted and horned puffin, and pigeon guillemot (Klosiewski and Laing 1994; D. Irons, pers. comm.). Colony trends for kittiwakes have been inconsistent with changes in total numbers, although kittiwake productivity has dropped between 1984 - 1989 and 1990 - 1993 (D. Irons, pers. comm.). The population of pigeon guillemots *(Cepphus columba)* in PWS has decreased from about 15,000 in the 1970's (Isleib and Kessel 1973) to about 3,000 in 1993 (Sanger and Cody 1993). Based on censuses taken around the Naked Island complex (Naked, Peak, Storey, Smith, and Little Smith Islands), pre-spill counts (ca. 2,000 guillemots) were roughly twice as high as post-spill counts (ca. 1,000 guillemots; Oakley and Kuletz 1993). Pigeon guillemots are listed as "Not recovering" in the 1994 Exxon Valdez Oil Spill Restoration Plan.

Common murres were among the species most damaged by the oil spill, but most of the oiled birds nested outside PWS (Piatt et al. 1990). Murres are also listed as "Not recovering" in the 1994 Exxon Valdez Oil Spill Restoration Plan.

Seabird diets: The best evidence for a shift in trophic resources for seabirds within Prince William Sound comes from pigeon guillemots. No long-term data sets exist for other species (Springer 1993) or, like black-legged kittiwakes, they exhibit great year to year variability (D. Irons, unpubl. data).

In 1994, sand lance accounted for only about 1% of prey items fed to guillemot chicks at Jackpot Island and about 8% at Naked Island (Oakley and Kuletz 1993); in contrast, in 1979 the sand lance component at Naked Island was about 55% (Kuletz 1983). Gadids were much more prevalent in the diet of guillemot chicks on Naked Island in 1994 (ca. 30%) than they were in 1979-1981 (< 7%; Kuletz 1983).

Pre-spill studies of pigeon guillemots breeding at Naked Island suggest that sand lance are a preferred prey during chick-rearing (Kuletz 1983). Breeding pairs that specialized on sand lance tended to initiate nesting attempts earlier and produce chicks that grew faster and fledged at higher weights than did breeding pairs that preyed mostly upon blennies and sculpins, at least in years when sand lance were readily available. Consequently, the overall productivity of the guillemot population was higher when sand lance were available.

The decline in the prevalence of sand lance in the diet of guillemots breeding at Naked Island might be a key element in the failure of this species to recover from the oil spill. The schooling behavior of sand lance, coupled with their high lipid content relative to that of gadids and nearshore bottom fish, might make this species a particularly high-quality forage resource for PWS pigeon guillemots. This is consistent with the observation that other seabird species (e.g., puffins, murres, kittiwakes) experience enhanced reproductive success when sand lance are available

(Pearson 1968; Harris and Hislop 1978; Hunt et al. 1981; Vermeer 1979, 1980).

Outside the Sound, there is evidence of a shift in forage species and in seabird diets and populations in the North Pacific and Bering Sea (Springer 1993), but the significance of this to conditions in PWS remains unknown. Hatch (unpubl. data) showed a great increase in pollock in 1994 compared to 1978 and 1990 in diets of tufted puffins and a corresponding decrease in sand lance in diets of both tufted puffin and rhinoceros auklet *Cerorhinca monocerata* at Middleton Island. Summarizing data from five species in the Gulf of Alaska, Piatt and Anderson (1995) documented a dramatic shift from capelin to other species, primarily sand lance.

Forage Species

Forage species include planktivorous fishes and invertebrates. Planktivorous fish species that occur in PWS and are known or likely prey of apex predators include Pacific herring (*Clupea pallasi*), Pacific sand lance (*Ammodytes hexapterus*), walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*) and eulachon (*Thaleichthys pacificus*). Among these, Pacific herring are commercially valuable in PWS and have been studied extensively by Alaska Department of Fish and Game (ADF&G) to facilitate management. Data available for Pacific herring include population size, year-class abundance, and growth. Walleye pollock are commercially valuable in the western GOA and the Bering Sea; consequently there are considerable data describing populations and biology in those area, but relatively little information exists on pollock in PWS. The other fish species are not commercially important in Alaska and have received little study (Adkinson 1993), although some scattered information allows a preliminary assessment of their life-history features, distributions and food habits.

Pacific herring populations in PWS are monitored through egg surveys, with subsamples aged to estimate year-class abundances. Through the 1980's herring abundances were relatively high in PWS, with cyclical strong year classes. In 1993 and 1994 herring populations declined sharply. Adults had relatively high incidences of lesions caused by viral hemorrhagic septicemia (VHS), and the mean size at age was abnormally low. Apparently herring populations in PWS have been seriously stressed in recent years. Although linkage to EVOS has not been clearly demonstrated, problems with herring may stem from post-EVOS changes in the pelagic production system of PWS. In that case, other forage species may have been similarly affected. Herring are prey for many apex predators, including seabirds and marine mammals.

In the western GOA and Bering Sea juvenile walleye pollock are planktivorous, and are preyed upon by apex predators. In Shelikof Strait in April, walleye pollock comprised about 99% of midwater planktivores (Brodeur and Merati 1993). In PWS walleye pollock are probably an important forage species. In a bottom trawl survey of PWS, walleye pollock were the most abundant species (Parks and Zenger 1979), and walleye pollock were the most abundant larval fishes found in ichthyoplankton samples collected in 1989 after the EVOS (B. Norcross, pers. comm.). Juvenile walleye pollock are very important constituents of the diets of piscivorous seabirds (Springer and Byrd 1989; Divoky 1981) and marine mammals (Lowry et al. 1989; Pitcher 1980, 1981).

Pacific sand lance occur throughout the GOA and are important forage species wherever they occur. They are planktivorous, feeding on euphausiids and copepods, with euphausiids more important in winter months (Craig 1987 a). Throughout their range, calanoid copepods have generally been reported as their principal prey (Simenstad et al. 1979; Rogers et al. 1979; Cross et al. 1978; Craig 1987 a,b). Pacific sand lance have been reported as prey for a variety of marine seabirds (Sealy 1975; Vermeer 1979; Drury et al. 1981; Springer et al. 1984; Wilson and Manuwal 1986). They are also eaten by many marine mammals including harbor seals (Pitcher

1980) and Steller's sea lions (Pitcher 1981). There is little information on the abundance and distribution of sand lance in the PWS area, but they are probably an important intermediate link in the food webs that support apex predators.

Two smelt species, capelin and eulachon, are probably important forage species in PWS. In a bottom trawl survey conducted in April, eulachon was the fifth most abundant species collected overall, but it was the dominant species at depths over 200 fm. (Parks and Zenger 1979). These fish were ready to spawn and apparently were intercepted while migrating to their spawning grounds in rivers. Eulachon are important forage species throughout Alaska, and may be the most important forage fish in the southern Bering Sea (Warner and Shafford 1981).

Capelin spawn on nearshore sandy substrates. In the northern Gulf of Alaska (Kodiak) they spawn in May and June (Warner and Shafford 1978; Pahlke 1985). They are prey of many piscivorous seabirds (Baird and Gould 1985) and marine mammals (Fiscus et al. 1964).

A striking feature of the forage fishes, and one that has important implications for this project, is the difference among the species in spawning times and locations. Spawning aggregations, migrations to spawning grounds, and post-spawning dispersion patterns must result in temporal and geographic variation in availability of forage fishes. The structure of reproduction among the potentially important forage fishes is:

SPECIES	SPAWN TIME	LOCATION
Pacific sand lance	December-February	Shallow nearshore
Pacific herring	March-April	Intertidal, shallow subtidal hard substrates, macrophytes
Walleye pollock	April-May	Pelagic, deep
Eulachon	April-May	Streams, near tide-water
Capelin	May-June	Intertidal, shallow subtidal depositional beaches

Initial analysis of diets (Sturdevant 1995) demonstrated considerable overlap in diet between pollock and sand lance, pink salmon fry and sand lance, and between herring and capelin, suggesting the potential for competitive interactions between guilds of forage fish species. However, these analyses were based on limited samples and size classes, so the situation is likely to be more complex (Sturdevant 1995).

Macrozooplankton: Euphausiids, shrimp, mysids, and amphipods are a central component in the diets of sand lance, capelin and pollock, as well as of young salmon (Clausen 1983; Coyle and Paul 1992; Livingston et al. 1986; Straty 1972). When aggregated in sufficient densities, macrozooplankton are fed on directly by marine birds (Coyle et al. 1992; Hunt et al. 1981 a,b; Oji 1980). Swarming behavior by breeding euphausiids (Paul et al. 1990 b) and physical factors (Coyle et al. 1992; Coyle and Cooney 1993) may concentrate macrozooplankton and micronekton into aggregations of density suitable for efficient foraging by predators. Unfortunately, there is little information on the abundance, distribution and fluctuations of these key invertebrate taxa in the EVOS impact region. In the GOA, zooplankton abundance has varied on a decadal time scale (Brodeur and Ware 1992); and, superimposed on longer cycles, there are interannual fluctuations as high as 300% (Frost 1983; Coyle et al. 1990; Coyle and Paul 1992; Paul et al. 1990 a, 1990 b, 1991; Paul and Coyle 1993). Such variability in abundance may directly or indirectly affect populations of apex predators in PWS.

Objectives

In 1995, The Trustee Council authorized a pilot one-year project to test the following hypotheses.

General Hypothesis:

A shift in the Prince William Sound marine trophic structure has prevented recovery of injured resources.

> **prediction:** A trial project in 1995 will show that the proposed projects can detect differences between bird species, between bird colonies and between fish species, in diet, distribution, behavior or other attributes that would provide initial support for this general hypothesis.

Working Hypotheses

These working hypotheses are more specific aspects of the general hypothesis, addressing particular species or trophic aspects.

1. The trophic structure of PWS has changed at the decadal scale

testable assumption: Intra-annual variability in diet and other trend data are less than at the annual or decadal level;

a. prediction: Historical data on bird and predatory fish diets, net samples, fisheries landings, and other available data will show shifts in trophic structure at the decadal scale.

b. prediction: Changes will be linked to shifts in environmental conditions

test: Analysis of available data will show shifts at the decadal level. Such shifts will be coherently expressed across different data sets. Historically, forage species that eat each other or have high diet overlaps will show inverse population trends.

task: Appendix L.

2. Planktivory is the factor determining abundance of the preferred forage species of seabirds

testable assumptions: We can measure fish diet and we can measure some relative index of forage fish abundance, population trends should be visible within the three-year sample period of this study.

a. prediction: Diets will differ between forage species.

b. prediction: Forage species differ in their daily energy budgets and in the food rations that satisfy such demands

test: Species with favorable energy balances will be more common and have positive population trends. Species with high diet overlaps or a trophic relationship will show inverse trends over the three years of the study.

tasks: Appendices A, C

3. Forage species differ in their spatial responses to oceanographic

processes

testable assumption: We can identify and sample forage fish species acoustically and/or with nets and make simultaneous environmental measurements.

a. prediction: The occurrence of each forage species is associated with a predictable suite of environmental conditions, such as date, depth, or water temperature.

b. prediction: The condition-indices and growth rates of forage species will differ in relation to a predictable suite of environmental conditions.

test: Measure the distribution, abundance, and condition of forage species with simultaneous collection of environmental data; cross correlate or use multivariate statistics to identify relevant parameters that separate species.

task: Appendix A

4. Productivity and size of forage species change the energy potentially available for seabirds

testable assumptions: Forage fish differ measurably in body condition and size between species, between seasons, and between years; we can detect trends in forage species over three years or hindcast trends based on historical data (e.g.seabird diets and herring landings)

a. prediction: Spawning species will be richer energetic prey than are non-spawners

b. prediction: Spawning aggregations are larger than non-spawning aggregations

c. prediction: Measures of fish productivity reflect direction and changes in fish stocks

test: Compare size and proximate analyses of forage species with multi-year population indices to identify body-condition parameters that can be used to monitor fish populations.

tasks: Appendices A, B, G

5. Forage fish characteristics and interactions among seabirds limit availability of seabird prey

testable assumptions: Prey differ in depth, school size, fish size, distance offshore; seabirds differ in foraging characteristics.

a. prediction: Inter- and intra-specific interactions of seabirds determine access to prey at patches

b. prediction: Differences in seabird morphology and foraging characteristics determine access to prey

test: During transects, record group size, group density, depth/duration of dive, frequency of foraging methods, distance foraged from colony, and competitive interactions for each seabird species.

test: Compare seabird species assemblages at food patches of different sizes and species.

tasks: Appendix B

6. Seabird foraging group size and species composition reflect prey patch size

testable assumption: School size for schooling species remains constant within but differs between species (Radovich 1979) or it varies within species in response to food levels (Duffy and Wissel 1988)

a. prediction: Inshore foragers will have smaller flock sizes than do off-shore foragers

b. prediction: Foraging flock group size will decline over the breeding season as birds shift from spawning herring to other prey with smaller school-patch sizes.

c. prediction: Foraging-flock composition will change with school size.

d. prediction: Inshore patches are smaller than offshore patches within and between prey species.

e. prediction: Patch (school) size is constant within species.

test: Regress mean seabird foraging group size on transects with mean patch size for each month and subregion of transects.

test: Determine characteristic patch size for forage species by month and distance/depth offshore.

tasks: Appendices A, B

7. Seabird diet composition and amount reflects changes in the relative abundance and distribution of forage fish at relevant scales around colonies

testable assumptions: Seabird foraging decreases with distance from colony so an effective foraging zone can be determined; acoustic sampling can determine relative abundance indices for each colony's foraging zone (relative biomass, number of schools, number of accessible schools, or, in the worst case, simply presence/absence of prey).

a. prediction: The greater the overlap in foraging zones between colonies, the less the difference in diet

b. prediction: Seabird diet composition directly reflects relative forage species abundance-indices in surrounding waters, as measured by acoustic surveys and by analysis of predatory-fish stomachs.

c. prediction: Seabird diet composition reflects forage fish acoustic abundance determinations, once these are corrected for relative availability, based on seabird species-specific foraging constraints.

test: Determine effective foraging ranges based on Eulerian (at-sea transects) and

LaGrangian (radiotracking of kittiwakes, murres and puffins; direct observation of guillemots).

test: Determine overlap in foraging zones between colonies

test: Compare black-legged kittiwake, pigeon guillemot, and tufted puffin diet data in Prince William Sound with acoustically-derived forage fish abundance-indices at appropriate scale, determined above.

test: Compare relative forage species proportions in seabird (tufted puffin, pigeon guillemot, black-legged kittiwake, common murre) diets in several study areas (PWS, Barrens) with acoustic indices and predatory fish stomachs, both within and between years.

tasks: Appendices A,B,D,E,F,J,K,M

8. Changes in seabird reproductive productivity reflect differences in forage fish abundance as measured in adult seabird foraging trips, chick-meal size and chick-provisioning rates

testable assumption: A linear relation exists between parameters (Occam's Razor). Some initial work (Irons 1992) indicates the presence of response thresholds and nonlinear responses but this needs to be confirmed. We assume that meal mass and provisioning rate vary; however, these may exhibit an asymptotic maximum.

a. prediction: Chick provisioning rates are linearly related to amount of food and to growth and survival of nestling black-legged kittiwakes, puffins, murres, and pigeon guillemots.

b. prediction: Meal mass per chick provisioning is linearly related to amount of growth and survival of nestling black-legged kittiwakes, tufted puffins, common murres, and pigeon guillemots.

c. prediction: Adults will respond initially to changes in food availability with changes in foraging effort (duration or length of trip), providing a buffer in predictions a and b.

test: Measure length of foraging trips, frequency of trips, meal size, growth and survival of young kittiwakes and guillemots, with additional data from pilot studies of tufted puffins and common murres.

tasks: Appendices E, F.G,J,M

9. Seabird reproductive productivity is determined by differences in forage fish nutritional quality

testable assumption: Differences in nutritional quality will be greater than any buffering in determining growth rate; substantial differences in forage prey species and seabird diet exist between sites.

a. prediction: Meal energy and nutritional content are linearly related to both short-term and fledging growth and body state parameters

test: Measure food, energy/nutritional intake, and resulting growth and body parameters in kittiwakes (2 sites), pigeon guillemots (2 sites: one benthic prey, one pelagic prey), and puffins (one site) in Prince William Sound where herring and sand lance have apparently been declining and of kittiwakes (one site), murres (one site) and puffins (one site) at the Barren Islands where capelin, a high-nutrient food, has recently been abundant.

tasks: Appendices G,D,E,F,J,M

10. Seabird species within a community react predictably to different prey bases

testable prediction: A synthesis of results from the present and existing research will provide a coherent picture of seabird/forage species interactions and their effects that is consistent with differences in species.

prediction: One or more parameters will be an effective alias for forage/seabird community interactions.

test: Develop a unified model that can predict future responses of seabird communities to changes in the forage base and to environmental change. We can then identify a few simple parameters that can be used to monitor the seabird community on a continuing basis.

task: All projects

Methods

APEX had two main components, one a sea, measuring seabird and fish abundance and foraging, the other measuring diet and reproductive success at colonies. While the project depends on interannual observations to test its hypotheses, we also believed that comparisons between sites within a year would be useful to give us early insights into the role of food in determining seabird success. We chose five sites in Prince William Sound (Shoup and Jackpot bays and Eleanor, Seal and Naked islands) and three in Cook Inlet (Kachemak Bay, and the Barren and Chiswell islands). We also designed our fish and at-sea bird surveys to cover the waters around these sites.

We attempted to use the same techniques to study the same species across all the sites, but logistic and distributional difficulties made such cross the board comparisons impossible, as no species nested at all eight sites and more intensive measures were difficult to employ at some of the less assessable sites. In addition, the short lead time between the awarding of the project and the start of the field season did not allow the months of meetings and discussion on standardization that have characterized the 1996 field effort.

The study chose a spectrum of seabird species to work on. The Pigeon Guillemot and Common Murre were chosen because they had been classified as injured by the Trustee Council. The kittiwake was chosen because its wide distribution made it the easiest species to compare between sites. Puffins were chosen because they were deep divers and have been widely and effectively used elsewhere.

To be effective, this study required tight cooperation between its various components. Many of the hypotheses involved integration of data from one component to another. For example, acoustic surveys and trawls gave us an index of forage species abundance (Appendix A) but not necessarily of availability to seabirds, which required data on foraging capabilities of different species

(Appendix B) and their foraging ranges (Appendices B,E,M). By combining data sets, we could compare prey availability with diet and reproductive data for individual seabird species (Appendices A,B,D,E,F,M). These in turn could only be evaluated in light of the nutritional quality of their food. This required proximate analysis of diet items and an energy/nutrient budget (Appendix G).

Similarly, to understand the interactions between forage species that might account for their shifts in abundance, we needed measures of their present abundance (Appendix A), their diets (Appendix C) and their energetic requirements (Appendix A). These in turn required some index of stability of the ecosystem and past evidence of shifts in its stability (Appendix L). Taken altogether, we should be able after several years to construct 'rules' about how the ecosystem works, that can be tested through monitoring.

Logistically, the components were also tightly linked. The pigeon guillemot component (Appendix F) provided logistic support for the puffin component (Appendix D) and the seabird energetics study (Appendix G) in PWS. The murre/kittiwake study on the Barren Islands (Appendix J) similarly supported the Lower Cook Inlet study (Appendix M). The energetics component (Appendix G) shared measurements of nestling parameters made by the guillemot, kittiwake, puffin and murre components (Appendices D, E, F, J, M). The seabird-foraging component (Appendix B) used the acoustic/trawl survey component (Appendix A), as well as survey work by the SEA project, as platforms for its data collection. Proximate, diet and energetic analyses of fish (Appendices A, C, G) depended on fish collected by the trawl surveys (Appendix A), the sampling of predatory fish from charter-boat captains (Appendix K), and on the reproductive studies of kittiwakes, puffins, murres and guillemots (Appendices D, E, F, J, M).

Results

General hypothesis:

A shift in the Prince William Sound marine trophic structure has prevented recovery of injured resources.

prediction: *A trial project in 1995 will show that the proposed projects can detect differences between bird species, between bird colonies and between fish species, in diet, distribution, behavior or other attributes that would provide initial support for this general hypothesis.*

Prey abundance and distribution and seabird foraging and diets
Acoustic and trawling surveys in Prince William Sound showed variability over time and between three sites in the north, southwest and central parts of the Sound. The central area around Naked Island had fewer shallower fish than did the two other areas. Surveys showed two general distributions of prey, a deeper, more offshore layer of pollock, with shallower concentrations of herring and capelin closer to shore (Appendix A).

In Lower Cook Inlet, there was a striking difference in prey abundance between the three study sites, with large concentrations and huge schools of capelin around the Barren Islands (Appendix K), with lesser amounts of prey, primarily sand lance in Kachemak Bay, and with few fish observed near the Chiswell Islands (Appendix M).

This variability in six areas of two major estuaries affected by the Exxon Valdez oil spill suggests that seabirds may sample different prey bases in different areas, setting the stage for them to respond differently to food. For example, fish school/patch size appears to be much smaller in Prince William Sound than in Lower Cook Inlet. This may in turn explain why Common Murres, a large-patch specialist is scarce in PWS, but common in Lower Cook Inlet.

Seabird foraging concentrations reflected the inshore/shallow, offshore/deep dichotomy, with puffins and glaucous-winged gulls foraging offshore, and with marbled murrelets and kittiwakes foraging closer to shore (Appendix B). Both types of feeding flocks had two deep-diving species (puffins and murrelets) and two shallow-feeding species (kittiwakes and gulls) which gathered some of their food through piracy of the deeper divers. However, many individual kittiwakes in Prince William Sound foraged alone at sites they returned to repeatedly, suggesting that opportunistic flock-foraging at food patches was not necessarily more effective than solitary efforts at familiar foraging sites. This suggests that different seabirds in PWS are exploiting different prey bases.

Analysis of diets showed that the offshore-foraging puffins in PWS did not feed much on herring, while kittiwakes (and by inference the marbled murrelets they often fed with) took a greater proportion of capelin and herring, although proportions varied between sites (Appendices D,E). Pigeon Guillemots, which forage by diving in shallow, inshore waters, also reflected the difference in prey in PWS. Schooling fish (primarily herring) were twice as abundant in guillemot diets at Jackpot Island where the acoustic survey showed concentrations of herring, than at Naked Island where the surveys showed lower numbers, primarily of capelin (Appendix F,G).

In Cook Inlet, capelin dominated kittiwake diets in the Barrens, reflecting their large concentrations in the area, but capelin were only half as important in puffin diets, being replaced by pollock, prowfish and sand lance (Appendix J). Common Murres fed predominantly on capelin in the Barrens (Appendix J).

The PWS and Cook Inlet diet data taken as a whole suggest that diets vary within species between sites and reflect at a mesoscale of months and tens of km's the apparent abundance of prey species.

Beyond abundance, not all fish are equal in energetic value. In marine ecosystems, protein is generally available, but lipids, which are the main source of energy, are much less available. Analysis of prey species showed a spectrum of lipid values ranging from almost 50% of dry mass for some herring to only 3% for some juvenile pollock (Appendix G). Sand lance, capelin and many benthic species taken by pigeon guillemots were intermediate. In addition, lipid levels varied between species, generally being highest in pre-spawning females (Appendix G). The energy density of forage fishes ranged from a low of 2.0 kJ/g wet mass in some prowfish consumed by puffins to a high of 10 kJ/g wet mass in some juvenile herring from Port Gravina. Consequently, piscivorous seabirds in the EVOS area can experience as much as a five-fold difference in energy intake based solely on the quality of the prey items consumed.

These data suggest that energetic values of fish are as important to measure as are their abundance and distribution when examining diet and the forage resources available for seabirds and other marine predators.

Reproductive Consequences

Given this variability in forage-species composition, abundance, and energetics and the resulting differences in seabird foraging, what are the consequences for seabird reproduction? Seabirds might be able to buffer such variability through various means, such as increasing foraging effort, lowering adult lipid levels, or decreasing nest attendance. It may only be at more extreme variations of forage fish that growth and survival of young or of adults are affected. This is an area where multi-year data would be necessary for an answer, but the finding of variability of one or more reproductive parameter between sites within a year would suggest that seabird reproduction is in fact sensitive to the degree of variability found in the two estuaries affected by the *Exxon Valdez* oil spill.

For kittiwakes, adults took twice as long and traveled four times the distance from Shoup Bay than from Eleanor Island. Eleanor meal sizes were smaller, so net intake was almost equal between the two islands. Species composition of meals was similar, but Shoup Bay meals were richer energetically (Appendix G). Growth rates did not differ between the two colonies in PWS (Appendices E,G). In contrast, growth was greater at the Barrens where capelin and older sand lance dominated diets (Appendices E, G, J). Brood reduction (death of one of the two young) was least and productivity was highest at Shoup Bay and the Barrens (Appendix E). These results and earlier work by Irons suggest that adult kittiwakes have a foraging buffer in terms of effort they can expend for foraging but that reproductive success may remain sensitive to the food that the adults can bring in. Additional years of study will probably be necessary to determine how this functions.

For Pigeon Guillemots, a greater proportion of diet was schooling fish at two sites (herring and sandlance at Jackpot Island and sandlance at Kachemak Bay) compared to Naked Island where benthic species predominated (Appendices F, G). Average meal size was smaller at Naked Island than at Jackpot Island (it was not measured at Kachemak Bay where the data were from a non-APEX project). Jackpot feeding rates were higher than at the other two sites, so the mass of food per day delivered at Jackpot was twice that at Naked Island (Appendix G). In contrast, the energy densities of the meals were similar at Jackpot and Naked islands.

Jackpot Island and Kachemak Bay, the sites of higher proportions of herring or sand lance in diets, had higher growth rates than did Naked Island (Appendix G) but the differences were not significant for the linear component of growth (Appendix F). Overall nestling productivity was not different between Jackpot and Naked islands as it had been in the previous year. However, Jackpot productivity was lower in 1995 than in the previous year, coincident with a drop in the proportion of herring between the two years.

The variability at Jackpot Island in diet and productivity between 1994 and 1995 was greater than it was at Naked Island (Appendix F), suggesting caution in forming conclusions, even with two years of data. However, the addition of fully comparable data from Kachemak Bay in 1996 from Project 96163 M and further comparisons with data from 1979-1981 and 1989-1990 may clarify the relative degrees of buffering and response to changes in food abundance that can occur.

For puffins, studied at a small colony in Prince William Sound and at a large colony in the Barrens, the results are paradoxical. Meal size was 10.3 g/meal at the Barrens and 13.7 g in PWS. Feeding rate was 4.9 meals/day in PWS but could not be measured in the Barrens. The diet in PWS was of low-lipid fish, with only 27% high-lipid herring (Appendices D,G). In contrast, at the Barrens, 41% of the diet was high-lipid capelin and sand lance (Appendix J). Growth was 11.5 g/d in the Barrens and 17.7 g/d in PWS. Nesting productivity, measured only in PWS, is comparable to that reported at larger colonies elsewhere in Alaska (Appendix G).

The Barrens would appear to have a more favorable food environment, but meal size and growth rates were lower. Differences in methods might explain this as might differences in feeding rate (measured only in PWS).

Roby (Appendix G) suggests that development of young puffins may be metabolically more efficient than that of kittiwakes and guillemots, which have higher feeding rates and richer food. He speculates that nest site availability in PWS may limit the population and that food, taken in the deeper offshore waters unexploited by most other PWS seabirds, may exceed demand. This is an extremely interesting problem in seabird ecology; however, because of the logistic and disturbance difficulties inherent with working on the very small PWS puffin population, APEX will not pursue this further at this time.

Fish Population Processes and Ecosystem Trends

While it appears that seabirds respond to food in Prince William Sound and Lower Cook Inlet, and there are scattered data showing shifts in the relative abundance of forage fish in seabird diets and fishery landings, a third element is missing, a mechanism for the shifts. Otherwise, our work runs the risk of simply being *post hoc* explanations of environmental variability. If instead, we can determine the factors causing an apparent shift in forage species, then we may have a means of predicting limits to recovery for injured seabird species and marine mammals, as well as a basis for future monitoring of recovery from the *Exxon Valdez* oil spill.

APEX has chosen to look at the roles of food and competition as organizing forces determining the relative abundances of forage species. Is one species out competing another for food or is predation by one species limiting another, so that--in both cases--populations of the second species are diminished? In contrast, the SEA ecosystem project has been looking more at factors that might affect very early stages in a population's reproductive cycle, such as currents, water stratification, or plankton levels as food. Together, the two studies may be able to provide an answer. At the worst, they will provide essential data on the degree of variability in the PWS ecosystem.

Such efforts require time series of data, as variability between years can be great and some processes may work in some years and not others. Also, there is evidence that single marine ecosystems may fluctuate between one or more relatively lengthy periods of stability punctuated by shorter periods of variability. An APEX analysis of 40 years of data on fish and crustaceans in fisheries catches showed major variations at the decadal scale (Appendix L). An abrupt change in species composition occurred in the late 1970's with crustaceans and forage fish (capelin, eulachon) declining, following a strong incursion of cod and an increasing population of pollock.

Why have capelin and other forage fish not recovered and why are pollocks abundant? To test for predation and competition for food, we have analyzed diets of pollock, herring, sand lance, capelin and eulachon. Most young of the year except large pollock predominantly took young calanoids in summer, while all species switched to euphausiids in fall.

There is no evidence that predation by one species limits another. The relatively high diet overlaps observed suggest the potential for competition for food but they may also simply reflect superabundant food.

Sampling up to now has been opportunistic. In 1996, a dedicated sampling effort will look at diets of co-occurring fish (mixed or adjacent schools) and diel diet patterns. These efforts have the second objective of helping us provide oceanographic explanations for the occurrence of different forage fish species in relation to foraging opportunities for seabirds. A review at the end of 1996 will determine if APEX can make a further contribution to determining why the forage fish community shifts.

Working Hypotheses

In several cases, tests of these hypotheses require multi-year data sets, so no conclusions are possible; in others, several years of data are preferable, but the hypothesis can be addressed in a preliminary fashion with one year's data. Because of potential interannual variability in oceanographic conditions, any conclusions must be viewed with caution.

1. The trophic structure of PWS has changed at the decadal scale

a. prediction: *Historical data on bird and predatory fish diets, net samples, fisheries landings, and other available data will show shifts in trophic structure at the decadal scale.*

Initial analysis of data from 40 years of fisheries landings show abundant evidence of such shifts, particularly beginning in the late 1970's (Appendix L). Projects E and F are preparing papers on evidence of such changes in the diets of Pigeon Guillemots and kittiwakes.

b. prediction: *Changes will be linked to shifts in environmental conditions*

No analysis has been undertaken.

2. Planktivory is the factor determining abundance of the preferred forage species of seabirds

testable assumptions: we can measure fish diet and we can measure some relative index of forage fish abundance, population trends should be visible within the three-year sample period of this study.

a. prediction: *Diets will differ between forage species.*

Species have been found to have generally high overlaps in diet (Appendix C).

b. prediction: *Forage species differ in their daily energy budgets and in the food rations that satisfy such demands*

No such analysis has been undertaken yet.

3. Forage species differ in their spatial responses to oceanographic processes

a. prediction: *The occurrence of each forage species is associated with a predictable suite of environmental conditions, such as date, depth, or water temperature.*

A general division between deep/offshore pollock and the other species inshore and in shallow water has been established. Further work inshore will attempt to refine differences between inshore species (Appendix A).

b. prediction: *The condition-indices and growth rates of forage species will differ in relation to a predictable suite of environmental conditions.*

No such analysis has been undertaken yet.

4. Productivity and size of forage species change the energy potentially available for seabirds

a. prediction: spawning species will be richer energetic prey than are non-spawners

Initial data indicate that spawning condition affects lipid levels (Appendix G).

b. prediction: *spawning aggregations are larger than non-spawning aggregations*

No such analysis has been undertaken yet.

c. prediction: *measures of fish productivity reflect direction and changes in fish stocks*

With only a single year's APEX data, no such analysis has been undertaken yet.

5. Forage fish characteristics and interactions among seabirds limit availability of seabird prey

a. prediction: *Inter- and intra-specific interactions of seabirds determine access to prey at patches*

Kleptoparasitism is a significant factor in some foraging aggregations (Appendix B).

b. prediction: *Differences in seabird morphology and foraging characteristics determine access to prey*

Diving species appear to have better access to fish than do surface-feeding species, making fish available to the later through piracy or by driving the fish to the surface. Surface-foragers are positively correlated with divers (Appendix B).

6. Seabird foraging group size and species composition reflect prey patch size

a. prediction: *Inshore foragers will have smaller flock sizes than do off-shore foragers*

Not yet analyzed.

b. prediction: *Foraging flock group size will decline over the breeding season as birds shift from spawning herring to other prey with smaller school-patch sizes.*

APEX has not sampled spring spawning herring and attendant birds yet.

c. prediction: *Foraging-flock composition will change with school size.*

The data do not support this hypothesis (Appendix B).

d. prediction: *Inshore patches are smaller than offshore patches within and between prey species.*

Additional inshore data in 1996 will allow this to be tested (Appendix 1).

e. prediction: *Patch (school) size is constant within species.*

Not yet analyzed.

7. Seabird diet composition and amount reflects changes in the relative abundance and distribution of forage fish at relevant scales around colonies

a. prediction: *The greater the overlap in foraging zones between colonies, the less the difference in diet.*

Analysis of this is occurring in Projects 96163 E and M.

b. prediction: *Seabird diet composition directly reflects relative forage species abundance-indices in surrounding waters, as measured by acoustic surveys and by analysis of predatory-fish stomachs.*

Initial data from a pilot project (Appendix K) suggests such a link at the Barrens between seabird diets and halibut stomach contents.

c. prediction: *Seabird diet composition reflects forage fish acoustic abundance determinations, once these are corrected for relative availability, based on seabird species-specific foraging constraints.*

See Results under General Hypothesis and Appendices G and M for very initial conclusions. Initial data suggest almost no overlap in zones for Pigeon Guillemots, based on their short foraging ranges (Appendix F). Kittiwake colonies in the Sound potentially overlap a great deal but in practice foraging ranges appear to be considerably less than maximum; however, individual site preference may complicate this picture (Appendix E). Depth of foraging appears to limit access to food, although further work on inshore schools is needed (Appendix B).

8. Changes in seabird reproductive productivity reflect differences in forage fish abundance as measured in adult seabird foraging trips, chick-meal size and chick-provisioning rates

a. prediction: *Chick provisioning rates are linearly related to amount of food and to growth and survival of nestling black-legged kittiwakes, puffins, murres, and pigeon guillemots.*

See Results under General Hypothesis

b. prediction: *Meal mass per chick provisioning is linearly related to amount of growth and survival of nestling black-legged kittiwakes, tufted puffins, common murres, and pigeon guillemots.*

See Results under General Hypothesis

c. prediction: *adults will respond initially to changes in food availability with changes in foraging effort (duration or length of trip), providing a buffer in predictions a and b.*

See Results under General Hypothesis

9. Seabird reproductive productivity is determined by differences in forage fish nutritional quality

a. prediction: *Meal energy and nutritional content are linearly related to both short-term and fledging growth and body state parameters*

See Results under General Hypothesis

10. Seabird species within a community react predictably to different prey bases

Several years of data will be required to test this although an initial analysis suggests some such general rules may operate (See Results under General Hypothesis)

Discussion

For APEX, 1995 was a pilot-project year. It successfully demonstrated that variations in seabird reproductive performance and foraging appear linked to mesoscale differences in food distribution. High performance at the Barrens for kittiwakes was associated with capelin, medium performance at Shoup, Kachemak and Jackpot bays for kittiwakes and pigeon guillemots was associated with herring and sand lance, and poor performance was associated with lower levels of pelagic forage fish in the central part of Prince William Sound. In contrast, puffins seem to march to a different metabolic drummer, with diet not appearing to produce differences between the Barrens and PWS.

While diet makes a difference, a single pilot year was not sufficient to determine how it operates, even when comparing between sites. Was food abundance/availability the mechanism? Did limits to parental foraging effort determine success? Or was it differences in food quality? Or is it some combination of factors? If so, are they the same for all species? As the APEX project accumulates data, we should be able to answer these questions.

The results of the fish distribution and sampling work were especially dramatic. A clear picture has emerged of deep, offshore pollock and inshore, shallower concentrations of herring and capelin. Our sampling in 1996 has already shifted to focus on the inshore. In turn, we may well learn that we have to sample even closer inshore, almost onto the beach, to study the distribution and abundance of sand lance. It also became apparent that we need to understand why the different forage species differ in their distributions. Is it food or physical factors that cause forage species to occur in mixed or separate schools? How much competition occurs between species in such schools?

Studies of seabird foraging, which connect the fish and colony studies, also made dramatic strides, identifying deep-divers such as marbled murrelets and puffins as often necessary to bring fish to the surface. Piracy of these species by shallower-foraging seabirds appears common, suggesting that foraging and, perhaps indirectly, even reproductive success of certain seabirds species may be tied to the presence and activity of other seabird species. Such piracy could conceivably even limit the recovery of marbled murrelets, if the pressure on the reduced population is much greater than it was before.

In addition, we have exciting evidence of the relative plasticity of the different seabird species. Pigeon Guillemot reproductive success at the colony level appears to be linked to the presence of pelagic fish, even though the guillemot is an inshore, benthic feeder. In contrast, kittiwakes, despite strong flying ability, appear to have relatively narrow shallow-water foraging niches. Interestingly, individuals appear to pass by foraging flocks encountered on their way to their specific foraging areas. We need to understand the relative trade-offs involved in passing by these foraging opportunities.

More widely, by comparing the reproductive success of seabird species with differing foraging niches, we may be able to use seabirds to monitor fish abundance and availability in the future.

Conclusions

Much of what we are learning is still the natural history, the basic building blocks for understanding Prince William Sound and Cook Inlet. We can hardly monitor recovery or understand why it has not occurred if we haven't an idea of what "normal' is for a species or is prey. We need this to understand what happened after the spill of the *Exxon Valdez* and how this differed from normal environmental perturbations. Even the single year's APEX pilot project suggests that an ecosystem approach focusing on seabirds and their prey is an effective tool to be used toward such an understanding.

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APPENDIX A

APEX: 95163 A

APEX: 95163A

BIOMASS AND DISTRIBUTION OF FORAGE SPECIES IN PRINCE WILLIAM SOUND

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INTRODUCTION

Prince William Sound (PWS) is one of the largest areas of protected waters bordering the Gulf of Alaska (GOA), and provides a foraging area for large populations of apex predators including piscivorous seabirds. These avian predators were severely impacted by the *Exxon Valdez* oil spill (EVOS); and many -- especially common murres, marbled murrelets, pigeon guillemots -- suffered population declines that have not recovered to pre-EVOS levels (Agler *et al.* 1994). Piscivorous seabirds in PWS are near the apex of food webs based on pelagic production. They feed on an assemblage of forage species that include several fishes and may also prey on invertebrates such as euphausiids, shrimps and squid. Recovery of apex predator populations in PWS depends on restoration of important habitats and the availability of a suitable forage base. Since the 1970's there apparently has been a decline in populations of apex predators in the pelagic plankton production system, and it is not clear if failure to recover from EVOS-related reductions is due to long-term changes in forage species abundance or to EVOS effects.

Forage species include planktivorous fishes and pelagic invertebrates. Planktivorous fish species that occur in PWS and are known or likely prey of apex predators include Pacific herring *Clupea pallasi* ; Pacific sand lance *Ammodytes hexapterus* (Drury et al. 1981, Springer et al. 1984, Wilson and Manuwal 1984), walleye pollock *Theragra chalcogramma* (Springer and Byrd 1989, Divoky 1981), capelin *Mallotus villosus* , and eulachon *Thaleichthys pacificus* (Warner and Shafford 1981, Baird and Gould 1985). Pelagic invertebrates; including euphausiids, shrimp, mysids, amphipods; are found in the diets of sand lance, capelin and pollock, as well as young salmon (Clausen 1983, Coyle and Paul 1992, Livingston et al. 1986, Straty 1972). When aggregated in sufficient densities, macrozooplankton are fed on directly by marine birds (Coyle et al. 1992, Hunt et al. 1981, Oji 1980).

The research described in this report was part of a program (APEX) designed to determine if prey availability is limiting the recovery of seabird populations that were impacted by the EVOS. The main tool for measuring the distribution and abundance of forage fishes is hydroacoustics. Hydroacoustics can measure horizontal and vertical abundance and biomass at scales not possible by traditional net sampling techniques, and has been used to quantify fish (Thorne et al. 1977, Thorne et al. 1982, Mathisen et al. 1978) and the spatial patterns of a variety of aquatic populations (Gerlotto 1993; Baussant et al. 1993; Simard et al. 1993). In Alaskan waters, acoustics have been used to measure biomass relative to tidally-generated frontal features (Coyle and Cooney 1993) and the relationship between murre foraging, tidal currents and water masses in the southeast Bering Sea (Coyle et al. 1992). Acoustic sampling cannot positively identify the species of targets; consequently, net sampling must be conducted concurrently with acoustics to identify species and to provide size distribution data necessary for biomass estimations.

OBJECTIVES

1. Provide an estimate of the abundance and distribution of forage species in three study areas of Prince William Sound.

2. Describe the species composition of the forage assemblage and size distributions of the most abundant forage species.

3. Provide samples of forage fishes to NMFS for food habits studies, and other samples of forage species to other APEX and EVOS funded researchers.

4. Describe oceanographic conditions in the study area.

FIELD METHODS

Field studies were conducted in the summer (July and August) and in the fall of 1995. Surveys were conducted in three areas designated as the north, central and south study sites (Figure 1). In summer, sampling began in the Central area and had the following sequence:

20 July -	Loaded gear on charter vessels in Cordova
21 - 25 July	Acoustic, bird and trawl sampling the Central study area
26 - 28 July	Acoustic, bird and trawl sampling in the North study area
29 July	In transit
30 - 31 July	Acoustic, bird and trawl sampling in the South study area
1 - 4 August	Acoustic, bird and trawl sampling in the Central area
5 - 7 August	Acoustic, bird and trawl sampling in the North study area
7 August	In transit
8 August	Acoustic, bird and trawl sampling in the South study area
9 - 11 August	Acoustic bird and trawl sampling in Montague Island area
11 August	Acoustic, bird and trawl sampling in Port Gravina
12 August	Off-load gear in Cordova

Within each study site, hydroacoustic data were collected along a series of offshore, parallel, east-west transects spaced at 2.0 nautical mile (nm) intervals; and a series of inshore, zig-zag transects that usually ran between the shoreward ends of the offshore parallel series (Figures 2, 3, 4). Inshore transects are identified by the inclusion of a z in the transect code.

The summer survey was conducted from two vessels, an acoustic/bird observation vessel and a mid-water trawl vessel. Surveys were conducted during daylight hours, typically between 0600 and 2000. The acoustic vessel would acoustically survey a series of transects. Meanwhile, the mid-water trawl vessel collected trawl samples of targets designated by the acoustic vessel and conducted CTD sampling on all transects and at all stations where biological samples were collected.

From 8 October - 15 October additional sampling was conducted in the three study areas, with the following itinerary:

Sept. 29	Equipment and supplies loaded on R/V MEDEIA at Juneau
Oct. 8	Personnel board vessel in Cordova
Oct. 9	Acoustic and net sampling in the Central study area
Oct. 10	Acoustic and net sampling in the Southern study area
Oct. 11	Acoustic and net sampling in the Central study area
Oct. 12	Acoustic and net sampling in the Central study area
Oct. 13	Acoustic and net sampling in the Central and North study areas
Oct. 14	Acoustic and net sampling in the North study area.
Oct. 15	Acoustic and net sampling in the North study area, personnel disembark at Cordova

The fall survey was conducted from a single research vessel equipped for both acoustic and mid-water trawl sampling. Limited time available for fall sampling precluded a complete survey of the three study areas; consequently, the objectives were to investigate the distributional patterns of forage species in selected areas offshore and in nearshore embayments and to collect specimens for food habits and condition studies. This report includes the methods but no results from the fall sampling, as those data are still being analyzed.

Acoustic methods

Data were collected with a 420 kHz Biosonics Model 120-121 echo-integration system. The data were integrated over 1 m depth intervals, corrected for calibration and stored to disk. Standard transects were run at 6 knots with the transducers towed beside the vessel. Both side-look and down-look data were collected. The effective range of the equipment was 65 m from the transducers. All data and analyses in this report are based on transect data using this equipment.

Data were also collected with a 120 kHz DT4000 digital echo-sounder. The echo-sounder failed to function during the first pass through the study area. After repairs, the machine functioned during portions of the second half of the cruise, however, the data contained spikes of around 30 dB in magnitude, data from the bottom of fish schools and below fish schools occasionally blanked out, and secondary bottom reflections occasionally contaminated the data. The digital data set will require extensive editing to remove defective segements; consequently, results from analyses of digital data are not included in this report.

In the July/August cruise, acoustic data were collected on 167 individual transects, most of which were transects in the three study sites that were visited twice each (Table 2).

In the October cruise, acoustic data were collected on the preselected transect lines and at a number of collection sites within bays where concentrations of forage fishes occurred (Table 3).

Net Sampling methods

A mid-water trawl was the primary sampling tool used to sample acoustic targets. This net is a research-scale version of a mid-water commercial trawl used in Canada to catch herring (an important forage fish). Although the absolute net mouth opening is about 100 m2, the effective opening is about 50 m2. This size net has proven effective on larger nektonic forage fishes such as herring (Mike Halstead, Research Nets Inc. Seattle, Personal communication). The mesh sizes diminish stepwise from about 2" in the wings to 3/8" in the codend. An additional cod end liner with 1/8" mesh netting was sewn into the midwater trawl, this inner liner terminated in a plankton bucket with 0.5 mm nytex mesh that retained smaller macroplanktonic organisms.

In the July/August cruise, midwater trawl samples were collected at locations and depths specified by the researchers monitoring the acoustic sampling. Trawl samples were relatively evenly divided between shallow (< 25 m) and deep (> 25 m) depths with 31 and 29 samples from each, respectively (Table 4).

In the fall cruise the midwater trawl was again used, and, in addition, a 1 M2 NIO (Tucker) trawl was used to collect macrozooplankton. This net had a body and cod end of 0.5 mm mesh and was towed in a double oblique trajectory through depths with targets of interest. Twelve midwater trawl and six NIO net samples were collected in the fall cruise (Table 5).

SAMPLE PROCESSING

MacroInvertebrates.

Macroinvertebrates were preserved in 5 % buffered formalin.,

Fishes

Fish larger than about 50 mm were identified in the field and sorted to species. All fish were measured (fork length) unless net hauls contain large numbers of individuals of some species. Large catches were randomly subsampled by splitting the catch down to 100 - 200 individuals for measurement. Subsamples of all forage fish species were frozen and returned to the laboratory for future life history and energetics studies.

Hydrographic methods

A Seabird SEACAT CTD was used to sample the water column from the surface to 200 m depth, or to within 20 m of the bottom at shallower stations. This instrument has an internal data logger, and recorded conductivity, temperature and depth. In the summer cruise a total of 104 CTD profiles were collected at net collection stations and on each major transect line (Table 6). In the October cruise and additional six stations were sampled (Table 7).

ANALYTICAL AND STATISTICAL METHODS

Biomass estimates were developed by scaling acoustic data based on the length distributions of the dominant fish species collected by mid-water trawl in each study area. Estimates of the number of individual fish per cubic meter are determined by an equation relating acoustic target strength to fish length. The numbers of fish are then converted to an estimate of biomass per cubic meter using the length-weight relationship for the dominant species. Finally, biomass per cubic meter estimates are converted to biomass per square meter of surface by integrating the results over the depth of the sampled water column. Length to target strength relationships were taken from the literature, and the length-weight equations were from our unpublished data in PWS or from literature sources.

A randomization technique was used for statistical analyses. The data were integrated from 65 m depth to 25 m (deep) and from 25 m to the surface (shallow). The shallow and deep data sets from a given region during a survey were linked into a single data string. A random number generator was used to pick starting points in the string. A length of data equal to the average transect length was then extracted and a mean biomass computed. The procedure was repeated until a length equal to the total length of the data set was sampled once and a mean was computed.

The above procedure was repeated 1000 times in a boot-strapping technique. The average of the 1000 runs through the data set was computed, the values for each individual run were ranked; the 25th and 975th values indicate the 0.05 confidence intervals.

Geographic distributions of forage species were assessed by developing area plots of biomass density gradients determined through a kriging routine. The kriging method has a gridding algorithm (we used a minimum curvature algorithm) that estmates the data between transect lines based on estimates of spatial variation along the transect lines. Therefore, the most accurate point estimates are those occurring closest to the lines in regions where transect density is highest. Land masses were overlaid on the area plots after the gridding algorithm had been run.

RESULTS

JULY/AUGUST CRUISE

Hydroacoustic Biomass Estimates - Offshore Transects
Offshore biomass estimates of forage species in PWS varied temporally between surveys, vertically between shallow and deep depth strata, and geographically among the three study areas (Table 8, Figure 5). Biomass estimates increased in the second survey. This trend was most marked in the deep stratum of the North area, where the biomass estimate in the second survey was approximately three times higher than the first survey, although both the Central and South areas also had marked increases in deep strata biomass in the second survey. In the Central and South, biomass in the shallow stratum biomass changed relatively little between surveys, whereas in the North there was an increase in the second survey.

In the first survey there was no consistent variability between depths; as the North and South had higher biomass in shallow depths and the Central area had markedly lower biomass shallow. By the second survey, however, deep strata had the highest biomass in all three study areas, although in the South the difference was minimal.

Geographically, the Central area always had the lowest total biomass, especially in shallow depth stratum. The shallow depth stratum of the Central area was remarkable for the exceptionally low biomass estimate in both surveys. The North area in the second survey had the highest estimates of acoustic biomass in the two surveys.

North - offshore
In the first survey of the North, highest biomass estimates occurred in the Port Fidalgo area (Transects 01 and 02), apparently due to the presence of schools of 1+ age herring (about 150 mm long) in shallow depths, and in the southern end of Valdez Arm (Transect 03), where 1+ pollock occurred in the deep stratum (Table 9) The increase in biomass during the second survey may have been due to increased numbers of adult salmon in shallow depths and large, mature pollock (over 30 cm) that were caught in a midwater trawl sample on the second survey.

Central - offshore
In the Central offshore area there was very little sign of forage species in the shallow stratum, and biomass estimates were low (<0.1 g/m2) in both surveys. In the deep stratum the Central area had notable concentrations of 0+ age pollock in the southernmost transects (Transects 01, 02, 03), and the increase in the biomass estimate in the deep stratum on the second survey appears to have been due to increased size of those schools (Table 10).

South - offshore

In the South, biomass in shallow depths appeared to be comprised mainly of herring of several year classes. Maximum biomass tended to occur on transects crossing Knight Island Passage (Transect 05, Table 11). The biomass in the deep stratum was low, and probably was pollock; although limited catches preclude much certainty in assigning species identifications. Target strengths for the South deep stratum were based on data for pollock.

Hydroacoustic Biomass Estimates -Inshore Transects

The highest total biomass estimates in the summer surveys occurred on the nearshore transects, especially in the Central area on the first survey and the North area on the second survey (Table 12, Figure 6). In the North, high biomass estimates in the second survey were due to consistently high transect means in the Valdez Arm area south of the narrows (Transects VZ4, VZ5, and VZ6, Table 13). In the Central area the elevated biomass estimate in the first survey appears due mainly to a very strong acoustic signal that occurred on one transect (Transect NZ6, Table 14). In the South, nearshore biomass estimates were similar in the two surveys, and were influenced strongly by high mean biomass levels on transects in the Dangerous Passage area (Transects JZ1, JZ3m, Table 15).

HYDROACOUSTIC DISTRIBUTION PATTERNS

North Study Area - First Survey

The North area had highest biomass estimates above 25 m in Port Fidalgo and in parts of Valdez Arm (Figure 7). In the deep stratum there were also concentrations of acoustic targets in those general areas (Figure 8).

Above 25 m (Figure 7) the high biomass south of Bligh Island in Port Fidalgo is comprised of herring schools between km 5 and 12 on Transect V01A (Figure 9), while the less dense biomass on the east end of Port Fidalgo is due to a school of herring at 10 - 15 m depth on the east end of Transect V02A (Figure 10). The patchy occurrence of relatively high biomass areas in shallow depths Valdez Arm is due to the presence of many small but relatively intense acoustic returns from the upper 15 m such as those seen on the west end of V02A and the central part of V03A (Figures 10, 11). These targets could be small herring schools or groups of adult salmon.

From 25 to 65 m there were two areas of high biomass in the first survey of the North area, one in Port Fidalgo and in Valdez Arm west of Bligh Island. The first is due to three small but intense schools of unknown composition near the bottom on transect V01A (Figure 9), while the Valdez Arm concentration is due to a dense school of age 1+ pollock on transect V03A (Figure 11).

North Study Area - Second Survey

Biomass increased in the second survey of the North area in both depth strata. In shallow depths, acoustic biomass was concentrated around Bligh Island and in several locations in the south part of Valdez Arm (Figure 12). The deep biomass was concentrated in an area of Port Fidalgo just to the south of Bidarka Point (Figure 13).

The shallow biomass concentrations found in Valdez Arm were due to very strong acoustic signals from targets in the upper 20 m such as those that occurred on Transects V03A and V06A (Figures 14, 15). Attempts to sample these targets with the midwater trawl were generally futile, and signs of salmon in the area (many jumpers) suggest that many of those shallow targets may have been adult salmon migrating to spawning streams. However, small schools of herring may also have been in the area (a salmon caught in this area by angling had herring in its stomach).

The deep stratum had a notable dense school on Transect V02A in Port Fidalgo (Figure 16). This school was comprised of age 1+ pollock, indicating that, as in the first survey, deep biomass in the North region was mainly age 1+ walleye pollock.

Central Study Area - First Survey

In the Central area, biomass was generally low in the first survey (July 22 - 25), with higher biomass in the deep stratum. This pattern is apparent in an area map of shallow and deep biomass distribution (Figures 17, 18 - note the change in scale for the gray scale).

Above 25 m, most acoustic targets were found east of Knight Island on Transects N01A and N02A (Figures 19, 20) and to the west of Storey Island on the northern edge of the Central area (Transect N11W, Figure 21). Much of the shallow return on N01A and N02A appears to be vertical extensions of the dense schools of 0+ age pollock that are found deep in that area - this is obvious on transect N02A (Figure 20). The shallow returns around Storey Island (N11W, Figure 21) were not identified, but may have been migrating adult salmon.

Below 25 m the dominant forage fishes were 0+ walleye pollock (58 mm long). These fish were loosely concentrated to the east of Knight Island on the southernmost transects. These schools were densest in an area 5 - 10 km east of Knight Island (N02A, Figure 20), but there were notable concentrations further east. The main school to the east of Knight Island apparently was stretched over 10 km north to south (it appears on transect N01A, N02A and N03A, Figures 19, 20, 22) and was 1 - 3 km wide. It extended vertically for at least 30 - 40 m in the water column.

Central Study Area - Second Survey

Biomass levels in the Central area were higher in the second survey, due almost entirely to increases in the deep strata. The depths above 25 m had a distribution similar to the first survey (Figure 23, again note the biomass scale), while the deeper stratum again had schools of fish concentrated to the east of Knight Island (Figure 24).

As in the first survey, the shallow acoustic returns to the south were due vertical extensions of the dense schools of age 0+ pollock found deeper in the southern part of the Central Region (Transects N01A, N02A, Figures 25, 26); whereas shallow returns in the northern part of the Central area were due to small schools of fish near the surface (e.g. Transect N11E, Figure 27) - as in the first survey the identity of those shallow targets was not confirmed.

The increased biomass in the second survey was due largely to increased size and density of schools of age 0+ walleye pollock on transects N01A and N02A (Figures 25, 26), although other schools of 0+ pollock occurred elsewhere, as on Transect N11E where a dense school occurred just above the bottom to the east of Storey Island (Figure 27).

South Study Area - First Survey

On the first survey biomass was lower in the deep stratum, as indicated by the difference in the biomass scales between plots of the shallow and deep biomass distributions (Figures 28, 29). A notable concentration of fish occurs off Dual Head on transect J01A in both depth strata. In shallow depths this was a school of herring that actually occurred just off the fixed transect (J01A) and was recorded on transect J01ex (Figure 30). The scattering of weak targets typical of shallow depths in this area is apparent in the fixed transect J01A (Figure 31). Additional targets were present below the herring school but do not appear on the plot (Figure 30) because their biomass was too low to show up on this scale.

South Study Area - Second Survey

The surface plot of shallow returns in the second survey is dominated by several areas where small dense targets occurred (Figure 32), while the deep stratum had several areas of concentration near the south end of Dangerous Passage near the shores of Chenega Island (Figure 33).

The shallow returns off the southwest corner of Knight Island were two discrete schools on transects J01E and J05E. Similarily, the strong acoustic signal in Icy Bay is due to a single large target that may have been a discrete school of small fish such as herring.

The deeper targets that were observed on the south end of Dangerous Passage were epibenthic schools of unknown composition that occurred above the bottom in the nearshore parts of the transects J02A and J03A and around a ridge near the center of J02A (Figure 34).

NET SAMPLING

Fishes

Schools of fishes identified on acoustic transects were predominantly walleye pollock and herring. In all areas, walleye pollock were the most abundant fishes in deep strata, while in shallow strata herring were the dominant species in the North and South areas (Tables 16, 17, 18). In the Central area pollock were the dominant species in both shallow and deep strata. Other species that were notable components of catches were capelin, which were found in shallow depths of the Central study area around Naked Island (Table 17); eulachon - found in the deep stratum of the North area (Table 16); and both prowfish and crested sculpin that were found occasionally in samples from all depths and areas (Tables 16, 17, 18).

Walleye pollock in midwater trawl samples had size distributions that clearly identified them as ages 0+ (less than 1 year old, hatched in the spring of 1995) or age 1+ (1 year old, year class 1994, Table 19). Age 0+ pollock are < 100 mm long, wheras age 1+ pollock are typically between 100 and 200 mm, with no overlap between length distributions of the two age classes. The mean size of age 0+ pollock ranged from 58 mm in the Central area to 66 mm in the South (Table 19).

Most herring collected in mid-water trawl samples in the North area were of a length (mean 153 mm) consistent with age 1+. Samples of herring collected in shallow, nearshore areas with dip nets appeared to be 0+ age fish (mean length 77 mm, Table 19). Herring collected in the South area had several length modes, with little overlap between distributions. Apparently several age classes were found in herring schools in the South study area.

Jellyfish

Gelatinous zooplankters (including hydrozoan medusae, scyphozoans and ctenophores) were visually conspicuous and common components of trawl samples in Prince William Sound. Net sampling often damages gelatinous zooplankters so that they are not identifiable, and their distensible form allows smaller specimens to pass through nets. However, because of their potential importance as both prey and predators of other forage species, data were collected on their abundance and distribution in trawl samples. Gelatinous zooplankters were not enumerated to species during the initial transects in each area because of identification problems, but in subsequent sampling were recorded as belonging to Cyanea capillata, Chrysaora melanaster, *Phacellophora camtschatica, Aequorea* sp., hydrozomedusae, ctenophores and unidentified jellyfish.

Gelatinous zooplankters (hereafter collectively referred to as jellyfish) were collected in 55 trawl samples during the summer sampling, with more being present in trawl samples (33 trawl samples) from the Central area than from the North (15 trawl samples) or the South area (7 trawl samples) . Few individual specimens were collected in the South area (69), but large numbers were present in trawls from both the Central (655) and North (492) areas.

Different distributional patterns were present for the species. *Cyanea capillata* was present in all areas but more numerically predominate in the North and South, representing 37%, 9% and 36% of the identified jellyfish in the North, Central and South areas, respectively (Table 20). *Chrysaora melanaster* was more uniformly distributed, constituting 18%, 17% and 27% of the jellyfish in the North, Central and South areas, respectively. *Phacellophora camtschatica* was uncommon to rare in all areas, representing 9%, 3% and 1% of all jellyfish in the North, Central and South areas, respectively. The hydromedusae *Aequorea* sp. perhaps had the most skewed distributional pattern, representing 59% of all jellyfish in the Central area, but only 10% in the North and <1% in the South area. Many small, unidentified hydromedusae were present in the North area but were absent in other areas. Ctenophores were rare in all areas, perhaps due to sampling bias related to their smaller sizes.

Euphausiids

Euphausiids (hereafter referred to as krill) are common macrozooplankton herbivores in Prince William Sound (PWS). Of the 24 krill species that have been reported from the Northeast Pacific Ocean, five were collected in both summer and fall 1995 sampling in PWS; the same five species were collected in the 1994 PWS sampling. *Euphausia pacifica* and four congeneric species, including *Thysanoessa inermis, T. longipes, T. raschii* and *T. spinifera* were collected.

The mid-water trawl used in our sampling did not have an optimum mesh size for efficient collection of krill. However, all species in our collections were of the same approximate size (15-25 mm total length) and we assume sampling biases to be similar for all species. Smaller species and early life history stages may not have been collected with our sampling gear. Also, krill are known to have robust diurnal migration patterns and generally are in the upper water column during the night hours. Most of our trawl sampling was conducted during the daylight hours to coincide with seabird observations, and krill were collected only in deep tows during the summer collections. The shallowest trawl in the summer which contained krill was to 60 m depth. Because our hydroacoustic gear sampled effectively only to 65 m depth, few hydoacoustic targets were identified as krill. All krill collected during the summer months were adults; early life history stages may have passed through the large mesh, but it is also reasonable to expect that krill hatching in April or May would be adults by late July/August.

The most striking pattern of krill distribution during the summer sampling was that no krill were collected in the Central area despite intensive sampling (33 trawl tows) to a variety of depths. The same sampling gear collected five krill species in both the North and South areas (Table 21). During the summer most krill species were present at all sampling sites where krill were collected, however *T. inermis* and *T. longipes* were collected at only two sites. A distribution gradient in abundance of the species appeared to be present: *T. rashii* was numerically abundant in the North area, while *T. spinifera* and *T. inermis* were most abundant in the South area (Table 21). Another impressive attribute of the krill collections in PWS was the variability in species composition between sites. Where multiple samples were collected at the same site, little variability was present.

Some indication of spatial variability in condition of krill was present. The length-weight relationship of *T. spinifera* varied greatly between collections in the North and South area (Figure 35), even though the length range of specimens from the two areas were similar.

The wet weight of the krill individuals varied between 0.112 g for the largest species (*T. spinifera*) and O.040 g for the smallest species (T. rashii); the average *T. rashii* specimen weighs 36% of the average wet weight of the average *T. spinifera* specimen. Despite its smaller size, *T. rashii* was the predominant species by biomass (49%) in the North, while *T. spinifera* was the predominant species by biomass (64%) in the Central and South (65%).

HYDROGRAPHY

Prince William Sound is a large estuary, with large amounts of freshwater input from rainwater and meltwater from glaciers and snowfields. The resultant salinity gradients are largely responsible for stratification of the water column in the Sound. In the summer of 1995 all three study areas had gradients in temperature and salinity in the upper 50 m, with surface temperatures ranging from 12 - 15° C. and salinities from 17 - 30 o/oo (Figures 36, 37, 38). Below about 50 m temperatures were typically <5° C. with salinities above 32 o/oo.

Physical conditions in the three study areas were generally similar, although conditions in the upper 30 m of the water column varied somewhat as the result of differences in the amount and type of fresh water runoff. The Central study area was least influenced by freshwater runoff, and consequently had the highest salinity in surface waters. Both the South and North study areas had lower surface salinity, with lowest salinity in the South, where large amounts of glacial meltwater produced a near-surface layer of very cold (<5° C.) water that was not present in the North (Figures 36, 37, 38).

Over the time period of the two surveys in each study area conditions remained relatively stable. In both the North and Central areas there are indications that the upper 50 m was becoming somewhat fresher and warmer (Figures 36, 37). The South study area showed relatively little change between the surveys, and the upper water column had a marked lens of cold water on both surveys (Figure 38).

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Table 1. Locations of transects and transect lengths in three study areas.

Northeast Area - (East/West Boundaries - Variable)

Transect Number	Latitude	General Location	From/To	Length(NM)
FFV01A	60°46.2'	S Port Fidalgo	shore to 147°0'	13.20
FFV02A	60°8.2'	S Bligh Is.	146°0' to 147°5'	17.05
FFV03LLB	60°0.2'	Landlocked Bay	shore to shore	1.60
FFV03TT	60°0.2'	S Tatitlek Narrows	shore to shore	2.40
FFV03VA	60°0.2'	Bligh Reef	shore to 147°0'	10.30
FFV04BB	60°2.2'	Boulder Bay	shore to shore	1.00
FFV04VA	60°2.2'	E Glacier Is.	shore to shore	9.80
FFV05VA	60°4.2'	Valdez Arm	shore to shore	10.90
FFV05GIW	60°4.2'	W Glacier Is.	shore to 147°0'	2.55
FFV06GBE	60°6.2'	inner Galena Bay	shore to shore	1.50
FFV06GBW	60°6.2'	outer Galena Bay	shore to shore	1.40
FFV06VA	60°6.2'	Valdez Arm	shore to shore	5.50
FFV06CB*	60°56.2'	Columbia Bay ent.	shore to shore	5.25
FFV06LB	60°56.2	Long Bay ent.	shore to shore	1.90
FFV07VA	60°58.2'	Valdez Arm	shore to shore	4.35
FFV08VA	61°00.2'	Valdez Arm	shore to shore	4.10
FFV09VA	61°02.2'	Valdez Arm/Jack B.	shore to shore	5.15
FFV10VN	61°04.2'	Valdez Narrows	shore to shore	1.00
FFV11PV	61°06.2'	Port Valdez	shore to shore	11.30
			TOTAL	110.25

Table 1. Continued

Central Area - (East/West Boundaries - 147°12.0' to 147°42.0')

Transect Number	Latitude	General Location	From/To	Length(NM)
FFN01A	60°22.3'	N Montague St.	147°12.0' to shore	12.60
FFN02A	60°24.3'	Manning Rocks	147°12.0' to shore	14.45
FFN03A	60°26.3'	N Seal Is.	147°12.0' to shore	12.50
FFN04A	60°28.3'	N Knight Is.	147°12.0' to shore	12.60
FFN05A	60°0.3'	S Smith Is.	147°2.0' to shore	11.90
FFN06A	60°2.3'	N Smith Is.	147°2.0' to shore	10.45
FFN07E	60°34.3'	NE Eleanor Is.	147°2.0' to shore	10.25
FFN07W	60°4.3'	NW Eleanor Is.	shore to 147°2.0'	3.35
FFN08A	60°6.3'	Eleanor Pass.	147°12.0' to 147°42.0'	14.80
FFN09E	60°38.3'	SE Naked Is.	147°12.0' to shore	3.95
FFN09W	60°8.3'	SW Naked Is.	shore to 147°42.0'	7.00
FFN10E	60°0.3'	E Naked Is.	147°12.0' to shore	3.55
FFN10C	60°0.3'	McPherson Bay	shore to shore	1.80
FFN10W	60°0.3'	W Naked Is.	shore to 147°42.0'	7.35
FFN11E	60°2.3'	E Peak Is.	147°12.0' to shore	4.70
FFN11W	60°2.3'	W Peak Is.	shore to 147°42.0'	8.40
FFN12E	60°4.3'	E Storey Is.	147°12.0' to shore	5.35
FFN12W	60°4.3'	W Storey Is.	shore to 147°42.0'	7.80
			TOTAL	152.80

APPENDIX A-14

Table 1. Continued

Southwest Area - (East/West Boundaries - 148°05.0' / 148°16.0')

Transect Number	Latitude	General Location	From/To	Length(NM)
FFJ01E	59°5.0'	Whale Bay Entr.	148°5' to shore	2.96
FFJ01W	59°5.0'	Icy Bay	shore to shore	1.30
FFJ02A	59°7.0'	lower Dang. Pass.	shore to shore	3.66
FFJ03A	59°9.0'	S. Jackpot Is.	shore to shore	1.82
FFJ04A	59°21.0'	Dangerous Pass.	shore to shore	1.14
			TOTAL	10.88

Zigzags near shore

Northeast Area

Transect Number	Length
FFVZ1S	<1 fragments
FFVZ1N	1.1
FFVZ2S	runs through foul ground
FFVZ2N	1.5
FFVZ3S	2.1
FFVZ3N	<1
FFVZ4S	<1
FFVZ4N	1.0
FFVZ5S	1.0
FFVZ5N	<1
FFVZ6S	3.1
FFVZ6N	1.0
FFVZ7S	1.2
FFVZ7N	1.2
TOTAL	13.2

Table 1. Continued

Zigzags near shore

Central Area

Transect Number	Length
FFNZ1S	1.1
FFNZ1N	1.9
FFNZ2S	1.1
FFNZ2N	1.1
FFNZ3S	1.65
FFNZ3N	1.0
FFNZ4S	2.0
FFNZ4N	1.1
FFNZ5S	2.4
FFNZ5N	3.4
FFNZ6S	1.4
FFNZ6N	1.9
TOTAL	20.05

Southwest Area

Transect Number	Length
FFJZ1S	1.3
FFJZ1N	1.5
FFJZ2S	<1.0
FFJZ2N	<1.0
FFJZ3S	1.9
FFJZ3N	1.3
TOTAL	6.0

APPENDIX A-16

Table 2. Acoustic transects sampled on APEX cruise 95-1 in Prince William Sound.

TRANSECT	DATE	TIME START	LAT START	LONG START	TIME END	LAT END	LONG END
ffnz1s	21-Jul	11:39:40	60 25.62	147 45.31	11:50:44	60 26.03	147 39.92
ffnz2s	21-Jul	17:24:20	60 29.85	147 45.87	17:36:00	60 29.21	147 43.42
ffnz2e	21-Jul	17:51:16	60 30.75	147 40.70	18:02:26	60 30.29	147 38.89
ffn01a	22-Jul	9:13:16	60 26.27	147 14.01	11:38:24	60 25.21	147 45.21
ffn02a	22-Jul	12:26:07	60 27.10	147 41.56	14:50:26	60 26.68	147 13.93
ffnz3s	22-Jul	13:01:43	60 33.34	147 36.35	13:19:22	60 33.94	147 39.21
ffn03a	22-Jul	15:10:41	60 28.61	147 12.47	17:21:43	60 29.03	147 43.26
ffnz2n	22-Jul	17:37:09	60 30.04	147 43.62	17:49:52	60 30.05	147 39.70
ffn04a	23-Jul	8:08:22	60 30.79	147 38.34	10:31:18	60 31.45	147 13.03
ffn08a	23-Jul	8:19:03	60 38.61	147 44.02	11:33:00	60 39.70	147 13.83
ffn08e	23-Jul	9:38:33	60 41.00	147 36.40	10:08:25	60 39.11	147 29.12
ffn05a	23-Jul	10:52:27	60 32.18	147 13.07	12:59:32	60 33.19	147 42.42
ffn09e	23-Jul	11:57:44	60 40.39	147 12.98	12:42:53	60 40.65	147 23.71
ffnz3n	23-Jul	13:20:26	60 34.81	147 38.62	13:29:43	60 33.90	147 34.64
ffn06a	23-Jul	13:31:19	60 34.90	147 41.41	15:40:17	60 35.92	147 13.24
ffn06e	23-Jul	14:42:28	60 36.01	147 28.26	14:44:29	60 34.89	147 28.93
ffn07e	23-Jul	16:14:28	60 35.25	147 17.22	18:05:43	60 37.07	147 39.45
ffnz5s	23-Jul	17:26:34	60 43.24	147 31.04	17:48:53	60 42.96	147 31.76
ffn07w	23-Jul	19:08:42	60 37.16	147 39.91	19:42:31	60 36.76	147 49.08
ffn12e	24-Jul	9:55:47	60 46.78	147 28.97	10:52:54	60 46.25	147 14.21
ffn11e	24-Jul	11:12:54	60 45.22	147 13.90	11:55:34	60 44.82	147 27.14
ffn11x	24-Jul	11:57:19	60 45.95	147 29.10	12:08:55	60 45.31	147 24.80
ffn09w	24-Jul	13:44:15	60 40.07	147 29.27	14:54:09	60 41.32	147 49.32
ffnz6s	24-Jul	14:53:48	60 48.35	147 21.34	15:04:03	60 45.18	147 22.09
ffn11w	24-Jul	15:23:50	60 44.54	147 49.36	16:46:15	60 45.33	147 27.33
ffnz5n	24-Jul	17:07:31	60 50.99	147 29.24	17:24:55	60 44.27	147 32.64
ffn10w	24-Jul	17:51:25	60 42.70	147 32.34	19:03:20	60 42.47	147 49.28
ffv01a	25-Jul	7:55:21	60 47.29	146 37.24	10:33:28	60 47.99	146 67.63
ffn12w	25-Jul	8:05:59	60 46.51	147 49.55	9:25:43	60 47.05	147 31.35
ffv01x	25-Jul	8:09:14	60 48.45	146 36.43	8:27:44	60 47.61	146 43.96
ffv02a	25-Jul	11:02:46	60 49.59	147 12.99	15:30:23	60 50.86	146 31.63
ffv02x	25-Jul	12:36:00	60 49.98	146 52.77	12:43:49	60 50.56	146 51.85
ffnz6n	25-Jul	15:04:58	60 45.76	147 22.28	15:23:06	60 46.30	147 27.51
ffv03tt	25-Jul	17:51:18	60 51.74	146 44.09	18:09:58	60 52.33	146 49.23
ffvz2n	26-Jul	14:30:31	60 61.99	146 48.78	14:44:10	60 56.15	146 50.83
ffv02x2	26-Jul	15:33:52	60 51.59	146 35.44	15:52:54	60 54.34	146 35.17
ffv03llb	26-Jul	17:02:21	60 52.60	146 39.65	17:14:32	60 52.20	146 36.09
ffvz3s	27-Jul	8:03:29	60 58.03	146 38.91	8:20:48	60 63.87	146 48.20
ffv07va	27-Jul	9:03:07	60 59.95	146 46.81	9:44:57	60 59.55	146 59.53
ffv03va	27-Jul	9:08:01	60 52.21	146 54.39	10:47:34	60 52.13	147 16.51
ffv08va	27-Jul	10:22:51	61 01.07	146 50.83	11:08:04	61 02.35	146 43.71
ffvz5s	27-Jul	11:09:04	61 03.21	146 50.71	11:19:28	61 02.62	146 42.84
ffv04va	27-Jul	11:14:21	60 53.82	147 10.20	12:46:37	60 55.05	146 47.67

Table 2. Continued

TRANSECT	DATE	TIME START	LAT START	LONG START	TIME END	LAT END	LONG END
ffv09va	27-Jul	11:42:50	61 03.78	146 45.96	12:41:48	61 05.44	146 54.19
ffvz6s	27-Jul	13:36:00	61 05.03	146 47.97	14:03:48	61 04.45	146 46.75
ffvz7s	27-Jul	14:34:46	61 07.47	146 47.73	14:47:10	61 06.46	146 42.06
ffv05va	27-Jul	15:15:46	60 56.59	146 46.73	18:12:25	60 58.16	146 50.52
ffv06gbe	28-Jul	7:49:12	60 57.92	146 46.04	8:01:58	60 58.24	146 38.31
ffv06gbw	28-Jul	8:29:35	60 58.40	146 42.73	8:41:41	60 58.54	146 42.84
ffvz4nx	28-Jul	10:00:02	60 60.64	146 53.06	10:09:38	60 62.80	146 59.76
ffvz4n	28-Jul	10:10:24	60 63.15	146 59.08	10:21:47	61 00.89	146 51.87
ffv09vax	28-Jul	11:58:53	61 03.78	146 42.33	12:05:50	61 04.29	146 48.90
ffvz6n	28-Jul	14:04:41	61 04.73	146 45.84	14:16:29	61 05.01	146 49.46
ffv10vn	28-Jul	14:17:46	61 05.74	146 48.24	14:24:55	61 04.92	146 44.75
ffvz7n	28-Jul	14:48:17	61 07.38	146 41.62	14:59:45	61 07.47	146 46.45
ffv11pv	28-Jul	15:00:52	61 07.94	146 45.16	16:54:58	61 07.18	146 24.76
ffj04a	29-Jul	8:30:50	60 29.33	148 07.15	8:38:56	60 21.44	148 11.77
ffjz3s	29-Jul	8:56:09	60 20.16	148 17.54	9:13:15	60 19.86	148 17.50
ffj03a	29-Jul	9:14:11	60 19.15	148 17.52	9:30:33	60 27.40	148 13.75
ffj02a	29-Jul	9:58:49	60 17.25	148 15.45	10:32:34	60 25.84	148 17.29
ffjz1s	29-Jul	10:50:44	60 24.19	148 22.00	10:55:37	60 21.08	148 19.01
ffj01e	29-Jul	13:09:09	60 15.13	148 10.29	14:06:26	60 23.24	147 62.94
ffj05e	29-Jul	14:38:37	60 21.52	147 56.93	15:33:16	60 21.31	148 05.90
ffjz4s	29-Jul	16:39:49	60 12.22	148 09.02	16:50:44	60 11.75	148 15.08
ffj06a	29-Jul	16:57:49	60 19.69	148 07.09	17:07:51	60 11.55	148 07.16
ffjz5s	29-Jul	17:19:29	60 18.83	148 10.68	17:29:36	60 09.69	148 12.07
ffj07a	29-Jul	17:31:17	60 17.97	148 13.94	17:35:13	60 10.26	148 11.56
ffjz3n	30-Jul	8:40:07	60 29.97	148 13.25	8:55:19	60 20.78	148 16.51
ffjz1n	30-Jul	10:40:16	60 22.41	148 18.24	10:49:52	60 24.86	148 20.80
ffj01ex	30-Jul	11:35:45	60 22.74	148 17.72	11:49:08	60 20.45	148 18.95
ffj05ex	30-Jul	15:40:01	60 13.01	148 05.46	16:06:12	60 21.34	148 05.95
ffjz4n	30-Jul	16:28:19	60 21.10	148 05.70	16:38:56	60 12.94	148 08.02
ffjz5n	30-Jul	17:08:51	60 19.99	148 06.01	17:18:35	60 10.64	148 10.13
2fn01a	1-Aug	8:54:25	60 24.80	147 14.29	11:01:16	60 25.05	147 44.21
2fnz1s	1-Aug	11:01	60 22.38	147 36.86	11:12:00	60 23.37	147 36.41
2fn012a	1-Aug	11:46	60 24.21	147 40.74	14:30:00	60 24.40	147 12.00
2fn03a	1-Aug	14:48	60 26.27	147 11.98	16:53:00	60 26.35	147 36.90
2fnz2s	1-Aug	16:53	60 26.35	147 36.90	17:05:00	60 27.33	147 35.88
2fnz2n	1-Aug	17:05	60 27.33	147 35.88	17:17:00	60 28.27	147 37.19
2fn04a	2-Aug	8:07	60 28.29	147 36.97	10:09:00	60 28.19	147 12.86
2fn05a	2-Aug	10:35	60 30.35	147 11.97	12:26:00	60 30.36	147 35.99
2fnz3s	2-Aug	12:26	60 30.36	147 35.99	12:44:00	60 31.28	147 33.42
2fnz3n	2-Aug	12:44	60 31.28	147 33.42	12:55:00	60 32.25	147 32.86
2fn06a	2-Aug	12:55	60 32.25	147 32.86	17:54:00	60 32.45	147 12.03
2fn07e	2-Aug	18:14	60 34.26	147 11.94	19:54:00	60 34.35	147 32.88
2fn10c	3-Aug	8:09:36	60 43.25	147 31.52	8:20:50	60 46.37	147 28.10
2fn07w	3-Aug	8:13	60 34.24	147 35.66	8:46:00	60 34.31	147 41.87
2fn10e	3-Aug	8:35:38	60 42.79	147 27.81	9:16:35	60 42.36	147 13.50
2fn08a	3-Aug	9:09	60 36.21	147 41.97	14:20:00	60 36.30	147 12.00
2fn11e	3-Aug	9:40:35	60 44.55	147 13.65	10:26:17	60 45.74	147 22.81

Table 2. Continued

TRANSECT	DATE	TIME START	LAT START	LONG START	TIME END	LAT END	LONG END
2fnz6s	3-Aug	10:33:35	60 47.26	147 23.42	10:45:24	60 45.71	147 24.97
2fn08ax	3-Aug	10:43	60 36.96	147 26.71			
2fn12e	3-Aug	11:03:31	60 47.28	147 25.88	11:58:18	60 46.27	147 13.22
2fn09e	3-Aug	14:42	60 38.30	147 12.22	15:17:00	60 38.34	147 19.19
2fnz4n	3-Aug	15:17	60 39.29	147 19.19	15:36:00	60 39.29	147 16.49
2fnz4s	3-Aug	15:36	60 39.29	147 16.49	16:08:00	60 40.28	147 18.70
2fnz4nx	3-Aug	16:08	60 40.28	147 18.70			
2fnz5n	3-Aug	16:14:10	60 47.54	147 32.17	16:34:56	60 44.45	147 32.64
2fnz5s	3-Aug	16:35:48	60 43.64	147 33.12	16:56:21	60 42.84	147 30.95
2fn10ex	4-Aug	8:28:24	60 46.54	147 24.45	8:32:19	60 43.46	147 20.47
2fv01a	4-Aug	9:41:53	60 48.06	146 64.75	11:50:53	60 48.10	146 38.13
2fn11ex	4-Aug	10:27:07	60 45.99	147 23.62	10:31:09	60 46.87	147 23.71
2fnz6n	4-Aug	10:46:14	60 46.40	147 24.22	11:02:16	60 46.59	147 25.70
2fv02a	4-Aug	12:19:40	60 50.22	146 38.22	15:16:07	60 50.56	147 12.06
2fn12w	4-Aug	12:56:31	60 46.86	147 31.04	14:12:35	60 47.52	147 49.30
2fv02x	4-Aug	13:53:43	60 56.61	146 54.29	13:54:57	60 56.60	146 54.65
2fn11w	4-Aug	14:33:42	60 45.44	147 49.66	16:03:22	60 45.57	147 30.88
2fv03a	4-Aug	15:47:00	60 52.26	147 17.89	17:31:02	60 56.46	146 54.70
2fn10w	4-Aug	16:57:28	60 42.58	147 31.87	18:02:59	60 42.96	147 49.04
2fn09w	4-Aug	18:21:17	60 41.49	147 42.72	19:29:03	60 40.63	147 29.48
2fv03tt	4-Aug	18:31:02	60 51.98	146 47.79	18:45:49	60 51.95	146 45.00
2fvz2n	5-Aug	13:25:02	60 62.64	146 46.22	13:36:34	60 56.00	146 51.04
2fv06va	5-Aug	14:08:45	60 57.73	146 51.36	15:02:19	60 57.46	146 59.77
2fv07va	5-Aug	15:35:42	60 59.39	146 59.42	16:16:53	60 60.23	146 47.93
2fvz3s	5-Aug	17:02:18	60 63.30	146 41.01	17:26:19	60 57.31	146 38.42
2fv06gbe	5-Aug	17:27:28	60 56.92	146 38.49	17:39:12	60 57.61	146 44.74
2fv03ax	5-Aug	17:32:57	60 54.95	146 54.08	17:52:58	60 56.27	146 50.30
2fv03llb	5-Aug	19:12:16	60 51.36	146 38.36	19:26:12	60 52.85	146 37.82
2fv08va	6-Aug	7:59:59	61 01.65	146 57.81	8:38:27	61 02.57	146 45.65
2fvz5s	6-Aug	8:39:26	61 02.84	146 44.35	8:50:11	61 02.10	146 42.60
2fv04va	6-Aug	9:07:53	60 54.67	146 52.54	10:47:16	60 54.03	147 08.57
2fv05va	6-Aug	11:11:54	60 55.53	147 09.87	13:48:50	60 57.28	146 54.44
2fv05vax	6-Aug	12:47:16	60 62.42	146 49.15	13:18:05	60 62.53	146 46.97
2fvz7s	6-Aug	14:01:41	61 06.51	146 41.63	14:14:31	61 07.03	146 42.41
2fvz6s	6-Aug	14:44:37	61 04.40	146 42.34	15:15:55	61 04.50	146 55.69
2fv09va	6-Aug	15:17:01	61 04.55	146 54.60	16:06:33	61 04.19	146 38.75
2fv06gbw	6-Aug	16:38:33	60 58.54	146 44.53	16:47:36	60 57.85	146 44.96
2fvz4v	7-Aug	7:48:17	60 60.68	146 59.22	7:58:59	61 01.25	146 50.43
2fj04a	7-Aug	8:41:43	60 29.88	148 07.76	8:48:31	60 21.38	148 11.48
2fjz3n	7-Aug	8:49:22	60 21.09	148 12.90	9:03:03	60 20.91	148 11.75
2fjz3s	7-Aug	9:04:01	60 20.45	148 13.28	9:22:49	60 20.13	148 17.25
2fj03a	7-Aug	9:23:43	60 19.50	148 16.43	9:38:58	60 27.47	148 13.25
2fj02x	7-Aug	10:22:37	60 19.56	148 15.14	10:28:13	60 20.56	148 15.87
2fj02a	7-Aug	10:32:56	60 17.36	148 14.58	11:06:24	60 25.61	148 15.99
2fjz1n	7-Aug	11:07:21	60 25.40	148 17.22	11:25:10	60 24.90	148 23.56
2fjz1s	7-Aug	11:26:05	60 24.33	148 24.50	11:32:07	60 19.55	148 20.94
2fv11pv	7-Aug	11:53:39	61 07.56	146 24.78	13:47:18	61 08.83	146 44.96
2fj01e	7-Aug	12:15:40	60 23.49	148 14.42	13:15:05	60 23.81	147 63.74
2fj05e	7-Aug	13:46:39	60 21.85	147 56.38	14:37:28	60 21.98	148 06.01

Table 2. Continued

TRANSECT	DATE	TIME START	LAT START	LONG START	TIME END	LAT END	LONG END
2fvz7n	7-Aug	13:48:32	61 07.90	146 44.36	14:00:40	61 07.20	146 41.53
2fv10vn	7-Aug	14:15:39	61 06.47	146 44.24	14:22:01	61 05.43	146 48.02
2fvz6n	7-Aug	14:23:05	61 04.71	146 49.08	14:30:58	61 05.95	146 43.84
2fvz6sx	7-Aug	14:38:14	61 04.42	146 50.55	14:43:37	61 04.20	146 50.81
2fjz4s	7-Aug	14:51:23	60 21.98	148 06.25	15:03:06	60 21.98	148 06.25
2fj06a	7-Aug	15:04:26	60 21.98	148 06.25	15:13:56	60 19.68	148 06.90
2fjz5s	7-Aug	15:24:28	60 18.74	148 12.07	15:33:29	60 09.83	148 11.01
2fj07a	7-Aug	15:34:24	60 09.44	148 11.99	15:39:03	60 09.17	148 11.59
2fj05w	7-Aug	16:33:54	60 13.25	148 13.57	16:46:47	60 21.97	148 12.31
2fj04a	8-Aug	8:41:43	60 29.88	148 07.76	8:48:31	60 21.38	148 11.48
2fjz3n	8-Aug	8:49:22	60 21.09	148 12.90	9:03:03	60 20.91	148 11.75
2fjz3s	8-Aug	9:04:01	60 20.45	148 13.28	9:22:49	60 20.13	148 17.25
2fj03a	8-Aug	9:23:43	60 19.50	148 16.43	9:38:58	60 27.47	148 13.25
2fj02x	8-Aug	10:22:37	60 19.56	148 15.14	10:28:13	60 20.56	148 15.87
2fj02a	8-Aug	10:32:56	60 17.36	148 14.58	11:06:24	60 25.61	148 15.99
2fjz1n	8-Aug	11:07:21	60 25.40	148 17.22	11:25:10	60 24.90	148 23.56
2fjz1s	8-Aug	11:26:05	60 24.33	148 24.50	11:32:07	60 19.55	148 20.94
2fj01e	8-Aug	12:15:40	60 23.49	148 14.42	13:15:05	60 23.81	147 63.74
2fj05e	8-Aug	13:46:39	60 21.85	147 56.38	14:37:28	60 21.98	148 06.01
2fjz4n	8-Aug	14:39:02	60 21.98	148 06.25	14:50:28	60 21.98	148 06.25
2fjz4s	8-Aug	14:51:23	60 21.98	148 06.25	15:03:06	60 21.98	148 06.25
2fj06a	8-Aug	15:04:26	60 21.98	148 06.25	15:13:56	60 19.68	148 06.90
2fjz5n	8-Aug	15:14:49	60 19.37	148 06.13	15:23:38	60 10.14	148 11.63
2fjz5s	8-Aug	15:24:28	60 18.74	148 12.07	15:33:29	60 09.83	148 11.01
2fj07a	8-Aug	15:34:24	60 09.44	148 11.99	15:39:03	60 09.17	148 11.59
2fj05w	8-Aug	16:33:54	60 13.25	148 13.57	16:46:47	60 21.97	148 12.31
flock10	10-Aug	13:29:50	60 47.65	147 21.91	13:46:29	60 46.95	147 26.14
rocky1	10-Aug	17:34:44	60 27.99	147 09.60	19:22:59	60 28.53	147 10.58

APPENDIX A-19

Table 3. Locations and times of acoustic transects on APEX research cruise 95-2 in Prince William Sound.

DATE	TRANSECT	START TIME	START LAT.	START LONG.	END TIME	END LAT.	END LONG.
9-Oct	3FN01A	10:40	60 22.38	147 11.81			
9-Oct	3FN02A	16:56	60 24.2	147 11.9	18:05	60 24.19	147 26.66
10-Oct	3FJ05E	10:05	60 12.58	147 52.07	11:06	60 12.80	148 04.90
11-Oct	3FN03A	13:38	60 26.534	147 11.610	15:40	60 26.42	147 36.59
11-Oct	CENTRAL AREA	22:49	60 21.74	147 27.31	23:08	60 22.739	147 25.702
12-Oct	3FN06A	10:43	60 33.45	147 32.33			
12-Oct	CENTRAL AREA	11:47	60 32.41	147 19.48			
12-Oct	FORAGING FLOCK	12:01	60 32.16	147 20.19			
12-Oct	CENTRAL AREA	12:04	60 32.35	147 20.13	12:53	60 32.19	147 11.89
13-Oct	3FNZ45X	10:44	60 37.44	147 19.67	11:18	60 36.85	147 19.99
13-Oct	Galena Bay	20:48	60 55.93	146 36.58	21:31	60 57.22	146 43.04
14-Oct	3FVO2A	11:20	60 48.18	147 04.97			
14-Oct	FORAGING FLOCK	12:29	60 47.97	146 50.61	14:09	60 48.2	146 29.91
14-Oct	TWO MOON BAY	14:12	60 48.16	146 29.64	14:45	60 45.29	146 33.58
14-Oct	PORT FIDALGO	20:45	60 44.96	146 33.56	21:12	60 46.92	146 33.01
14-Oct	LANDLOCKED BAY	22:49	60 48.281	146 35.62	23:10	60 50.57	146 35.25
15-Oct	FORAGING FLOCK	10:40	60 44.746	146 44.134			
15-Oct	3FV14W	11:59	60 40.09	146 45.00			
15-Oct	FORAGING FLOCK	12:45	60 39.99	146 35.36			
15-Oct	FORAGING FLOCK	13:01	60 40.00	146 34.96			
15-Oct	3FV14W	13:21	60 40.02	146 34.71	13:34	60 40.03	146 32.20
15-Oct	3FV14E	14:05	60 40.14	146 25.66	15:07	60 40.22	146 13.43

APPENDIX A-20

Table 4. Midwater trawl samples collected on APEX cruise 95-1 in Prince William Sound.

DATE	START TIME	END TIME	STATION	TRANSECT/LOCATION	LATITUDE START	LONGITUDE START	LATITUDE END	LONGITUDE END	BOTTOM DEPTH	FISHING DEPTH
21-Jul	16:40	17:05	1	NE Montague	60 13.56	147 29.01			130	50-60
22-Jul	9:25	9:48	2	NW side of Montague	60 19.19	147 29.69	60 20.35??	147 28.49	120	16
22-Jul	12:23	13:09	3	Btw Applegate and Knight Is	60 22.31	147 29.66	60 22.11	147 34.08	162	60
22-Jul	14:35	15:12	4	Transect FFN02A	60 24.21	147 31.24	60 24.18	147 27.27	146	40-60
22-Jul	17:04	17:40	5	FFN03A; NW of Seal Is.	60 26.15	147 30.66	60 25.666	147 34.086	174	50-60
23-Jul	9:37	10:04	6	FFN04A	60 28.428	147 29.248	60 28.556	147 26.994	172	60
24-Jul	10:15	10:36	11	N. of FFNO8A; SW Naked Is.	60 36.771	147 27.516	60 36.941	147 29.474	20-50	6
24-Jul	10:53	11:14	11	N. of FFNO8A; SW Naked Is.	60 37.00	147 29.768	60 36.893	147 27.715	20-70	12
25-Jul	15:37	16:09	19	FFNZ6N; E. of Liljegren Pass	60 43.58	147 19.65	60 42.22	147 18.74	70-130	50
26-Jul	10:15	10:36	22	FFV01A; S. of Bligh Is.	60 46.40	146 45.58	60 46.23	146 47.45	185-200	20-30
26-Jul	11:07	11:26	22	FFV01A; S. of Bligh Is.	60 46.22	146 48.15	60 46.36	146 46.06	166-185	15-20
26-Jul	16:16	16:58	25	FFV02A; S. of Bligh Is.	60 47.80	146 43.98	60 47.88	146 44.99	65-90	10 - 20
26-Jul	18:10	18:24	26	FFV02A; S. of Graveyard Pt.	60 48.38	146 32.78	60 48.35	146 34.18	40	10
27-Jul	9:06	9:49	28	FFV02A, S.E. Bligh Is.	60 47.63	146 43.58	60 48.02	146 44.08	137-160	50
27-Jul	10:57	11:41	29	FFV03VA, W of Bligh Reef	60 50.94	146 56.29	60 50.78	146 56.77	120-160	80
28-Jul	8:45	9:10	35	Outer Galena Bay	60 56.278	146 41.399	60 57.710	146 43.666	200-220	90-110
30-Jul	12:37		43	Whale Bay near Dual Head	60 13.84	148 11.56	60 14.821	148 10.747	120-200	8 - 10
30-Jul	16:07	16:20	47	FFJ05E; Pt. Countess	60 12.914	148 04.986	60 12.321	148 05.423	80-120	10
31-Jul	9:04	9:29	50	NE. of Pt. Countess	60 14.504	148 07.708	60 14.28	148 09.76	288-380	50-60
31-Jul	11:15	11:49	50	NE. of Pt. Countess	60 15.898	148 09.913	60 14.564	148 07.555	240-320	50-60
31-Jul	13:04	13:17	52	E. of Bainbridge Pt.	60 11.072	148 02.209	60 11.76	148 02.135	80-130	20
1-Aug	9:17	9:37	53	FFN01A; E. end of transect	60 22.308	147 15.217	60 22.416	147 13.219	110	50-60
1-Aug	9:55	10:34	53	FFN01A	60 22.64	147 11.49	60 22.305	147 15.516	110	20
1-Aug	12:14	12:36	54	FFN01A; E. of Knight Is.	60 22.477	147 29.583	60 22.535	147 27.291	130-160	60
1-Aug	13:40	14:18	55	FFN02A	60 24.375	147 29.666	60 24.468	147 25.533	80-146	10
1-Aug	15:27	15:51	56	FFN03A	60 26.241	147 16.158	60 26.296	147 18.266	200	80
1-Aug	17:30	17:57	57	FFN03A	60 26.331	147 29.559	60 26.625	147 26.819	160	75-80
2-Aug	9:25	9:54	58	FFN04A	60 28.04	147 29.09	60 28.369	147 25.647	170	75-80
2-Aug	14:28	14:55	62	FFN07A	60 35.274	147 29.678	60 36.639	147 29.051	80-200	15-20
2-Aug	15:16	15:59	62	FFN07A	60 36.667	147 29.171	60 36.245	147 26.300	70-120	50-60
3-Aug	10:27	10:49	64	FFN08A	60 36.245	147 33.589	60 36.160	147 30.922	250-320	7
3-Aug	14:49	15:30	66	E. end of FFN08A	60 36.343	147 14.880	60 35.94	147 12.190	120-190	7
3-Aug	17:06	17:35	67	E. of Peak Is.	60 41.356	147 20.636	60 40.29	147 18.419	20-40	7
4-Aug	10:45	11:24	72	E.of Liljegren Passage	60 43.792	147 20.909	60 42.613	147 20.387	80-90	12
4-Aug	11:56	12:43	73	E.of Liljegren Passage	60 43.940	147 21.697	60 44.264	147 21.674	70-80	90-140
5-Aug	13:04	13:43	81	W. end of FFV01A	60 46.414	146 33.445	60 46.535	146 33.165	60-80	50-70
5-Aug	14:25	15:12	82	FFV02A; E. of Graveyard Pt.	60 48.287	146 35.539	60 48.052	146 40.199	100-140	80-100
5-Aug	17:29	18:02	84	S. of Bligh Is.	60 47.850	146 45.039	60 48.310	146 49.213	20-25	5 - 15
5-Aug	18:38	19:08	84	S. of Bligh Is.	60 48.28	146 49.438	60 48.672	146 50.059	40-60	15-20
6-Aug	12:51	13:17	87	off of SW tip of Bligh Is.	60 48.277	146 49.656	60 48.138	146 48.778	20-50	15-20
6-Aug	15:52	17:06	87	off of SW tip of Bligh Is.	60 48.011	146 49.823	60 47.927	146 49.460	30-50	20-30
7-Aug	8:33	9:03	93	Galena Bay	60 56.338	146 40.871	60 57.278	146 43.097	200-220	100-110
7-Aug	9:32	10:17	93	Galena Bay	60 56.334	146 41.600	60 58.024	146 44.061	200-240	160-180
7-Aug	14:08	14:37	94	E. of Storey Is.	60 41.531	147 21.085	60 42.112	146 20.657	40-100	12
7-Aug	15:58	16:30	94	E. of Storey Is.	60 41.057	147 21.800	60 42.331	147 20.399	30-50	15-20
8-Aug	13:20	13:53	100	Dual Head, Whale Bay	60 15.085	148 09.583	60 15.09	148 10.626	320-340	8
8-Aug	17:21	17:46	104	Bainbridge Passage	60 09.098	148 06.366	60 10.302	148 05.937	140	85-90
8-Aug	20:16	20:33	107	S. of Pt. Helen (Knight I.)	60 09.342	147 45.055	60 08.613	147 45.619	50-70	15-20
8-Aug	21:57	22:22	108	N. of Hogan Bay	60 11.574	147 43.306	60 12.802	147 42.094	25-50	15
9-Aug	8:59	9:42	109	E. of Discovery Pt.	60 14.159	147 41.429	60 12.205	147 42.696	50-70	30-50
10-Aug	10:09	10:34	111	off of SW tip of Naked Is.	60 36.956	147 29.751	60 36.790	147 27.982	50-100	15
10-Aug	11:44	12:27	111	off of SW tip of Naked Is.	60 36.648	147 28.172	60 36.680	147 27.421	30-80	15-60
10-Aug	13:13	13:44	112	S. of Naked Is.	60 36.538	147 19.616	60 35.943	147 22.413	80-140	80
10-Aug	15:11	15:40	113	E. of Naked Is.	60 40.597	147 18.564	60 39.377	147 17.121	40-70	12
10-Aug	16:10	16:50	113	E. of Naked Is.	60 39.708	147 17.718	60 39.780	147 17.077	20-40	5
10-Aug	19:00	19:14	114	Montague Pt.	60 22.998	147 004.031	60 22.300	147 03.145	20-30	20
10-Aug	19:34	19:40	114	Montague Pt.	60 22.324	147 02.572	60 22.643	147 02.875	30	surface
10-Aug	19:59	20:10	114	Montague Pt.	60 22.996	147 03.622	60 22.769	147 03.995	30-40	10
10-Aug	20:38	21:05	114	Montague Pt.	60 23.220	147 05.712	60 22.764	147 03.622	30	12
11-Aug	12:10	13:02	116	Port Gravina	60 40.236	146 24.248	60 40.398	146 23.819	40-50	20-30

APPENDIX A-21

Table 5. Midwater trawl and NIO net sampling locations during APEX October cruise in Prince William Sound.

DATE	TIME	STATION	HAUL #	GEAR	LOCATION	LATITUDE	LONGITUDE	BOTTOM DEPTH (M)	GEAR DEPTH (M)
9-Oct	12:32	1	1	NIO	FFN01A	60 22.51	147 27.61	129	2-Jan
9-Oct	12:57	1	2	NIO	FFN01A	60 22.78	147 27.52	75-125	2-Jan
9-Oct	15:12	1	3	Mid Water	FFN01A	60 22.05	147 26.29	67-85	30-50
9-Oct	18:32	1	4	Mid Water	FFN01A	60 21.99	147 26.57	63-100	50-60
10-Oct	19:37	2	1	Mid Water	E. arm of Whale Bay	60 09.102	148 12.47	52-108	30-60
10-Oct	21:40	2	2	NIO	E. arm of Whale Bay	60 09.31	148 12.28	80	50
11-Oct	21:00	3	1	Mid Water	Applegate Rocks	60 22.029	147 26.601	60-90	40-56
11-Oct	21:53	3	2	Mid Water	Applegate Rocks	60 22.75	147 24.30	60-90	50-60
11-Oct	23:13	3	3	NIO	Applegate Rocks	60 22.716	147 25.667	110	80
12-Oct	13:03	4	1	Mid Water	E. of Smith Island	60 32.236	147 12.556	90	40-60
12-Oct	20:28	4	2	Mid Water	E. of Smith Island	60 32.410	147 13.654	55-70	30-50
12-Oct	21:50	4	3	Mid Water	E. of Smith Island	60 33.03	147 19.622	80-100	20-60
13-Oct	11:31	5	1	Mid Water	SE corner of Naked Is.	60 32.482	147 20.450	50-90	45-65
13-Oct	21:43	6	1	Mid Water	Galena Bay	60 57.062	146 43.035	220	15-Oct
13-Oct	22:40	6	2	CTD	Galena Bay	60 56.438	146 42.050	180	150
13-Oct	23:00	6	3	Ring Net	Galena Bay	60 56.438	146 42.050	180	50
14-Oct	21:58	7	1	Mid Water	Landlocked Bay	60 50.550	146 35.210	95-106	20-Oct
14-Oct	23:19	7	2	Mid Water	Landlocked Bay	60 50.316	146 35.397	97	67-90
15-Oct	10:42	8	1	NIO	NW of Goose Is.	60 44.783	146 44.179	40-45	2
15-Oct	13:02	9	1	NIO	off Knowles Bay	60 39.96	146 35.036	32	2

APPENDIX A-22

Table 6. CTD stations sampled during APEX cruise 95-1 in Prince William Sound.

DATE	TIME	STATION	TRANSECT #, LOCATION	LATITUDE	LONGITUDE	DEPTH	GEAR DEPTH
22-Jul	10:50	2	FFN01A	60 22.80	147 15.60	210	100
22-Jul	13:45	3	Btw Ap'gate and Knight Is	60 22.12	147 30.42	148	140
22-Jul	15:35	4	FFN02A;E of Manning Rks	60 24.22	147 30.00	169	140
22-Jul	16:46	5	FFN03A; NW of Seal Is.	60 26.18	147 30.29	164	140
23-Jul	9:10	6	FFN04A	60 28.337	147 30.183	197	200
23-Jul	10:39	7	FFN05A	60 30.288	147 30.090	197	200
23-Jul	12:25	8	FFN06A	60 32.341	147 30.144	194	180
23-Jul	13:20	9	FFN07A.	60 34.226	147 29.875	197	200
24-Jul	8:20	10	FFN08A	60 36.166	147 35.246	362	200
25-Jul	8:02	14	FFN10W	60 40.34	147 34.72	503	200
25-Jul	8:35	15	FFN11W	60 42.29	147 35.15	500	200
25-Jul	9:20	16	FFN12W	60 44.29	147 35.08	580	200
25-Jul	9:35	16	FFN12W	60 44.08	147 35.16	580	200
25-Jul	11:25	17	FFN12E	60 44.32	147 15.10	273	200
25-Jul	11:57	18	FFN11E	60 42.27	147 15.08	176	160
26-Jul	9:06	20	FFV01A	60 46.21	146 40.02	110	100
26-Jul	9:36	21	FFV02A	60 48.24	146 40.00	72	60
26-Jul	12:19	22	FFV01A	60 46.8	146 44.80	173	160
26-Jul	14:00	23	FFV01A; W. end of line	60 46.25	146 59.5	438	200
26-Jul	14:34	24	FFV02A; end of line	60 48.27	146 59.69	322	200
27-Jul	12:30	29	FFV03VA	60 51.88	146 57.33	118	100
27-Jul	13:00	30	FFV04VA	60 52.38	146 58.60	373	200
27-Jul	13:20	30	FFV04VA	60 52.41	146 59.26	370	200
27-Jul	13:40	30	FFV04VA	60 52.37	147 00.34	380	200
27-Jul	14:12	31	FFV03VA	60 50.34	147 00.29	372	200
27-Jul	15:00	32	FFV05VA	60 54.16	147 56.92	348	200
27-Jul	16:11	33	FFV06VA	60 56.26	146 53.23	330	200
28-Jul	8:06	34	Inner Galena Bay	60 56.34	146 37.75	105	100
28-Jul	10:25	35	Outer Galena Bay	60 57.3	146 43.30	220	200
28-Jul	11:05	36	FFV07A	60 58.22	146 50.27	332	200
28-Jul	11:49	37	FFV08A	61 00.27	146 48.29	305	200
28-Jul	13:30	38	FFV09VA	61 02.35	146 43.95	318	200
28-Jul	15:30	39	FFV11VA	61 06.29	146 30.41	243	200
30-Jul	9:45	40	FFJ03A	60 19.07	148 09.90	236	200
30-Jul	10:23	41	FFJ02A	60 17.01	148 09.98	287	200
30-Jul	11:19	42	FFJ01W	60 15.54	148 16.66	151	140
30-Jul	13:20	44	FFJ01E	60 15.093	148 09.989	318	200
30-Jul	14:30	45	FFJ01E	60 15.01	148 00.01	596	200
30-Jul	15:15	46	FFJ05E	60 12.94	147 59.40	502	200
30-Jul	17:15	48	Bainbridge	60 10.96	148 06.34	117	100
30-Jul	18:50	49	FFJ05W; Whale Bay	60 13.06	148 10.00	106	100
1-Aug	10:50	53	FFN01A	60 22.305	147 15.516	117	100
1-Aug	12:00	54	FFN01A; E. of Knight Is.	60 22.32	147 30.01	154	140
1-Aug	13:16	55	FFN02A	60 24.38	147 29.99	166	160
1-Aug	16:05	56	FFN03A	60 26.296	147 18.266	152	140
1-Aug	17:15	57	FFN03A; reg. stat.	60 26.32	147 29.98	162	140
2-Aug	9:01	58	FFN04A	60 28.046	147 29.803	175	160
2-Aug	11:05	59	FFN05A	60 30.29	147 30.21	198	180
2-Aug	12:15	60	FFN06A	60 32.12	147 30.65	204	200
2-Aug	14:08	61	FFN07A	60 34.28	147 30.15	190	180
3-Aug	10:00	64	FFN08A	60 36.274	147 35.270	342	200
3-Aug	14:35	66	E. end of FFN08A	60 36.34	147 15.15	199	180
4-Aug	8:40	68	FFN09E	60 36.36	147 15.28	161	140
4-Aug	9:10	69	FFN10E	60 40.33	147 15.27	116	100
4-Aug	9:35	70	FFN11E	60 42.36	147 15.27	176	160
4-Aug	10:05	71	FFN12E	60 44.45	147 15.35	264	200
4-Aug	14:05	74	FFN12W	60 44.27	147 35.04	566	200
4-Aug	14:52	75	FFN11W	60 42.229	147 35.099	488	200
4-Aug	15:20	76	FFN10W	60 40.280	147 35.454	528	200
4-Aug	15:51	77	FFN09W	60 38.251	147 35.359	370	200

Table 6. Continued

DATE	TIME	STATION	TRANSECT #, LOCATION	LATITUDE	LONGITUDE	DEPTH	GEAR DEPTH
4-Aug	16:22	78	E. side of FFN08A	60 36.170	147 35.120	338	200
5-Aug	10:17	79	E.end of FFV01A	60 46.279	147 00.01	452	200
5-Aug	11:05	80	E. end of FFV02A	60 48.18	146 59.92	320	200
5-Aug	15:22	82	FFV02A	60 48.128	146 39.992	88	80
5-Aug	16:06	83	West end of FFV01A	60 46.323	146 39.945	139	120
6-Aug	9:36	85	FFV03VA	60 50.327	147 00.03	372	200
6-Aug	10:06	86	FFV04VA	60 52.215	146 59.705	375	200
6-Aug	18:10	88	FFV05VA	60 54.194	146 57.949	334	200
6-Aug	18:49	89	FFV06VA	60 56.215	146 53.526	327	200
6-Aug	19:21	90	FFV07VA	60 58.249	146 50.509	203	180
7-Aug	7:26	91	Galena Bay	60 57.96	146 44.033	211	200
7-Aug	7:50	92	Galena Bay	60 56.981	146 42.699	213	200
7-Aug	8:13	93	Galena Bay	60 56.389	146 41.545	182	160
7-Aug	15:02	94	E. of Storey Is.	60 42.063	147 20.803	30	20
7-Aug	15:10	94	E. of Storey Is.	60 41.897	147 20.147	118	100
7-Aug	15:24	94	E. of Storey Is.	60 42.054	147 19.012	126	120
8-Aug	8:55	95	Ewan Bay	60 23.902	148 09.071	34.6	20
8-Aug	9:06	95	Ewan Bay	60 23.40	148 08.36	36	20
8-Aug	9:15	95	Ewan Bay	60 22.93	148 07.91	85	80
8-Aug	9:28	95	Ewan Bay	60 22.58	148 07.51	93	80
8-Aug	9:43	95	Ewan Bay	60 21.89	148 06.56	97	80
8-Aug	10:41	96	FFJ03A; E. of Chenega I.	60 19.019	148 10.056	280	200
8-Aug	11:15	97	FFJ02A	60 17.032	148 09.986	290	200
8-Aug	11:47	98	Icy Bay	60 17.079	148 14.120	118	100
8-Aug	12:17	99	FFJ01W	60 15.096	148 17.296	153	140
8-Aug	13:03	100	FFJ01E	60 15.059	148 10.045	320	200
8-Aug	14:26	101	FFJ05W	60 1.93	148 09.950	91	80
8-Aug	15:31	102	FFJ01E	60 14.995	147 59.924	594	200
8-Aug	16:01	103	FFJ05E	60 12.949	147 59.967	379	200
8-Aug	18:04	105	Bainbridge Passage	60 11.004	148 05.959	116	100
8-Aug	19:17	106	Btw Fleming and Knight Is	60 10.903	147 54.074	394	200
8-Aug	20:47	107	S. of Pt. Helen (Knight I.)	60 09.037	147 45.346	46	40
9-Aug	12:14	109	E. of Discovery Pt	60 12.704	147 42.404	22	20
9-Aug	12:21	109	E. of Discovery Pt	60 12.686	147 42.277	55	40
9-Aug	12:27	109	E. of Discovery Pt	60 12.721	147 42.135	124	120
10-Aug	13:57	112	S. of Naked Is.	60 36.035	147 21.680	78	60
10-Aug	15:58	113	E. of Naked Is.	60 39.633	147 17.332	35	20
10-Aug	20:17	114	Montague Pt.	60 22.800	147 03.578	34	20
11-Aug	8:33	115	E. of Montague Pt.	60 22.506	147 03.453	24.5	20
11-Aug	8:46	115	E. of Montague Pt.	60 22.849	147 02.367	44.5	40
11-Aug	8:59	115	E. of Montague Pt.	60 23.143	147 01.260	90	80
11-Aug	13:20	116	Port Gravina	60 40.504	146 23.755	42	40

APPENDIX A-24

TABLE 7. CTD stations sampled during APEX October cruise in PWS.

DATE	TIME	STATION	HAUL #	GEAR	LOCATION	LAT. IN	LONG. IN	BOTTOM DEPTH (M)	GEAR DEPTH (M)
9-Oct	19:47	1	5	CTD	FN02A	60 22.80	147 20.91	93	80
10-Oct	22:06	2	3	CTD	FJ05E	60 10.38	148 11.57	80	75
11-Oct	23:52	3	6	CTD	APPLEGATE ROCKS	60 22.420	147 26.299	101	80
12-Oct	23:57	4	4	CTD	E. OF SMITH IS.	60 32.71	147 17.593	90	80
13-Oct	13:22	5	2	CTD	S.E. OF NAKED IS.	60 38.010	147 17.820	88	80
14-Oct	0:19	7	3	CTD	LANDLOCKED BAY	60 49.480	146 35.873	120	100

Table 8. Offshore biomass estimates (grams/square meter of surface) of forage fishes from acoustic data for the first and second surveys in the North, Central and South study areas of PWS from APEX cruise 95-1 in July and August 1995. Data are from two depth strata, shallow (S, 0 - 25 m) and deep (D, 26 - 65 m).

SURVEY	DEPTH (m)	BIOMASS ESTIMATE (g/m^2)		
		NORTH	CENTRAL	SOUTH
	0 - 25	0.241	0.032	0.158
FIRST	26 - 65	0.115	0.093	0.143
	TOTAL	0.365	0.125	0.301
	0 -25	0.257	0.052	0.120
SECOND	26 - 65	0.330	0.202	0.165
	TOTAL	0.587	0.254	0.285

Table 9. Mean biomass estimates for individual transects in the North offshore area.

TRANSECT	MEAN (G/M2)	MAX	TRANSECT LENGTH (nm)
FIRST SURVEY			
ffv01a	0.295	2.463	23.9
ffv01x	0.347	2.068	0.3
ffv02a	0.446	5.168	31.4
ffv02x	0.007	0.119	0.2
ffv02x2	0.245	0.848	0.5
ffv03llb	0.378	3.347	2.2
ffv03tt	0.328	2.268	3.0
ffv03va	0.243	13.663	18.3
ffv04va	0.138	2.378	17.4
ffv05va	0.176	4.012	3.8
ffv06gbe	0.359	0.749	2.3
ffv06gbw	0.244	2.625	1.6
ffv07va	0.229	4.011	7.6
ffv08va	0.131	1.826	7.1
ffv09va	0.086	0.673	8.8
ffv09vax	0.050	0.143	0.3
ffv10vn	0.026	0.064	1.1
ffv11pv	0.095	1.789	17.6
		total length	147.5
SECOND SURVEY			
2fv01a	0.213	1.377	23.5
2fv02a	0.303	4.136	31.5
2fv02x	0.097	0.107	0.1
2fv03a	0.877	7.952	18.4
2fv03ax	0.128	0.295	3.3
2fv03llb	0.284	6.137	2.5
2fv03tt	0.225	2.874	2.7
2fv04va	0.240	2.018	16.9
2fv05va	0.218	3.638	16.0
2fv05vax	0.105	2.454	0.2
2fv06gbe	1.145	2.202	2.2
2fv06gbw	0.382	0.781	1.6
2fv06va	0.822	10.119	9.7
2fv07va	1.131	7.112	7.5
2fv08va	1.265	5.068	6.7
2fv09va	0.840	3.255	8.7
2fv10vn	0.180	0.978	1.2
2fv11pv	0.377	5.184	17.5
		total length	170.2

Table 10. Mean biomass estimates for individual transects in the Central offshore area.

TRANSECT	MEAN (g/m2)	MAX	TRANSECT LENGTH (nm)
FIRST SURVEY			
ffn01a	0.264	12.645	22.6
ffn02a	0.197	15.141	25.6
ffn03a	0.068	5.034	22.6
ffn04a	0.243	119.001	22.9
ffn05a	0.046	2.587	21.6
ffn06a	0.034	2.196	19.0
ffn06e	0.027	0.055	0.2
ffn07e	0.058	6.109	19.2
ffn07w	0.020	0.167	5.7
ffn08a	0.110	44.306	27.3
ffn08e	0.157	14.637	0.4
ffn09e	0.034	1.575	6.7
ffn09w	0.027	0.762	12.5
ffn10w	0.024	0.742	13.0
ffn11e	0.022	0.109	7.7
ffn11w	0.354	42.450	15.1
ffn11x	0.053	1.235	0.5
ffn12e	0.277	19.817	9.5
ffn12w	0.155	6.573	13.9
		Total Length	266.0
SECOND SURVEY			
2fn01a	0.816	19.827	22.5
2fn02a	0.842	93.933	26.2
2fn03a	0.216	45.919	22.7
2fn04a	0.092	8.239	21.9
2fn05a	0.057	2.095	21.7
2fn06a	0.156	46.187	18.9
2fn07e	0.091	1.428	19.0
2fn07w	0.072	2.329	5.7
2fn08a	0.084	4.603	27.1
2fn08ax	0.459	22.897	0.4
2fn09e	0.119	1.173	6.5
2fn09w	0.121	7.352	12.7
2fn10c	0.017	0.328	2.0
2fn10e	0.118	3.198	6.2
2fn10ex	0.101	0.155	0.7
2fn10w	0.077	1.669	12.9
2fn11e	0.372	19.746	8.2
2fn11ex	0.072	0.127	0.2
2fn11w	0.083	1.814	14.8
2fn12e	0.159	3.152	9.3
		Total Length	259.5

Table 11. Mean biomass estimates for individual transects in the South offshore area.

TRANSECT	MEAN (g/m2)	MAX	TRANSECT LENGTH (nm)
FIRST SURVEY			
ffj01e	0.286	7.212	10.6
ffj01ex	0.759	20.305	0.5
ffj02a	0.248	2.423	6.0
ffj03a	0.140	0.880	2.8
ffj04a	0.069	0.210	1.3
ffj05e	0.357	4.867	9.1
ffj05ex	0.842	4.256	0.2
ffj06a	0.154	0.746	1.6
ffj07a	0.275	0.467	0.7
		Total Length	32.7
SECOND SURVEY			
2fj01e	0.301	8.328	10.9
2fj02a	0.799	6.312	5.9
2fj02x	0.692	1.962	0.2
2fj03a	0.108	0.227	2.8
2fj04a	0.161	0.771	1.2
2fj05e	0.819	33.706	9.2
2fj05w	0.062	0.223	2.4
2fj06a	0.150	0.360	3.8
2fj07a	0.144	0.839	0.8
		Total Length	37.2

Table 12. Nearshore biomass estimates (grams/square meter of surface) of forage fishes from acoustic data for the first and second surveys in the North, Central and South study areas of PWS from APEX cruise 95-1 in July and August 1995. Data are from two depth strata, shallow (S, 0 - 25 m) and deep (D, 26 - 65 m).

SURVEY	DEPTH (m)	BIOMASS ESTIMATE (g/m^2)		
		NORTH	CENTRAL	SOUTH
	0 - 25	0.163	0.428	0.439
FIRST	26 - 65	0.071	0.613	0.081
	TOTAL	0.234	1.041	0.520
	0 -25	0.687	0.106	0.363
SECOND	26 - 65	1.075	0.169	0.161
	TOTAL	1.762	0.275	0.524

Table 13. Nearshore mean biomass estimates for individual transects in the North area, with maximum estimate (MAX) for a 15 second data record

TRANSECT	MEAN (g/m2)	MAX	TRANSECT LENGTH (nm)
FIRST SURVEY			
ffvz2n	0.278	5.641	2.3
ffvz3s	0.593	3.904	3.4
ffvz4n	0.062	0.418	1.4
ffvz4nx	0.084	0.242	0.5
ffvz5s	0.044	0.109	1.7
ffvz6n	0.194	3.800	1.8
ffvz6s	0.057	0.210	5.2
ffvz7n	0.049	0.297	2.1
ffvz7s	0.110	1.967	2.0
			20.3
SECOND SURVEY			
2fvz2n	0.084	0.242	2.0
2fvz3s	1.224	4.356	3.6
2fvz4v	1.137	3.862	1.9
2fvz5s	0.670	3.452	1.8
2fvz6n	0.258	1.413	1.5
2fvz6s	1.177	4.125	4.7
2fvz6sx	0.546	1.202	0.1
2fvz7n	0.136	0.801	2.1
2fvz7s	0.173	1.123	2.3
			20.1

Table 14. Nearshore mean biomass estimates for individual transects in the Central area, with maximum estimate (MAX) for a 15 second data record

TRANSECT	MEAN (g/m2)	MAX	TRANSECT LENGTH (nm)
FIRST SURVEY			
ffnz1s	0.438	14.914	1.8
ffnz2e	0.022	0.146	0.2
ffnz2n	0.020	0.120	2.1
ffnz2s	0.012	0.029	1.9
ffnz3n	0.021	0.029	1.6
ffnz3s	0.019	0.042	2.8
ffnz5n	0.030	0.326	3.0
ffnz5s	0.024	0.119	3.7
ffnz6n	4.349	122.167	3.4
ffnz6s	0.038	0.133	1.9
			22.4
SECOND SURVEY			
2fn12w	0.036	0.422	13.9
2fnz1s	0.013	0.024	1.8
2fnz2n	0.662	28.606	2.0
2fnz2s	0.019	0.171	2.0
2fnz3n	0.287	8.459	1.8
2fnz3s	0.134	2.249	2.8
2fnz4n	0.116	0.553	2.5
2fnz4nx	0.407	1.403	0.2
2fnz4s	0.077	0.239	2.9
2fnz5n	0.089	0.420	4.0
2fnz5s	0.103	1.905	3.9
2fnz6n	0.168	1.224	3.1
2fnz6s	0.120	0.529	2.0
			43.0

Table 15. Nearshore mean biomass estimates for individual transects in the South area, with maximum estimate (MAX) for a 15 second data record

TRANSECT	MEAN (g/m2)	MAX		TRANSECT LENGTH (nm)
FIRST SURVEY				
ffjz1n	1.146	15.256		1.6
ffjz1s	1.326	14.562		0.8
ffjz3n	0.288	2.308		2.6
ffjz3s	0.267	0.603		3.0
ffjz4n	0.566	1.644		1.8
ffjz4s	0.126	0.546		1.8
ffjz5n	0.243	0.812		1.8
ffjz5s	0.249	0.636		1.7
			Total Length	15.2
SECOND SURVEY				
2fjz1n	0.150	0.925		2.9
2fjz1s	1.657	29.589		1.0
2fjz3n	0.405	13.352		2.3
2fjz3s	0.134	1.153		3.3
2fjz4n	0.689	6.705		0.0
2fjz4s	0.421	0.895		0.0
2fjz5n	0.192	0.513		1.7
2fjz5s	0.199	1.047		1.6
			Total Length	12.8

Table 16. Proportional composition of midwater trawl hauls in shallow (< 26 m) and deep (>25 m) depths of the North study area in PWS from APEX cruise 95-1 in summer 1995.

SPECIES		ALL DEPTHS	SHALLOW	DEEP
	N	5708	5150	558
POLLOCK	524	0.09		0.94
HERRING	5131	0.90	0.99	
SALMON	2			
CAPELIN	1			
EULACHON	32	0.01		0.06
PROWFISH	6			
CRESTED SCULPIN	11		0.01	
WOLFFISH	1			

Table 17. Proportional composition of midwater trawl hauls in shallow (< 26 m) and deep (>25 m) depths of the central study area of PWS from APEX cruise 95-1 in summer 1995.

SPECIES		ALL DEPTHS	SHALLOW	DEEP
	N	11008	815	10193
POLLOCK	10873	0.99	0.89	1.00
HERRING	4		0.01	
SALMON	28		0.03	
CAPELIN	60	0.01	0.07	
PROWFISH	7			
CRESTED SCULPIN	34			
SANDLANCE	1			
SANDFISH	1			

Table 18. Proportional composition of midwater trawl hauls in shallow (< 26 m) and deep (>25 m) depths of the south study area of PWS from APEX cruise 95-1 in summer 1995.

SPECIES		ALL DEPTHS	SHALLOW	DEEP
	N	1324	1314	10
POLLOCK	8	0.01		0.80
HERRING	1314	0.99	1.0	0.10
PROWFISH	1			
CRESTED SCULPIN	1			0.10

Table 19. Mean lengths of forage fishes collected in PWS during APEX cruise in summer 1995.

SPECIES (AGE)	STUDY AREA	HABITAT	N	LENGTH (mm)	STD. ERR
Herring (1+)	North	Offshore	413	153	0.94
Herring (0+)	North	Inshore	281	77	0.53
Herring (1+)	South	Offshore	212	151	1.43
Herring (0+)	South	Inshore	7	53	0.67
Pollock (1+)	North	Deep	228	183	0.82
Pollock (0+)	Central	Peak/Osprey Is	568	58	0.24
Pollock (0+)	Central	Kn. Is. Inside	713	58	0.17
Pollock (0+)	Central	Kn. Is. Outside	987	63	0.20
Pollock (0+)	South	Deep	30	66	1.76
Pollock (1+)	South	Deep	12	150	5.67

Table 20. Composition (percentage of total number identified) of jellyfish in mid-water trawl samples in North, Central and South sampling areas of PWS during summer sampling.

TAXA	NORTH	CENTRAL	SOUTH
Cyanea capillata	37	9	36
Chrysaora melanaster	18	17	27
Phacellophora camtschatica	9	3	3
Aequorea sp.	10	59	3
Hydromedusae	23	0	30
Ctenophores	0	2	0
Other/Unidentified	2	11	0

Table 21. Composition (percentage of total number identified) of krill in mid-water trawl samples in North, Central and South sampling areas of PWS during summer sampling.

TAXA	NORTH	CENTRAL	SOUTH
Euphausia pacifica	41	0	< 1
Thysanoessa inermis	0	0	38
T. longipes	5	0	0
T. raschii	51	0	5
T. spinifera	3	0	57

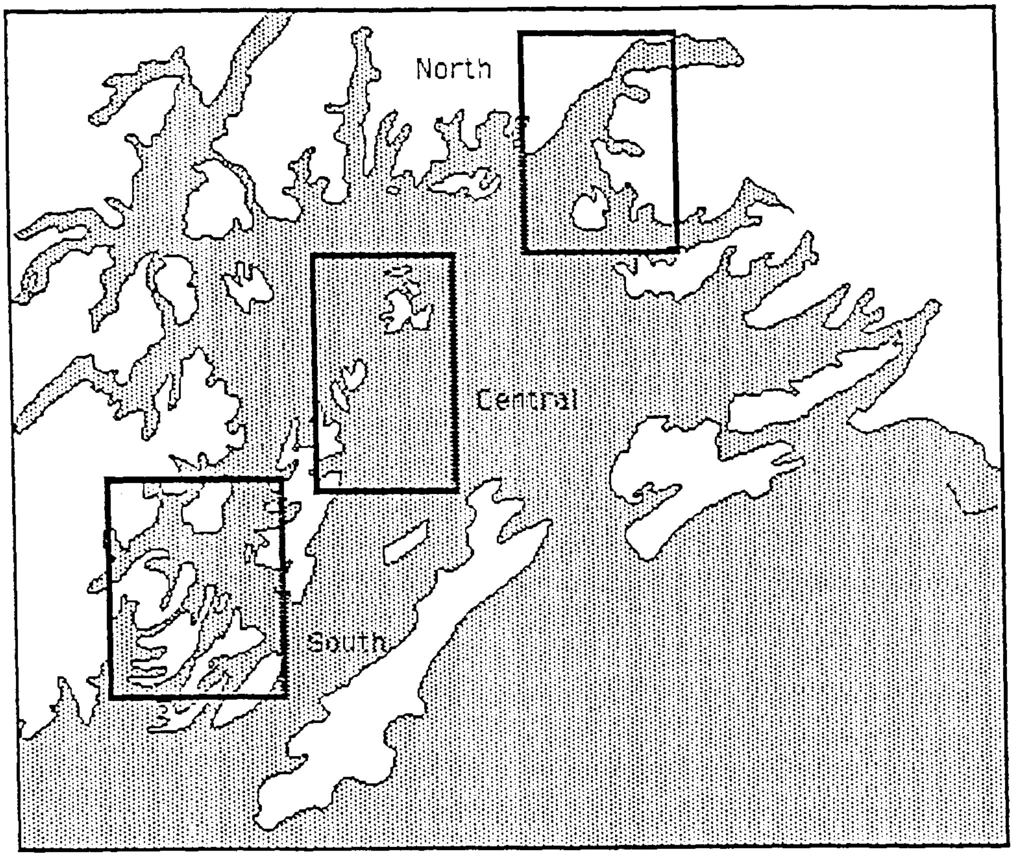

Figure 1. Locations of North, Central and South study areas within Prince William Sound.

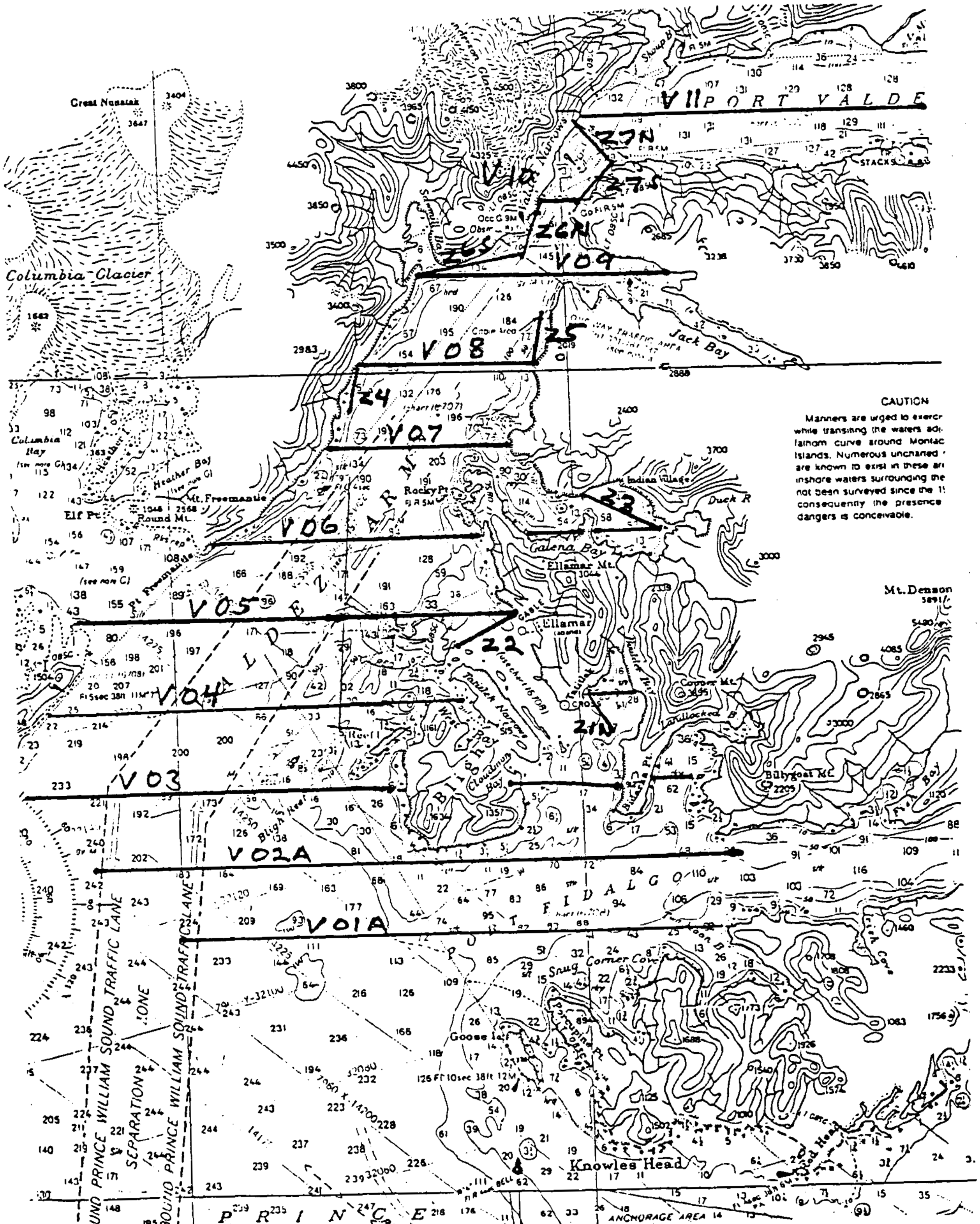

Figure 2. Hydroacoustic transect locations in the North study area of Prince William Sound

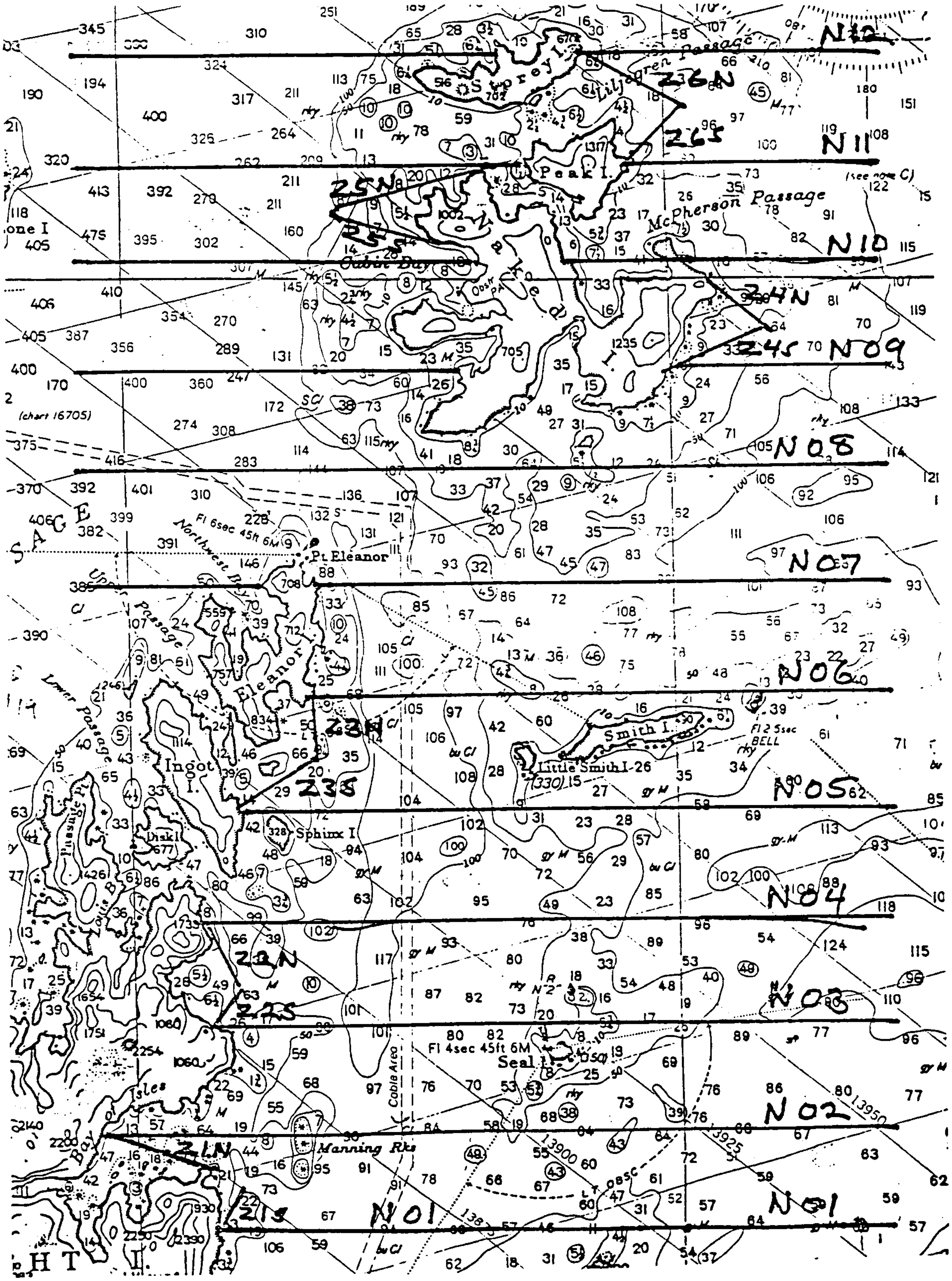

Figure 3. Hydroacoustic transect locations in the Central study area of Prince William Sound.

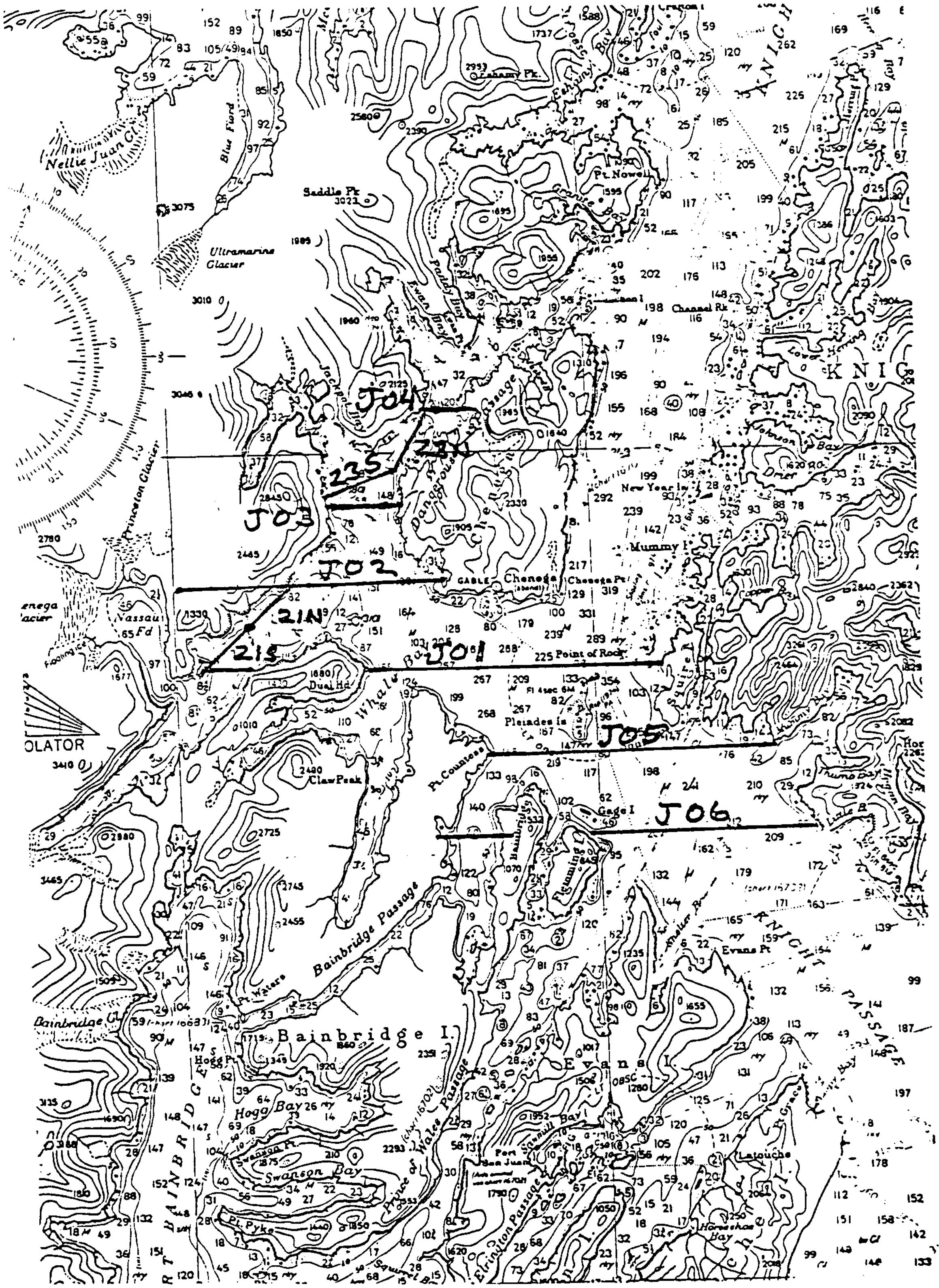

Figure 4. Hydroacoustic transect locations in the South study area of Prince William Sound.

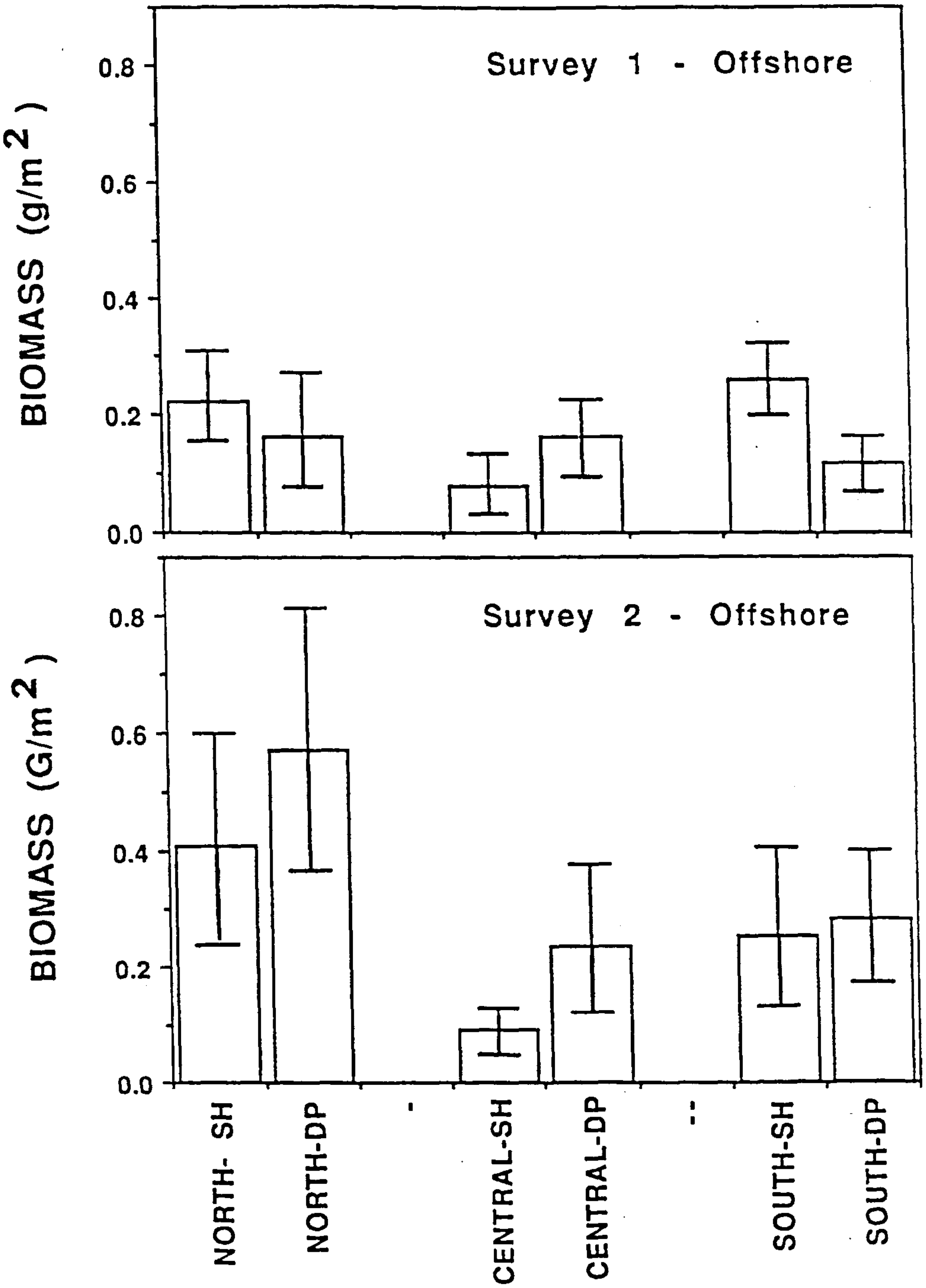

Figure 5. Mean offshore biomass estimates for shallow and deep strata in three study areas of Prince William Sound on the first and second surveys in July and August 1995. Error bars are the upper and lower 95 % confidence limits determined by bootstrapping.

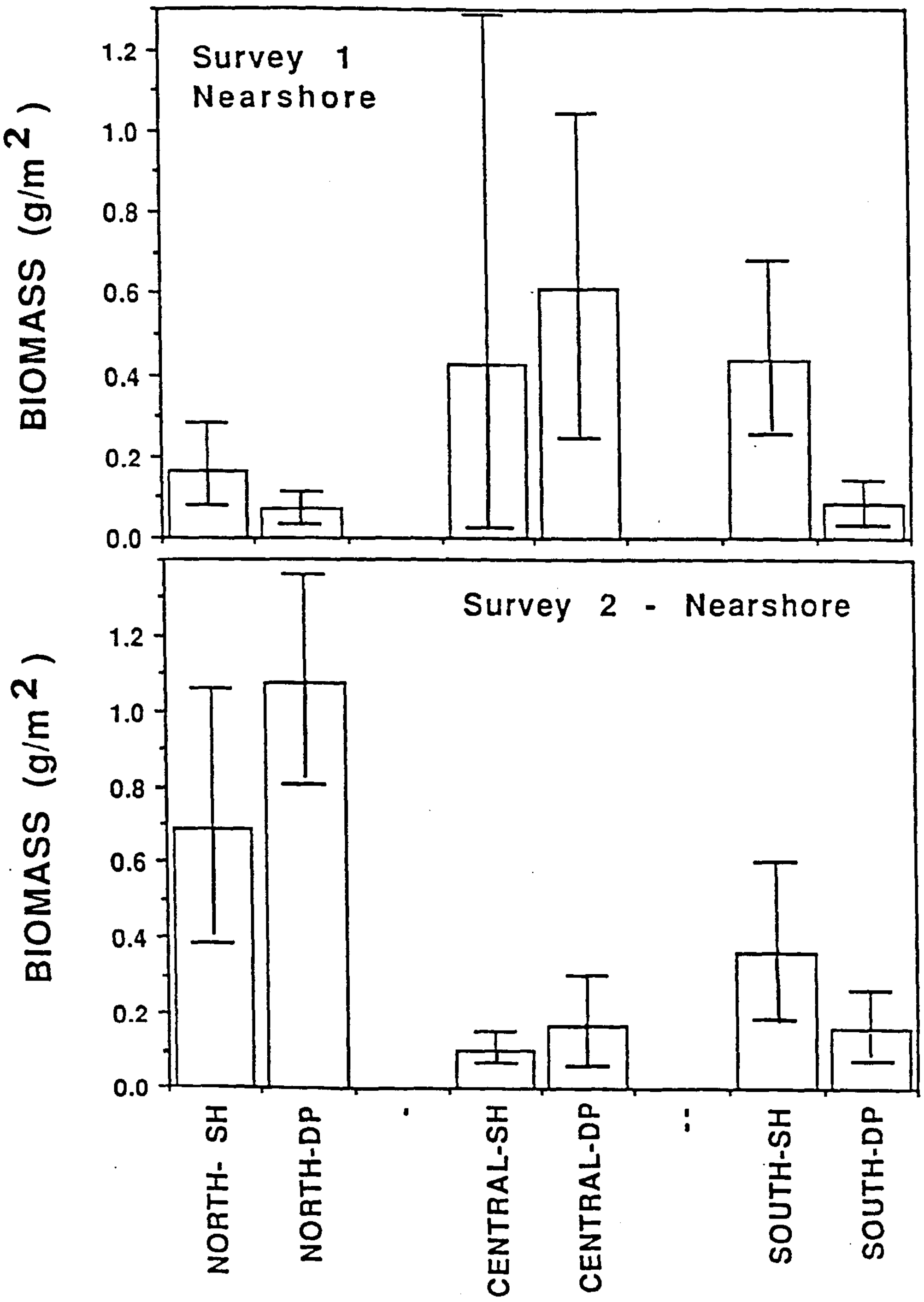

Figure 6. Mean nearshore biomass estimates for shallow and deep strata in three study areas of Prince William Sound on the first and second surveys in July and August 1995. Error bars are the upper and lower 95 % confidence limits determined by bootstrapping.

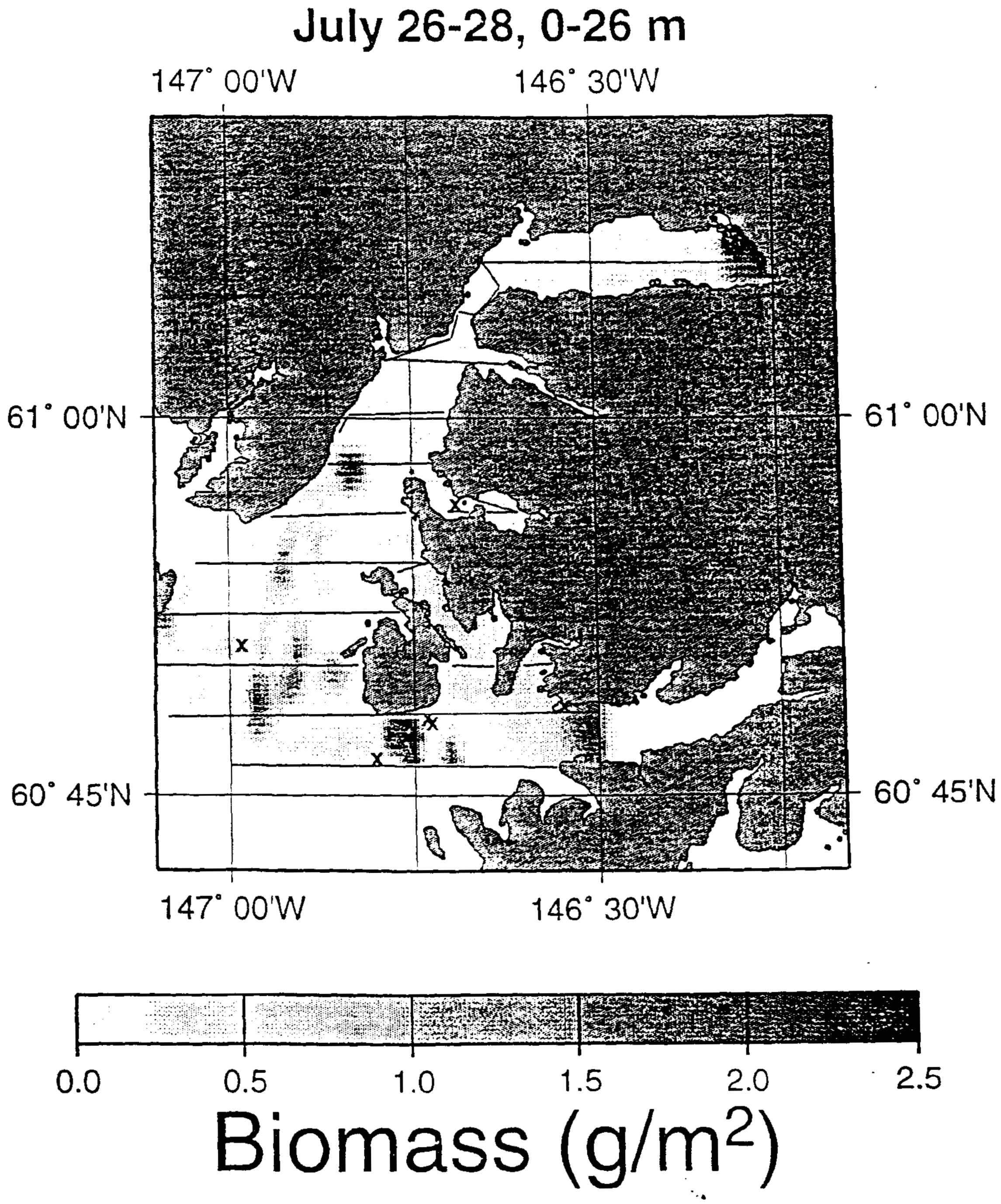

Figure 7. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the North study area during the first acoustic survey.

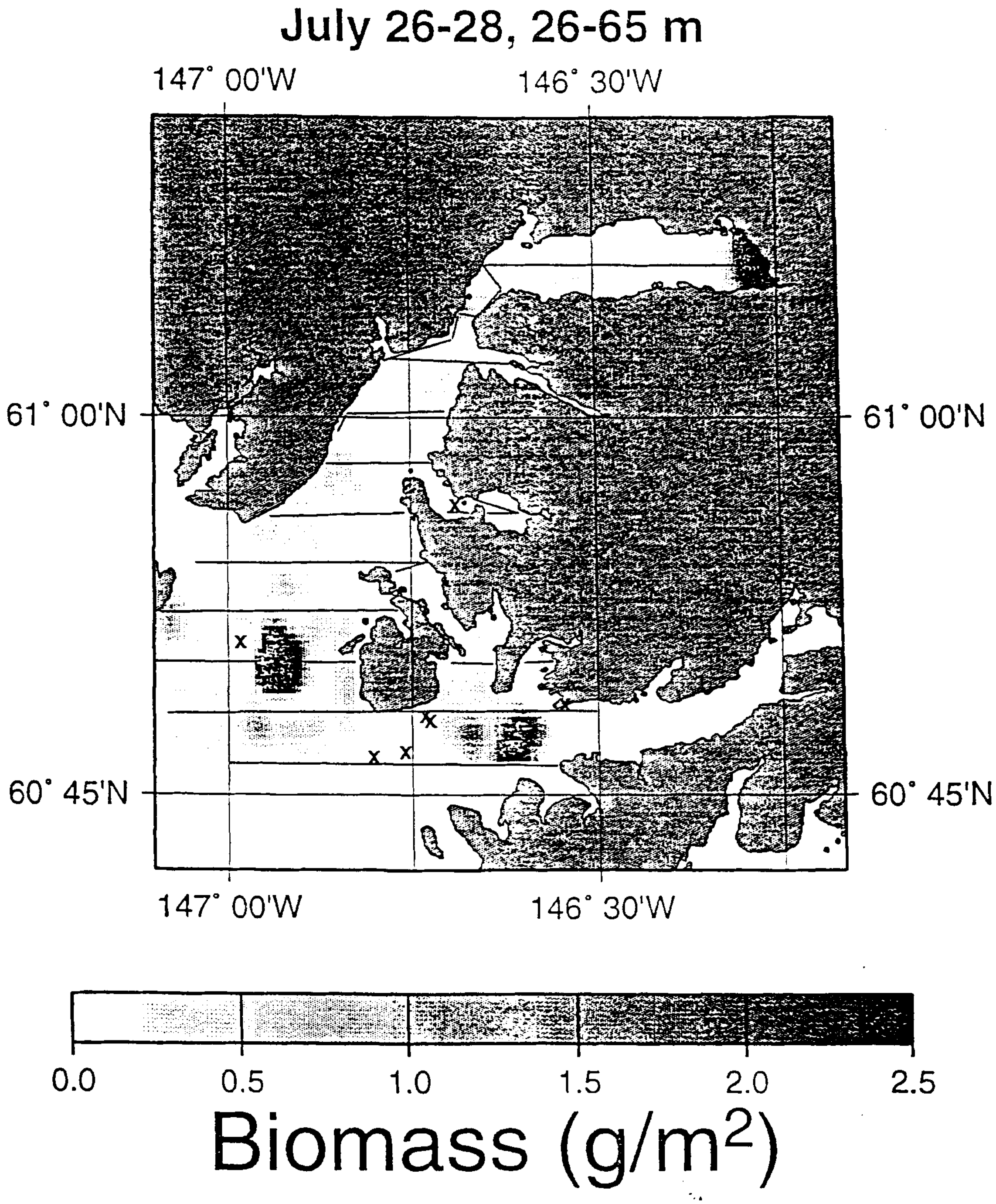

Figure 8. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the North study area during the first acoustic survey.

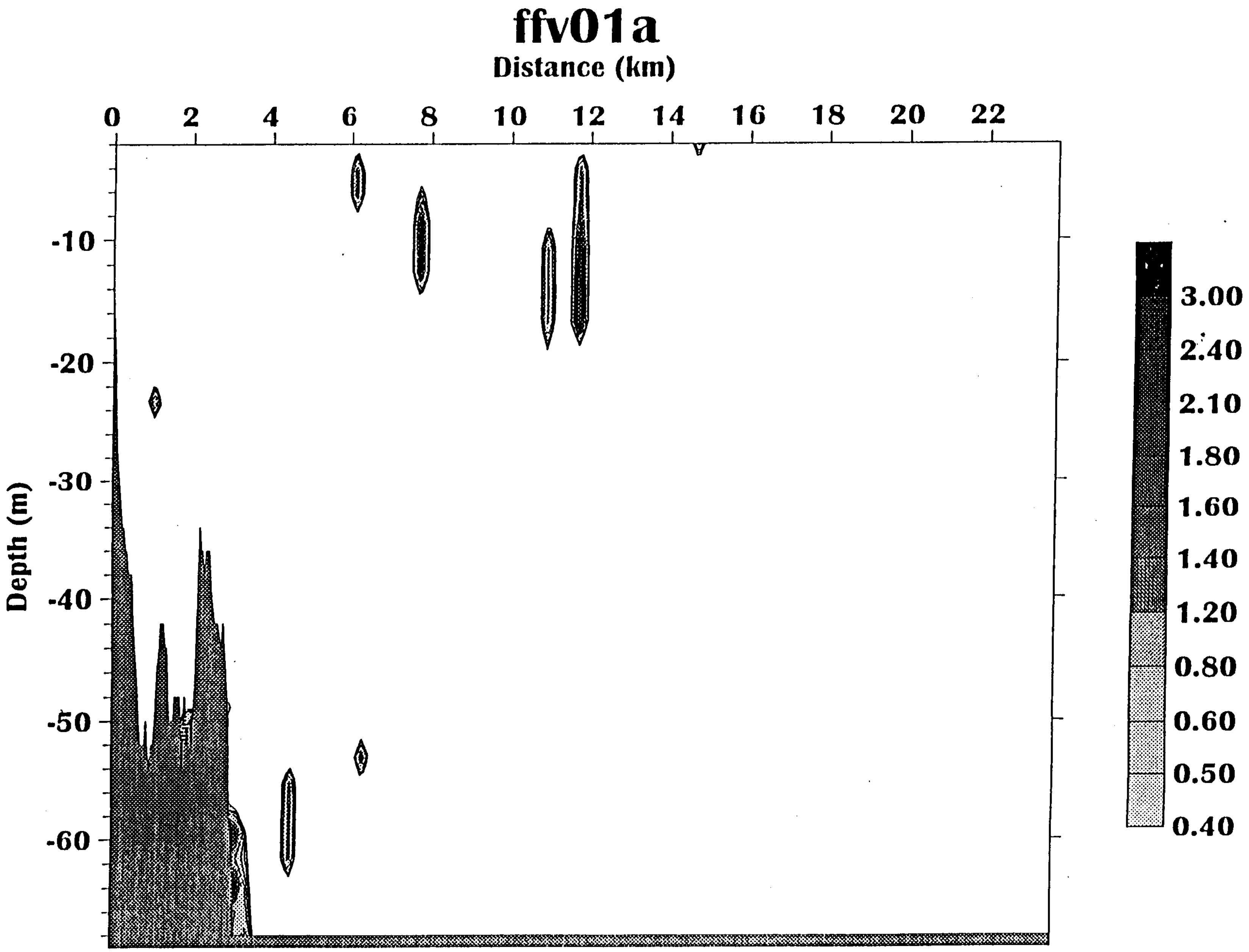

Figure 9. Distribution of biomass on transect V01A in Port Fidalgo (North area) during the first acoustic survey.

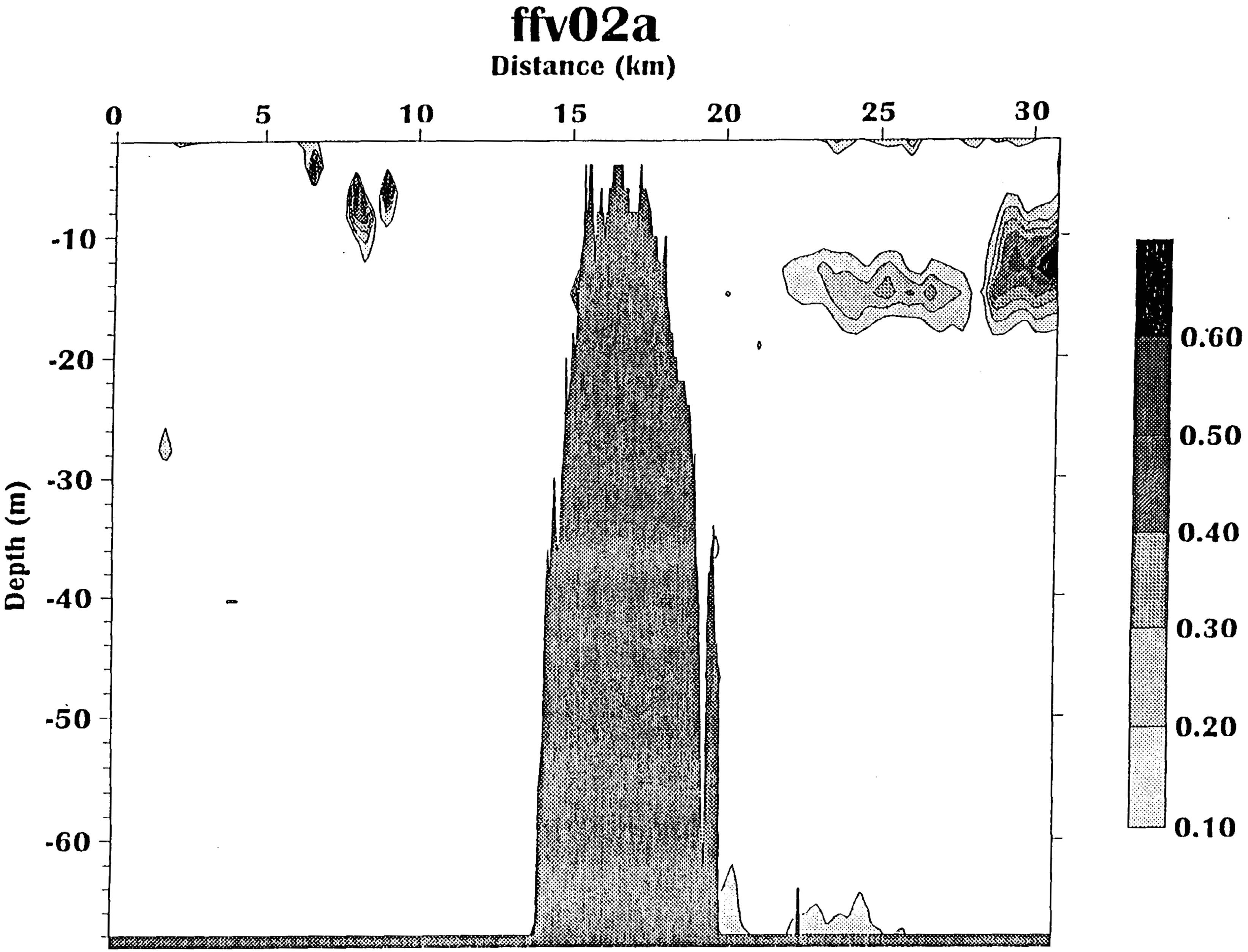

Figure 10. Distribution of biomass on transect V02A in Port Fidalgo (North area) during the first acoustic survey.

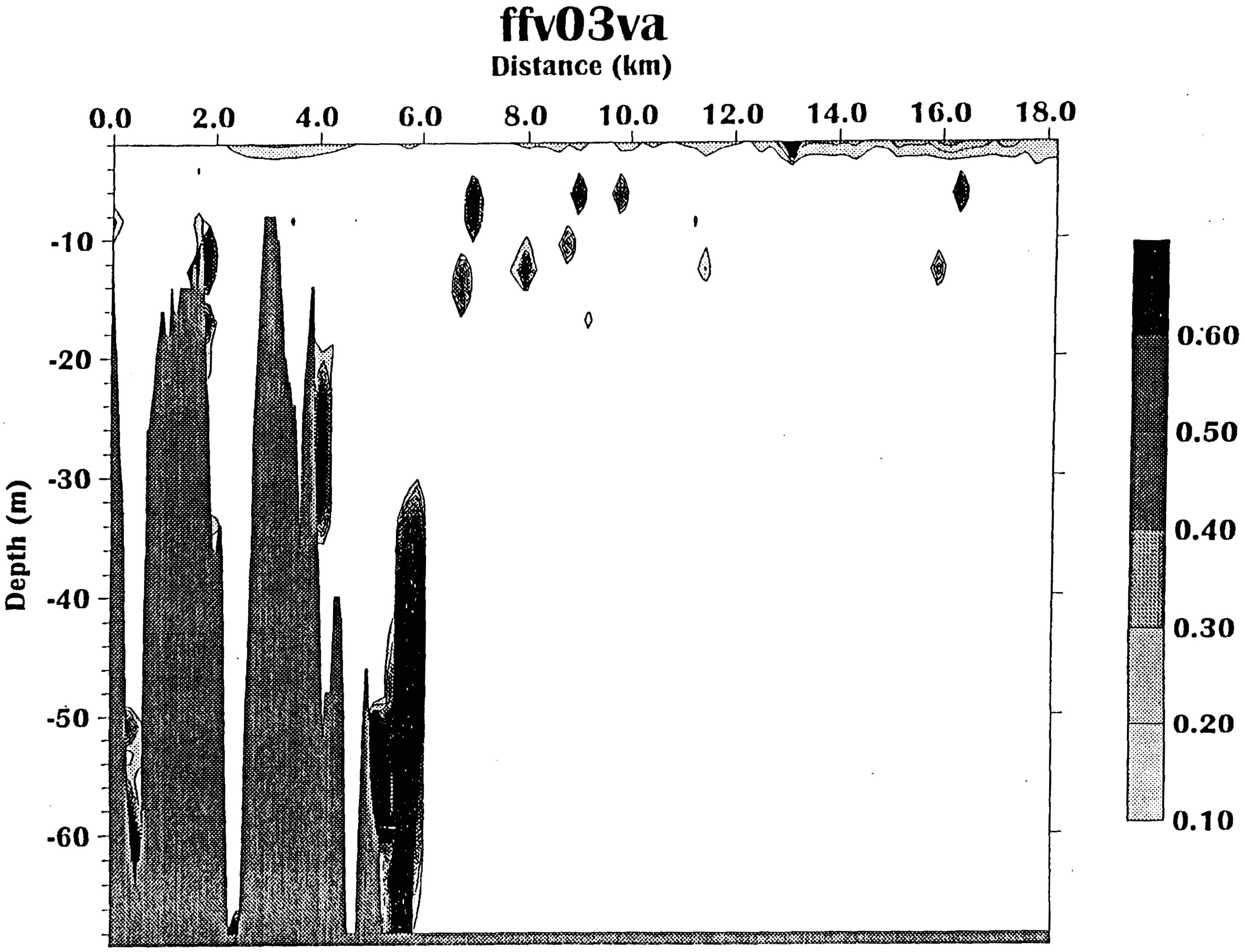

Figure 11. Distribution of biomass on Transect V03A in Valdez Arm (North area) during the first acoustic survey.

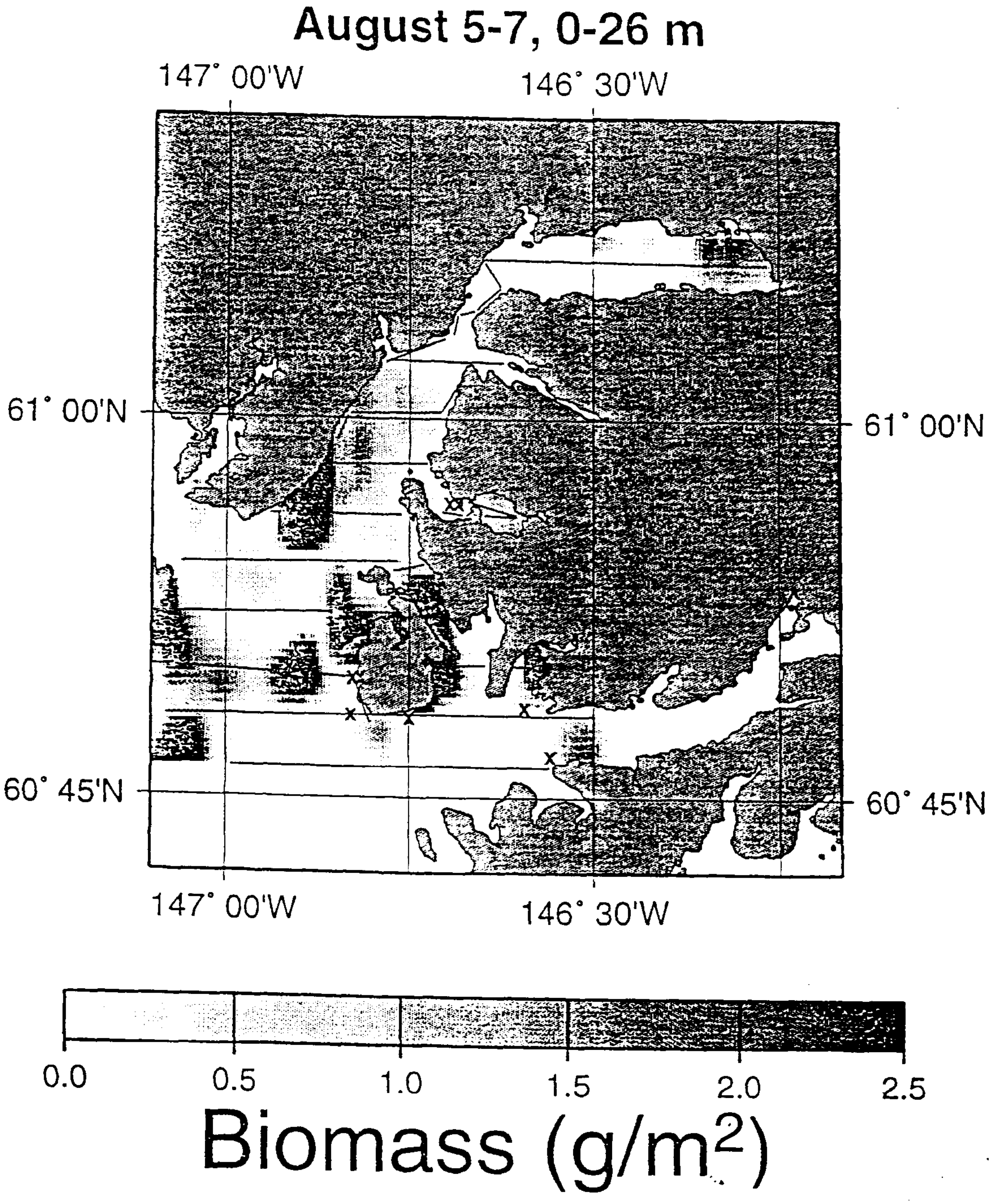

Figure 12. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the North study area during the second acoustic survey.

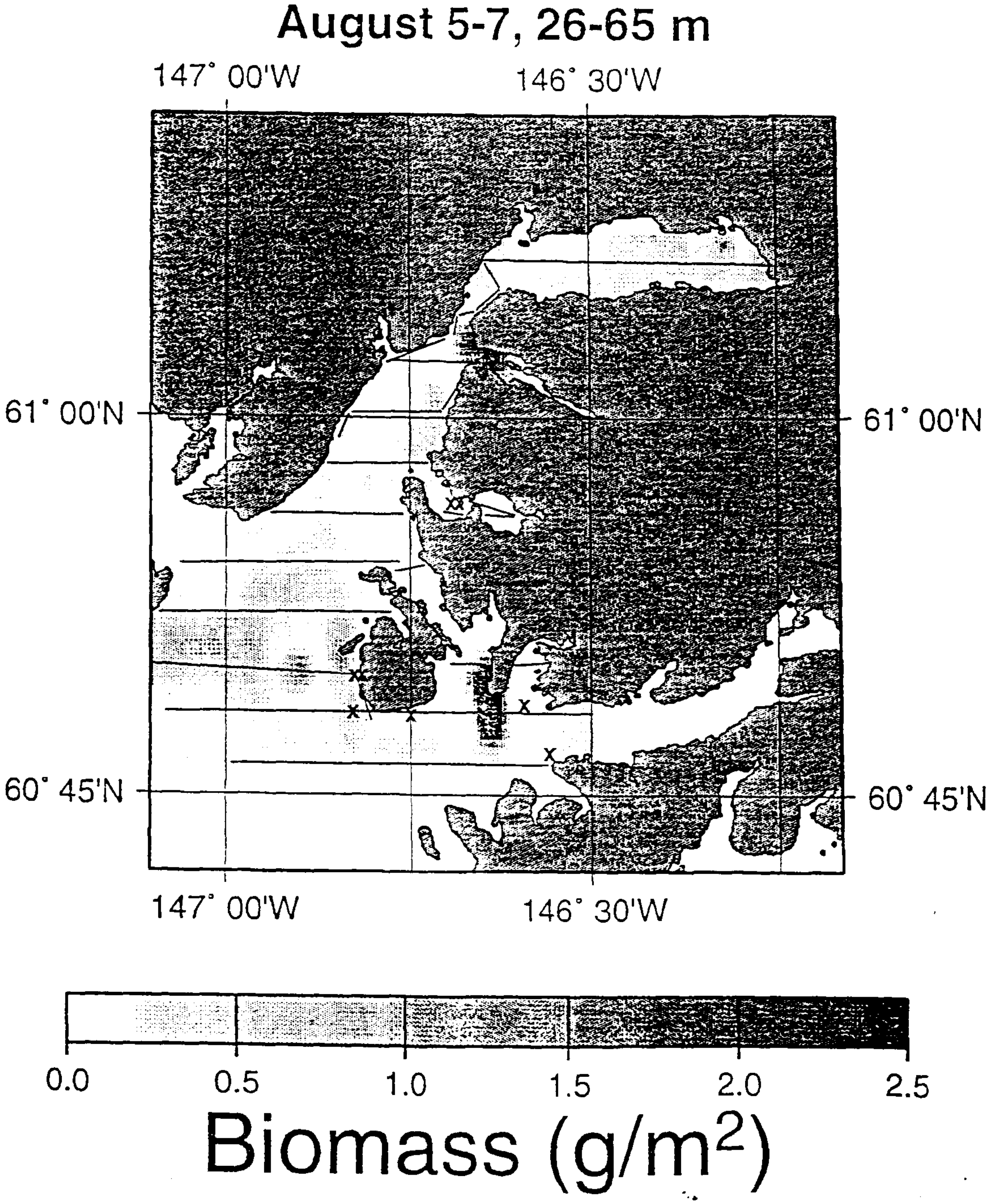

Figure 13. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the North study area during the second acoustic survey.

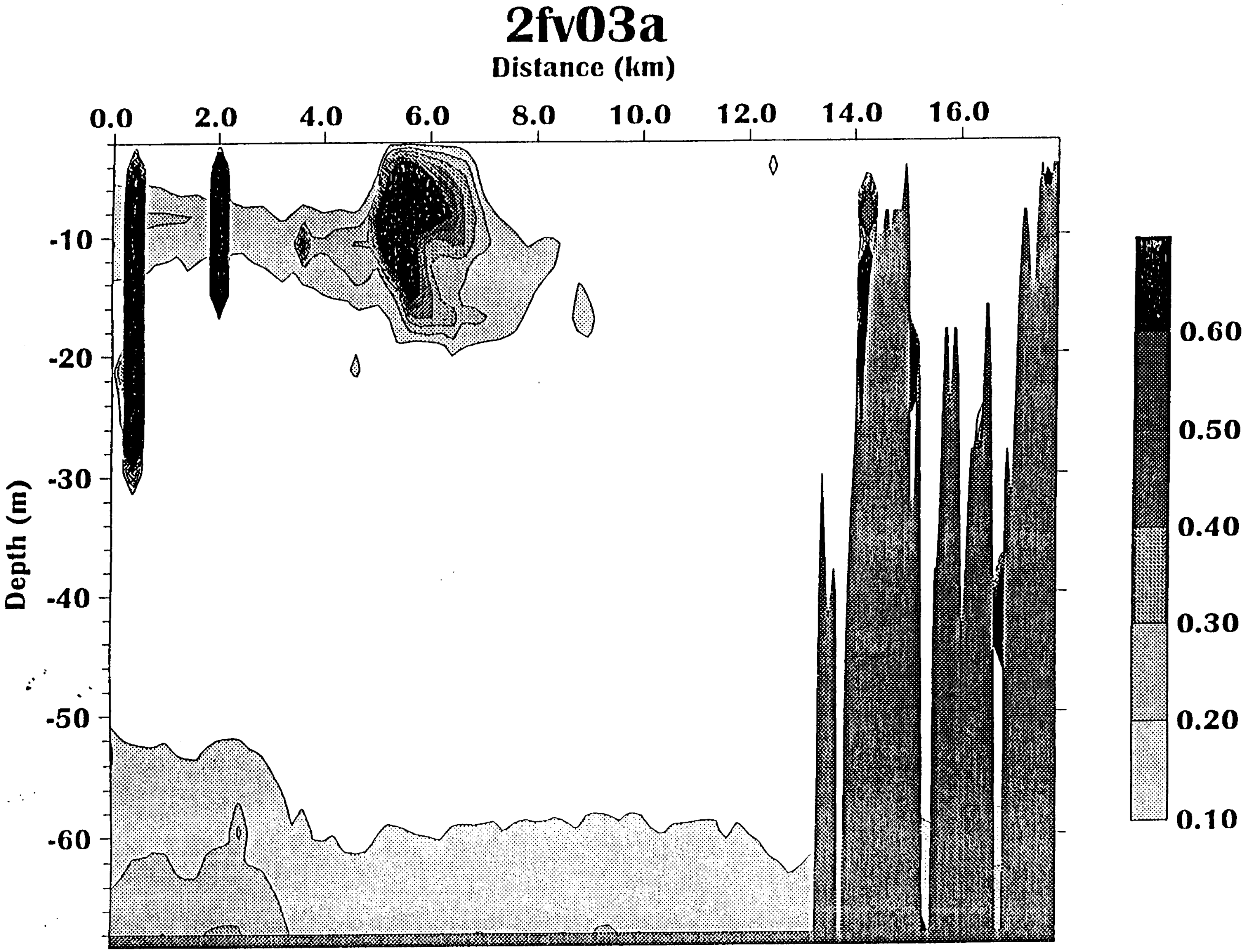

Figure 14. Distribution of biomass on Transect V03A in Valdez Arm (North area) during the second acoustic survey.

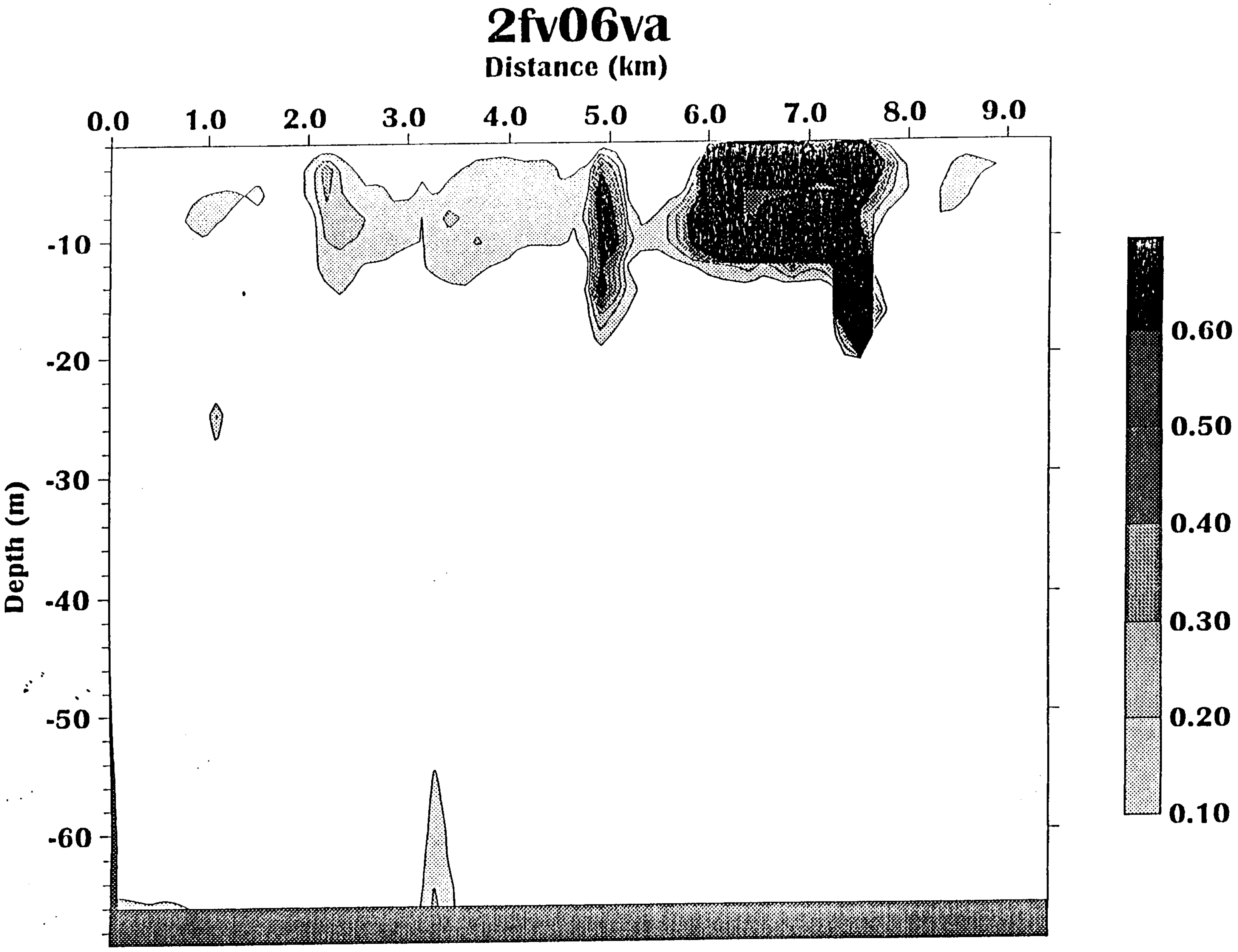

Figure 15. Distribution of biomass on Transect V06A in Valdez Arm (North area) during the second acoustic survey.

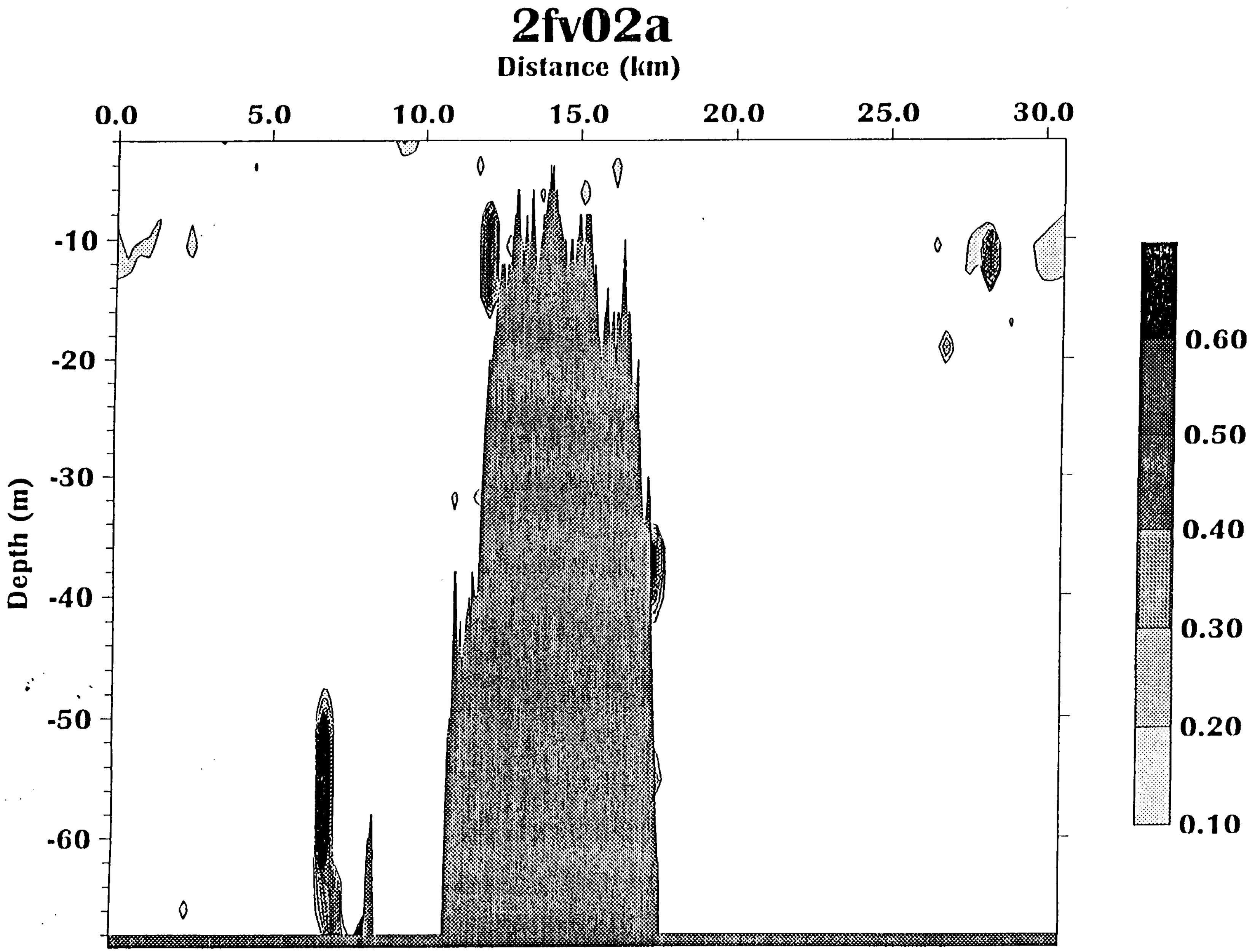

Figure 16. Distribution of biomass on Transect V02A in Port Fidalgo (North area) during the second acoustic survey.

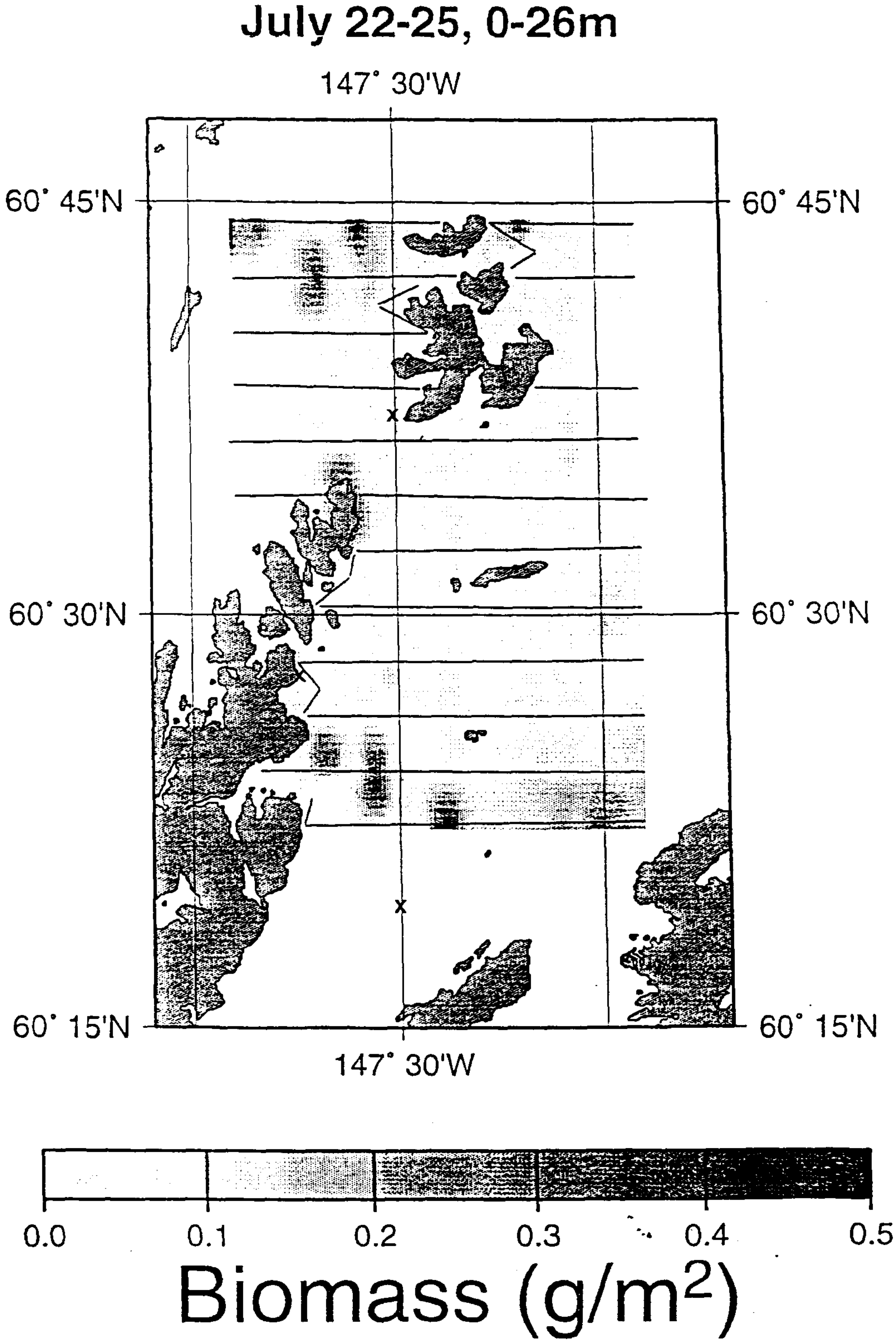

Figure 17. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the Central study area during the first acoustic survey.

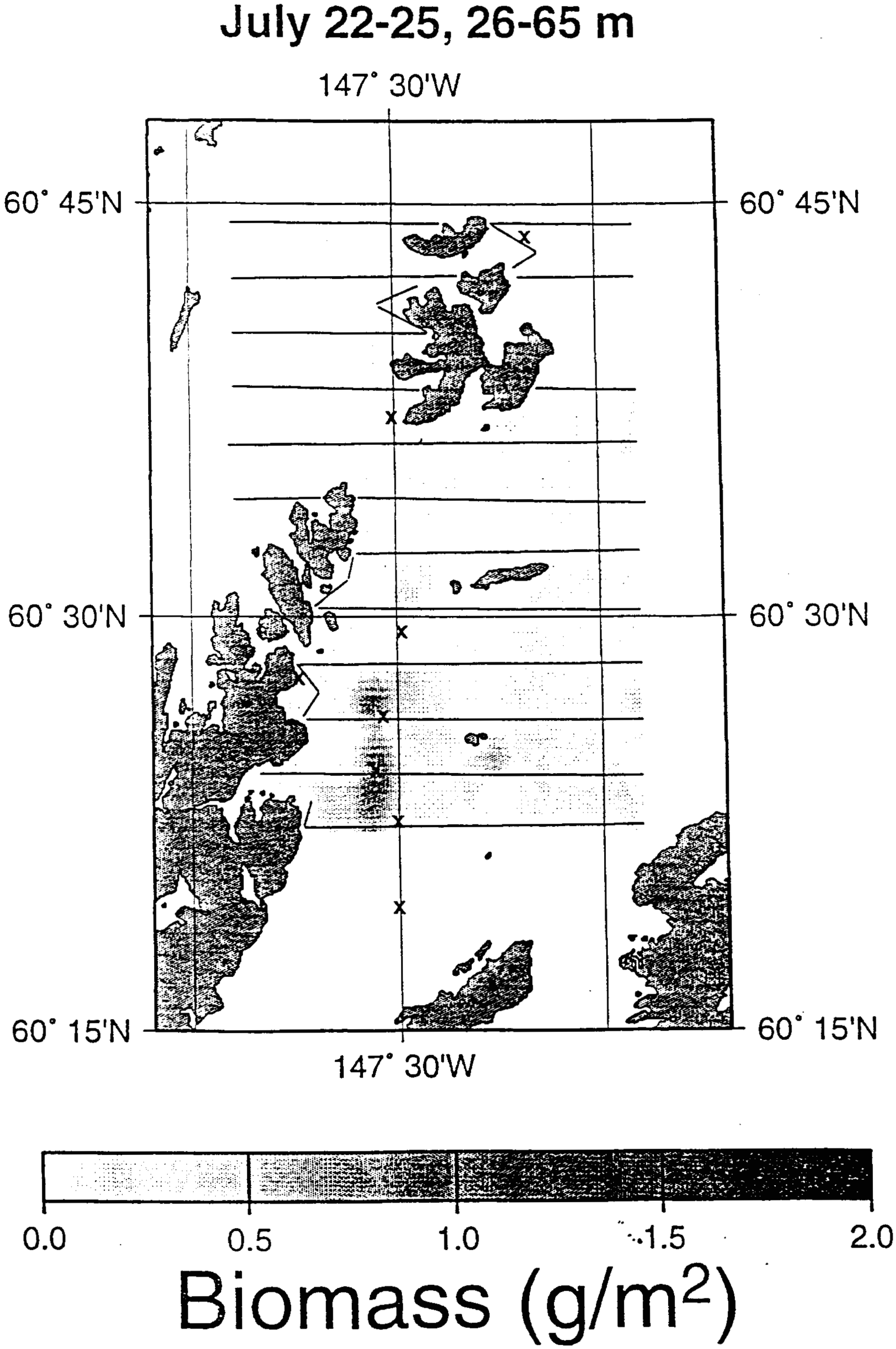

Figure 18. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the Central study area during the first acoustic survey.

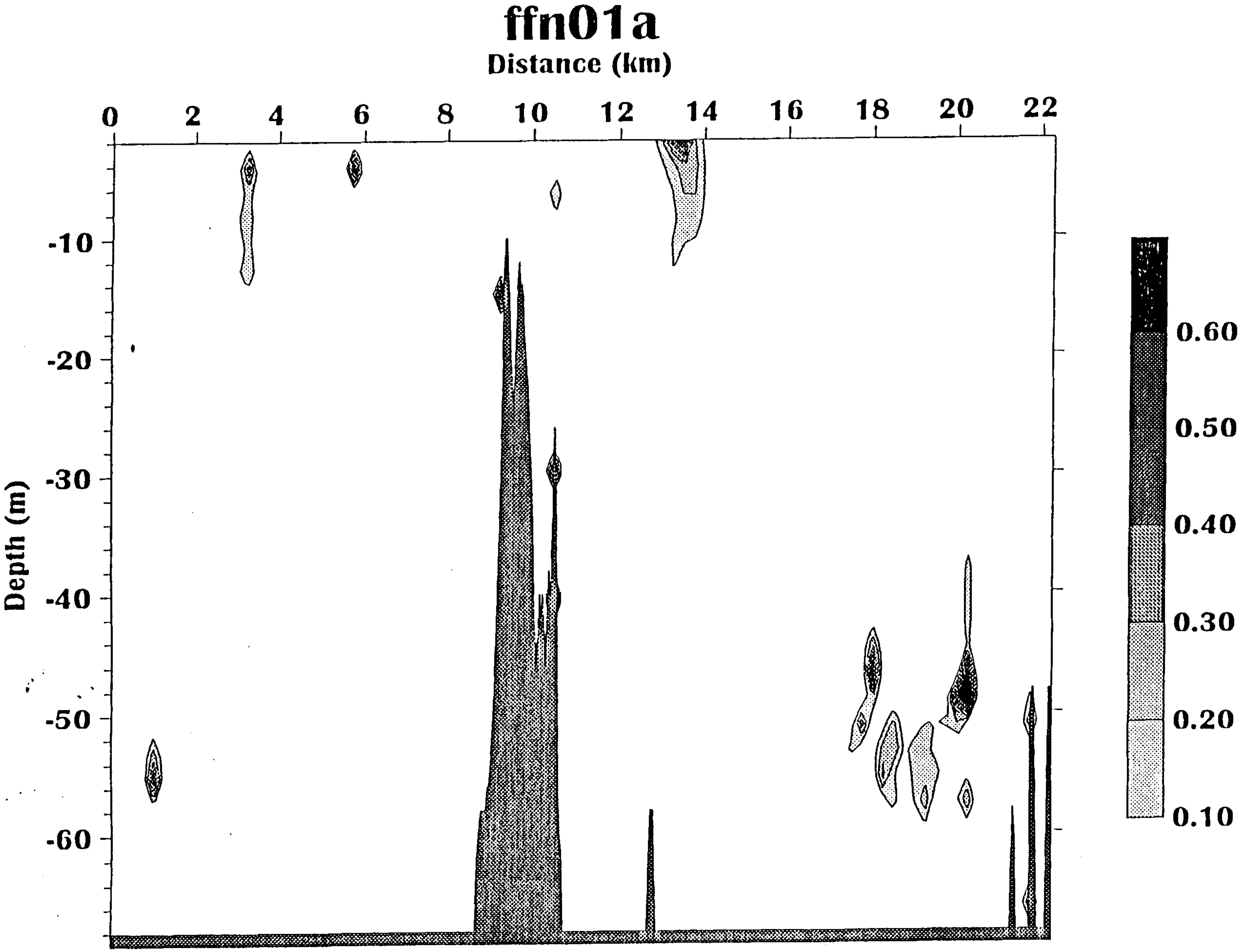

Figure 19. Distribution of biomass on Transect N01A east of Knight Island (Central area) during the first acoustic survey.

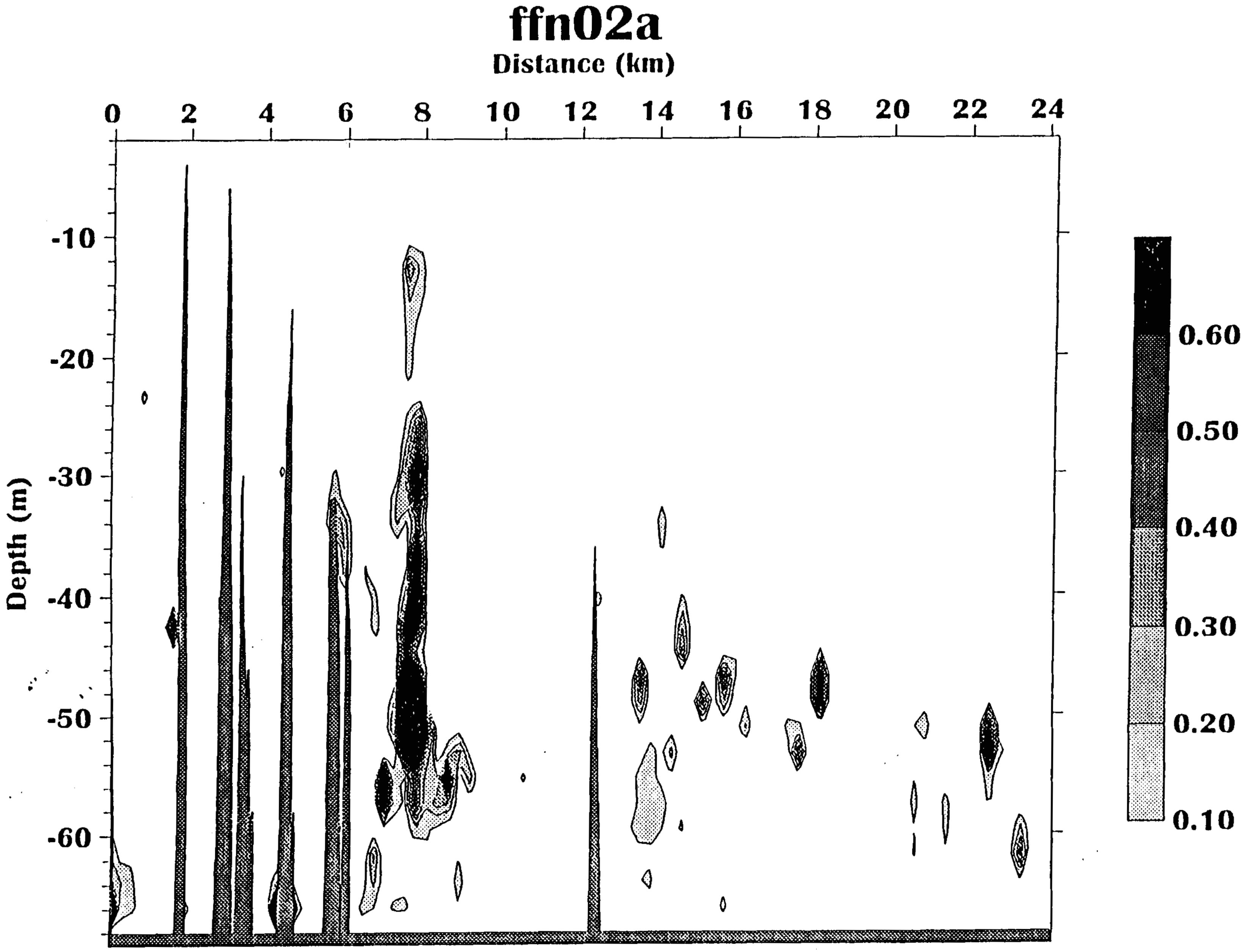

Figure 20. Distribution of biomass on Transect N02A east of Knight Island (Central area) during the first acoustic survey.

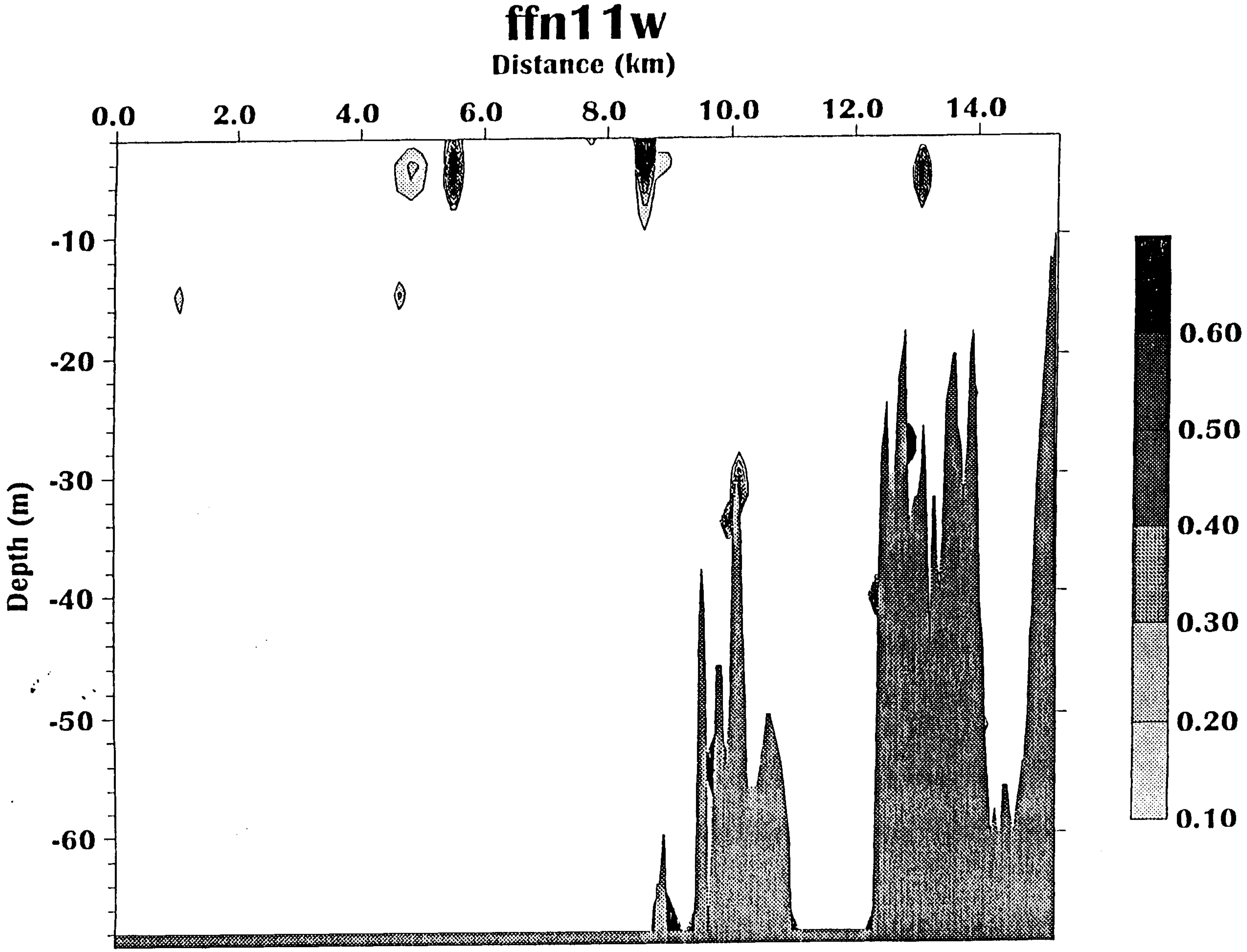

Figure 21. Distribution of biomass on Transect N11W west of Storey Island (Central area) during the first acoustic survey.

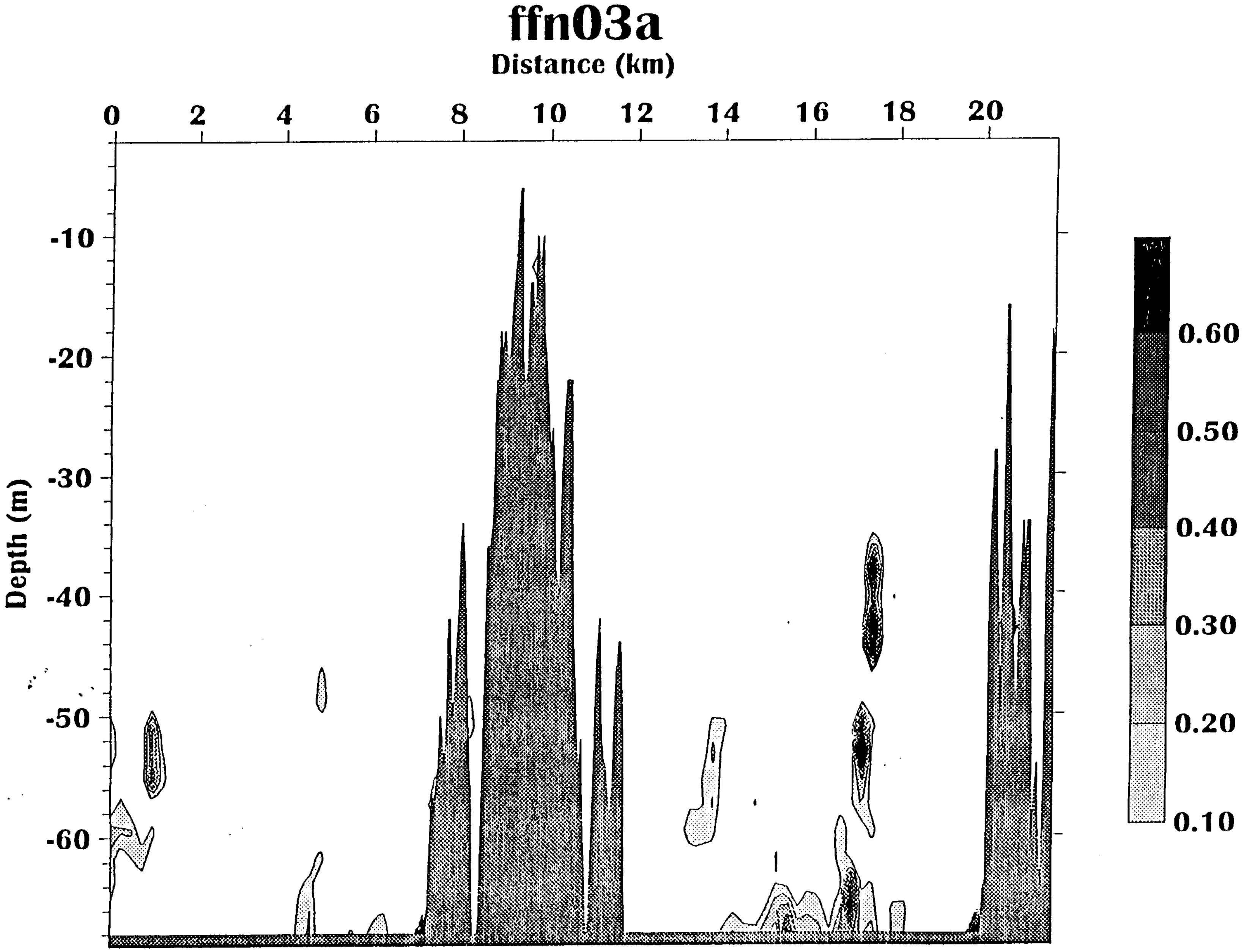

Figure 22. Distribution of biomass on Transect N03A east of Knight Island (Central area) during the first acoustic survey.

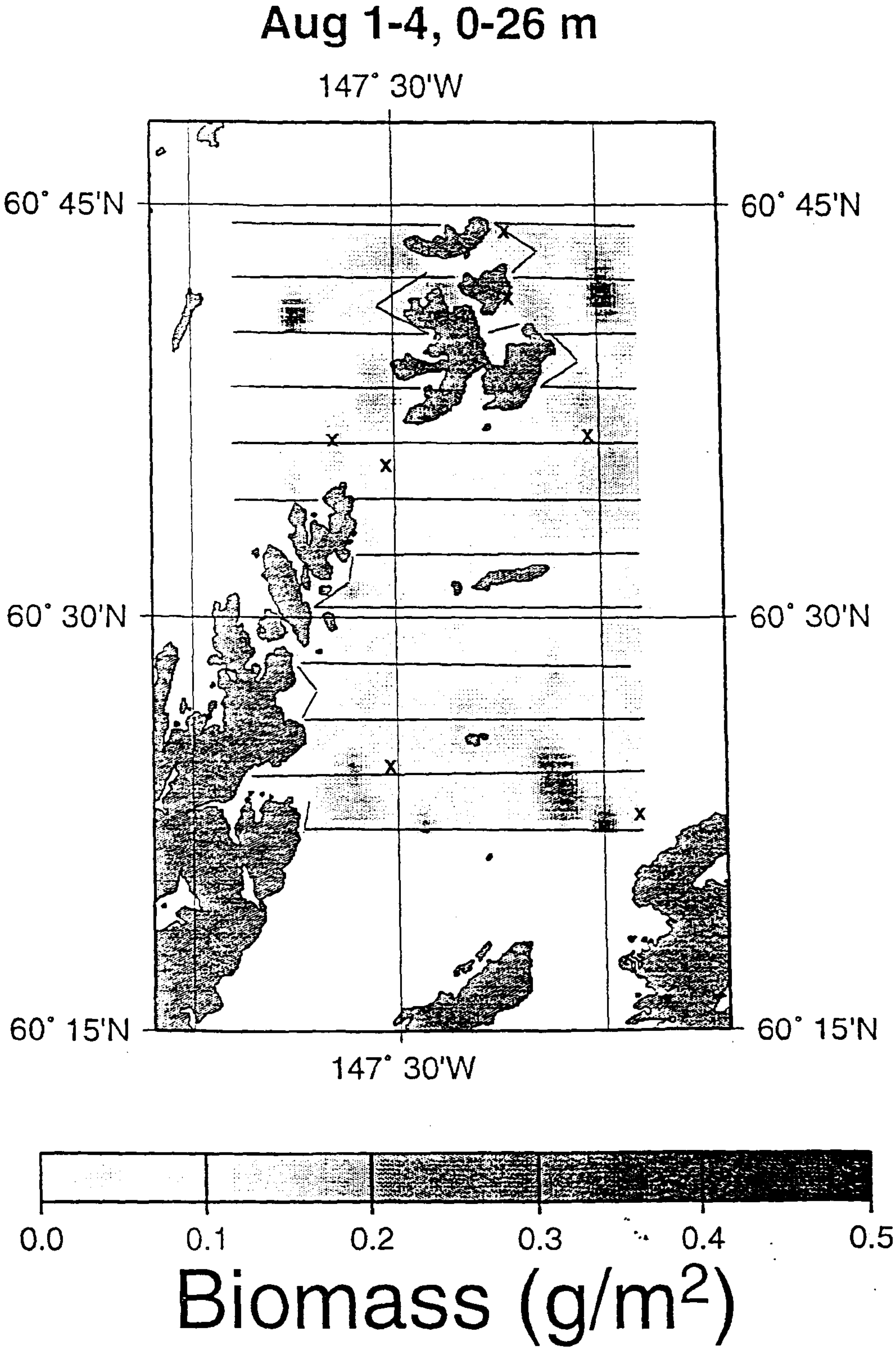

Figure 23. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the Central study area during the second acoustic survey.

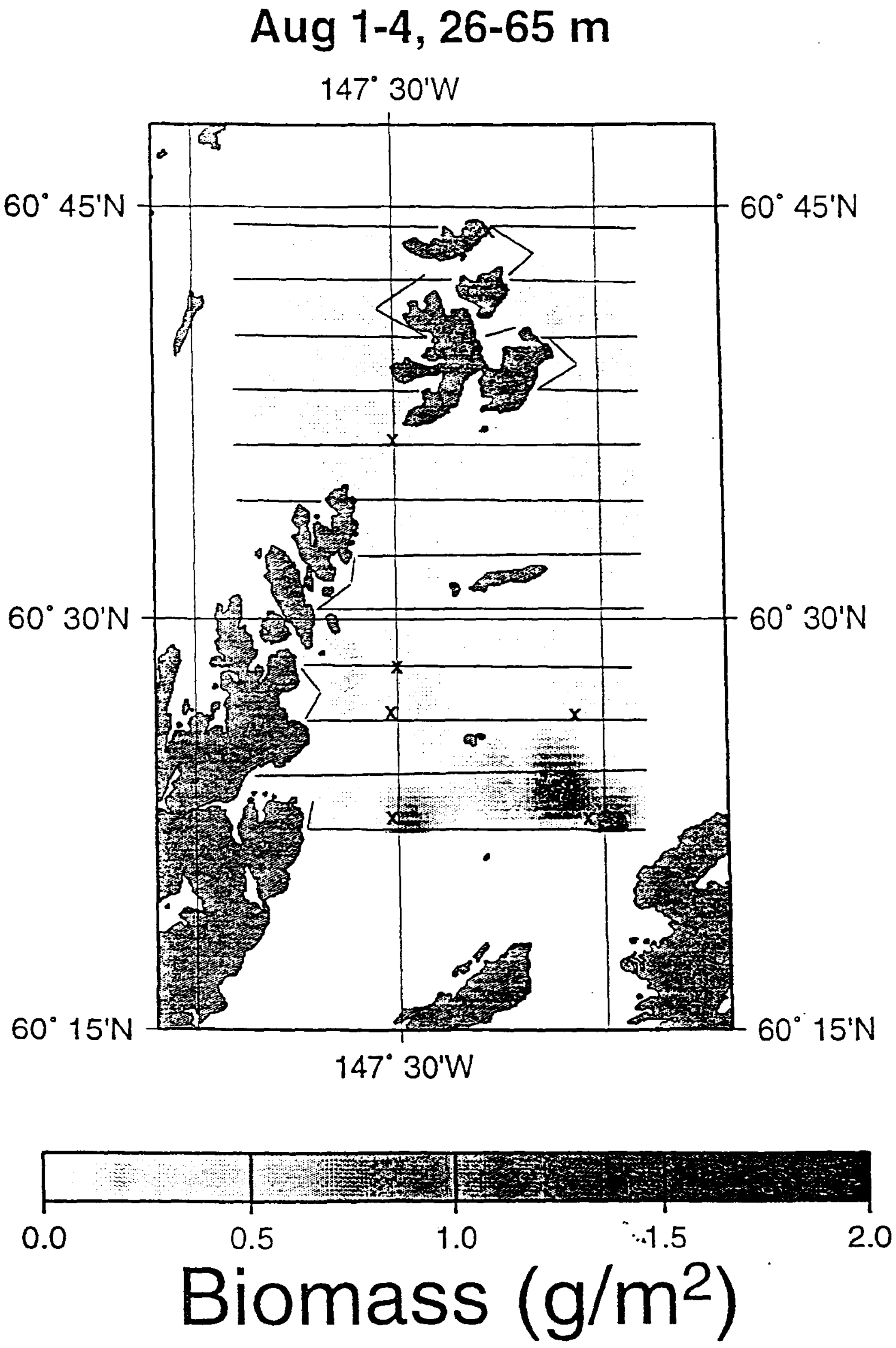

Figure 24. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the Central study area during the second acoustic survey.

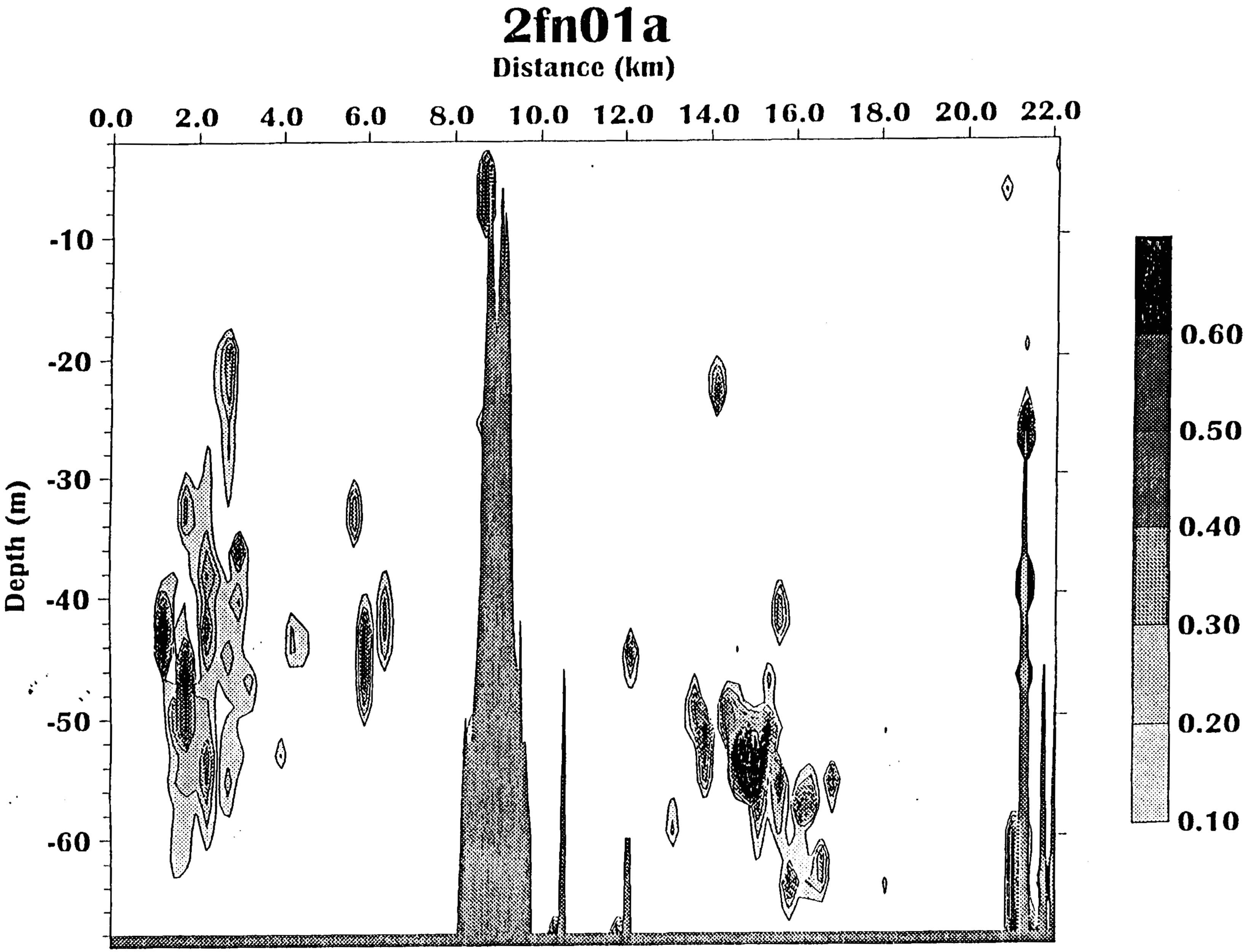

Figure 25. Distribution of biomass on Transect N01A east of Knight Island (Central area) during the second acoustic survey.

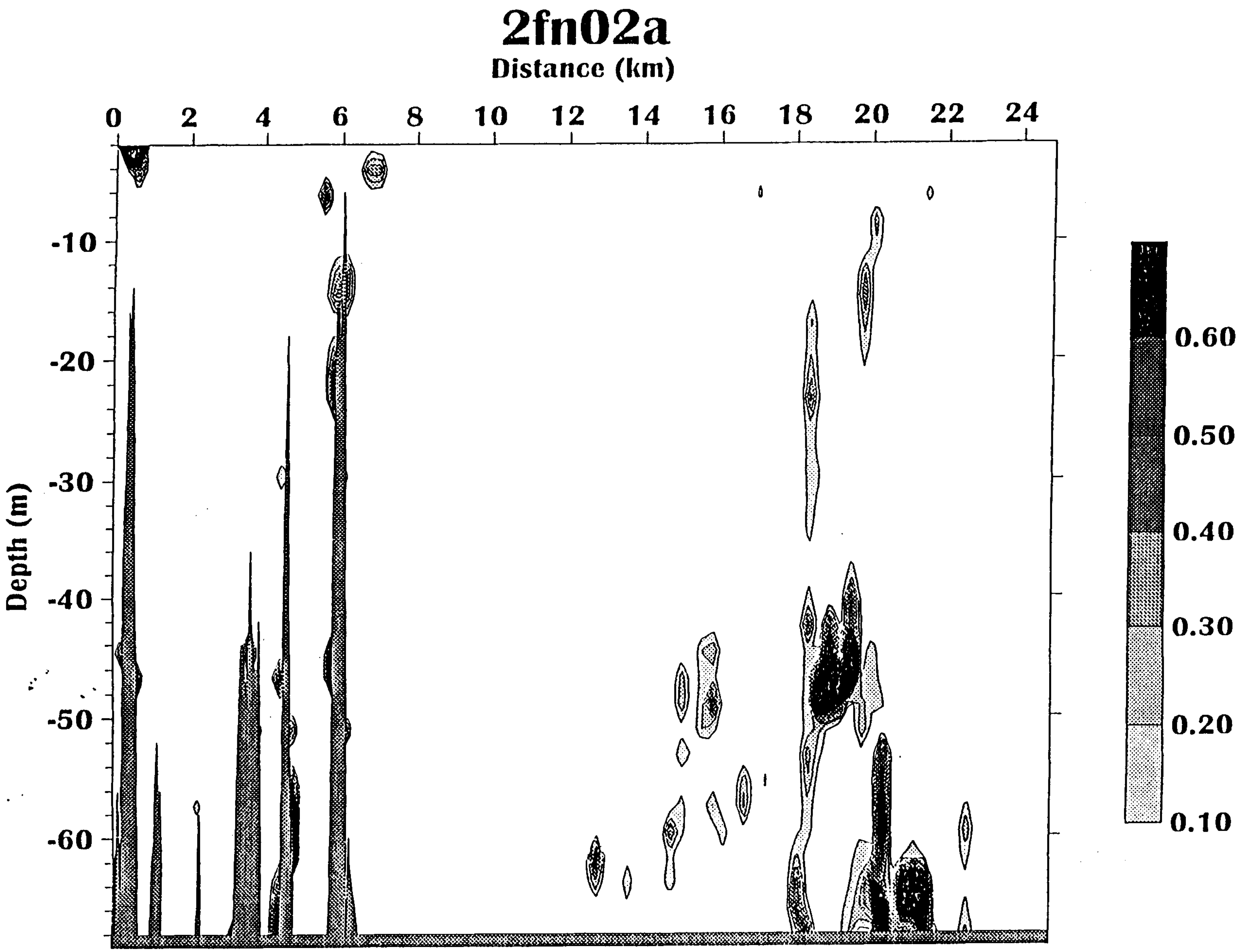

Figure 26. Distribution of biomass on Transect N02A east of Knight Island (Central area) during the second acoustic survey.

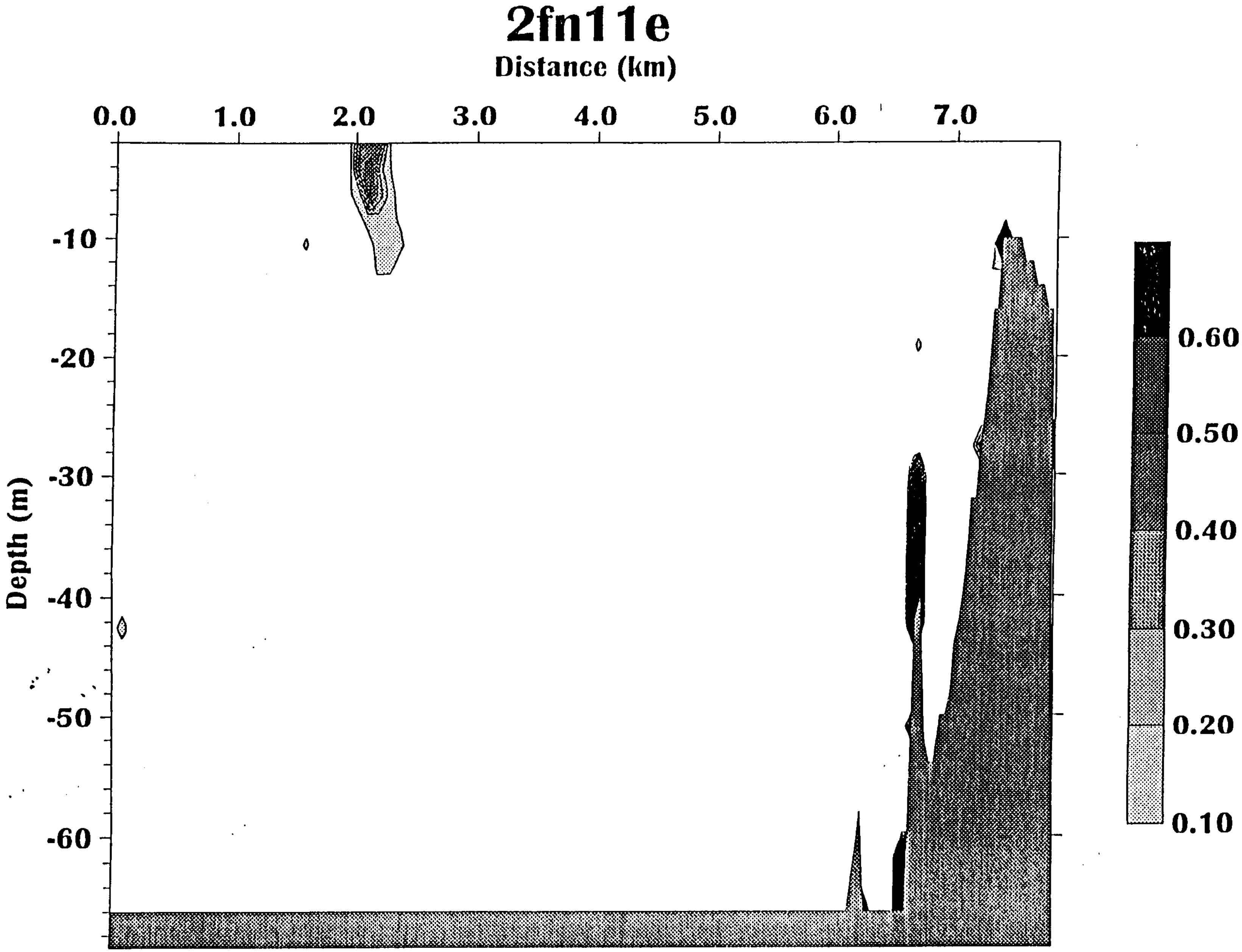

Figure 27. Distribution of biomass on Transect N11E east of Storey Island (Central area) during the second acoustic survey.

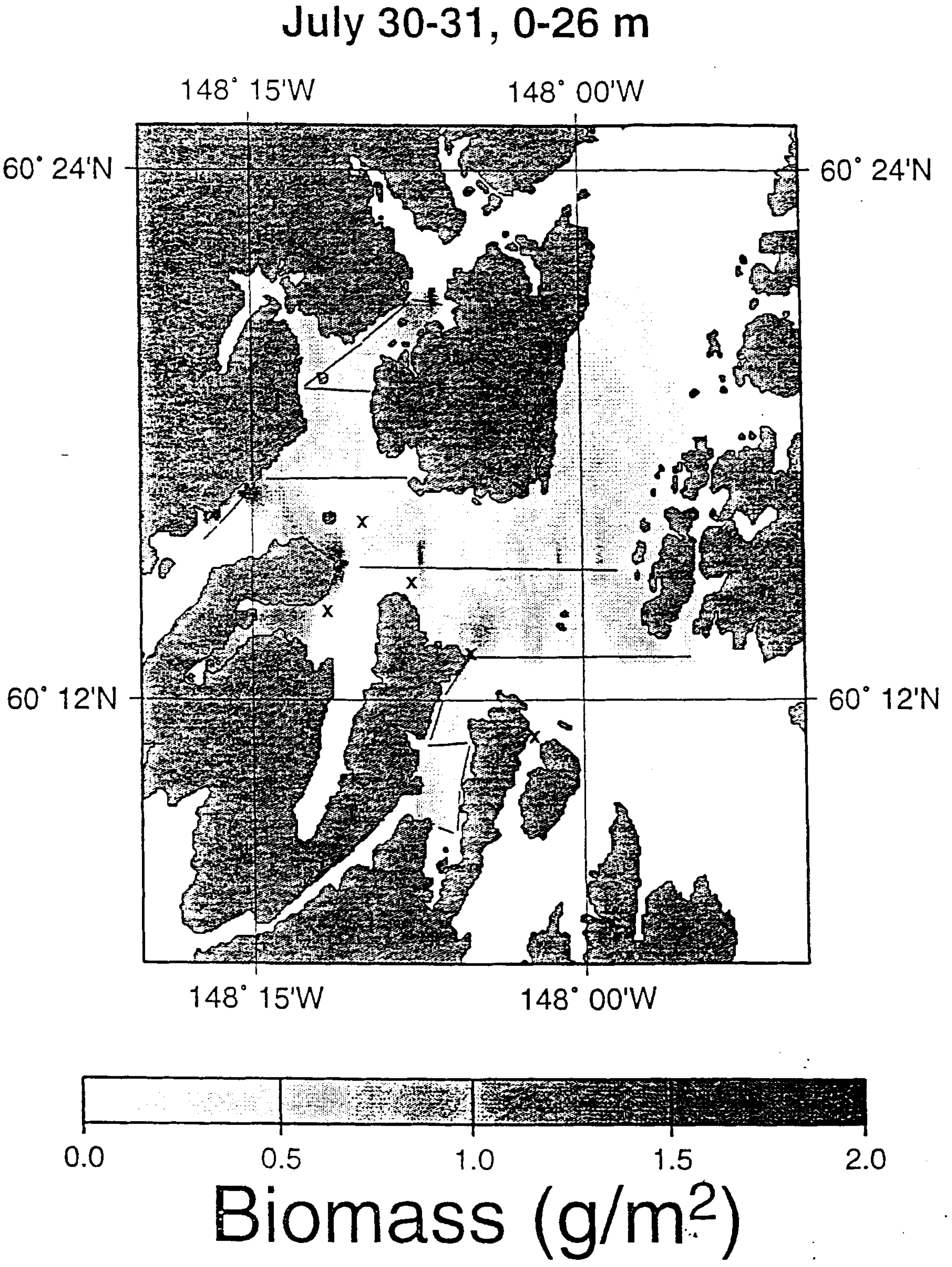

Figure 28. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the South study area during the first acoustic survey.

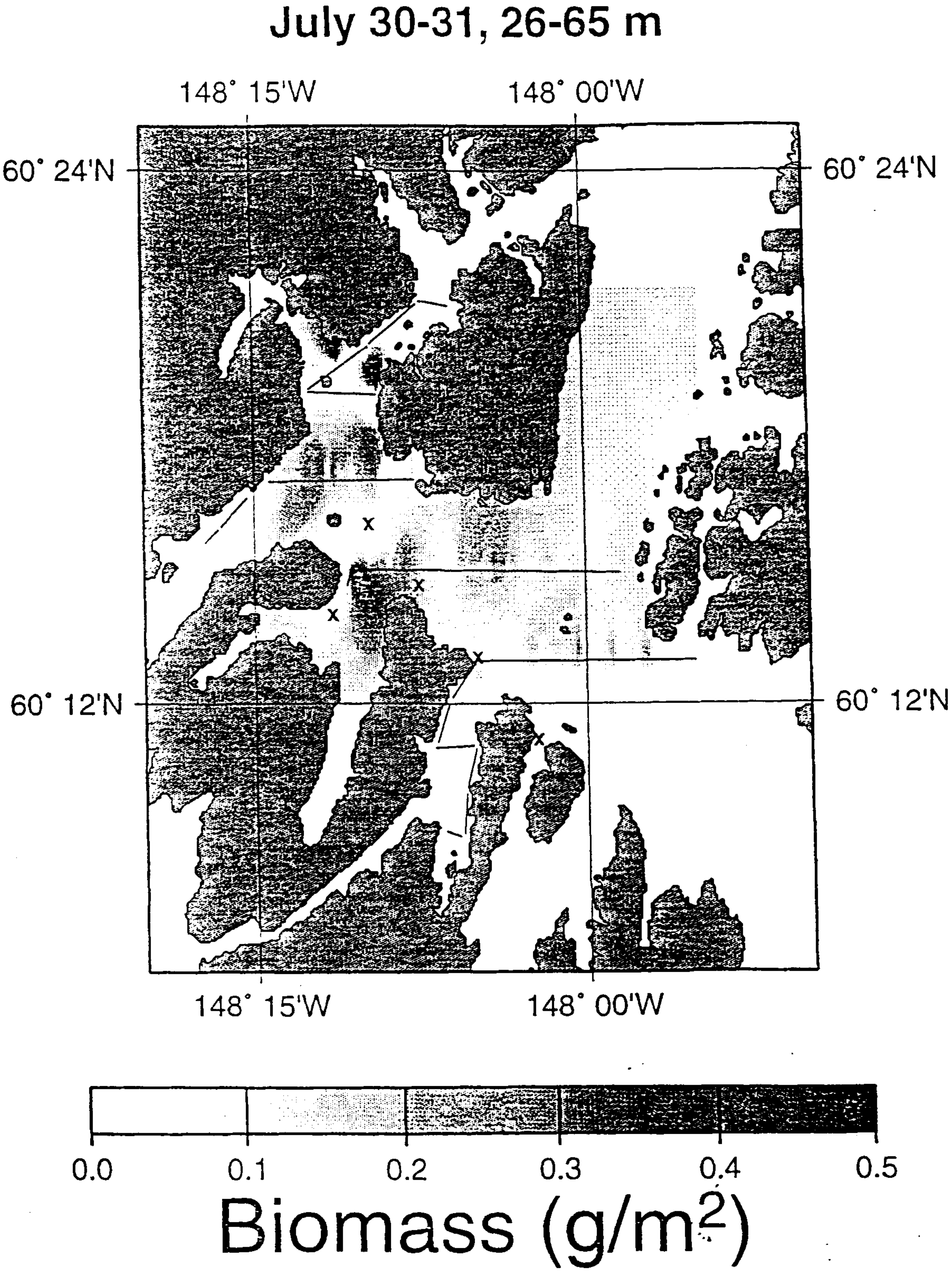

Figure 29. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the South study area during the first acoustic survey.

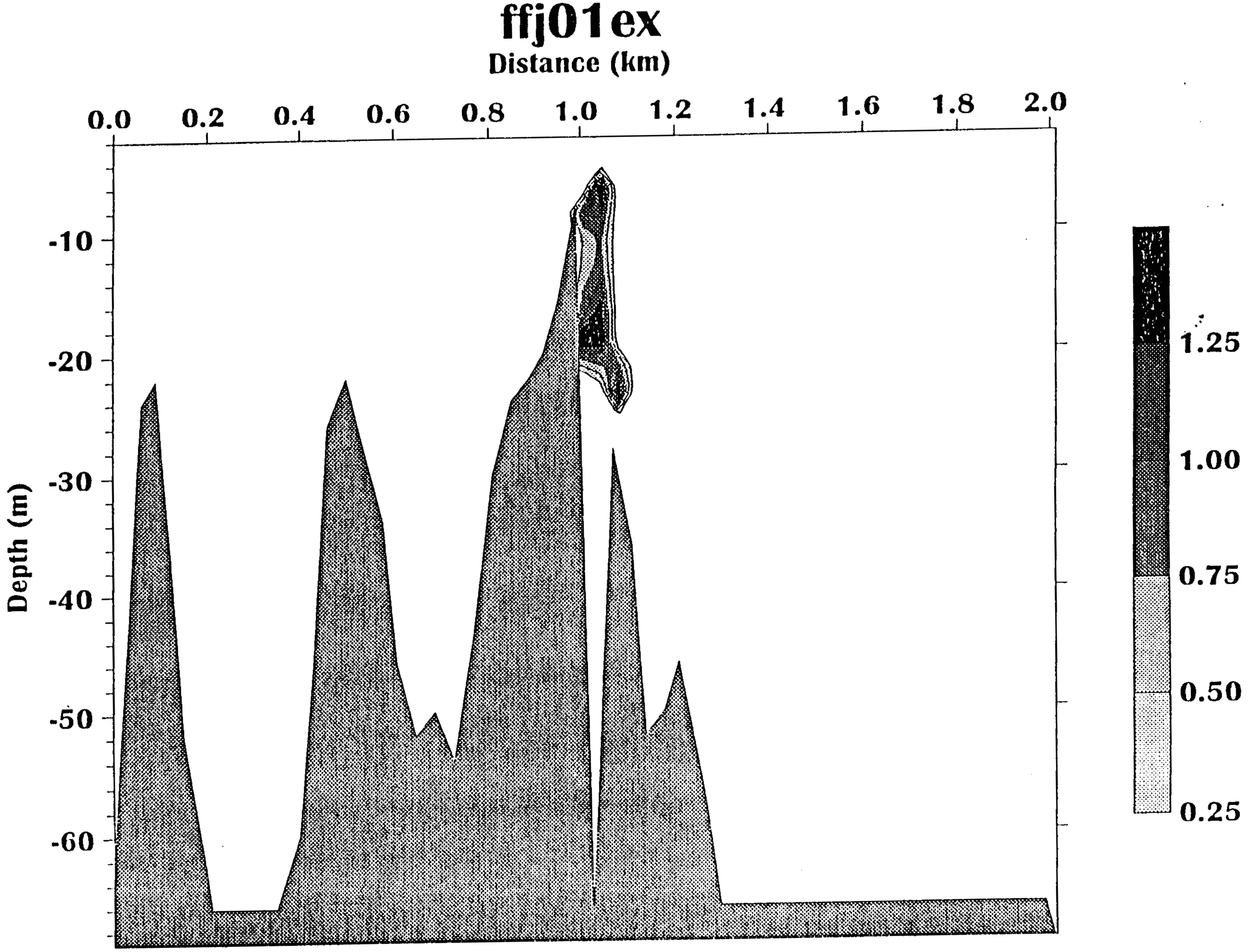

Figure 30. Distribution of biomass on Transect J01ex off Dual Head (South area) during the first acoustic survey.

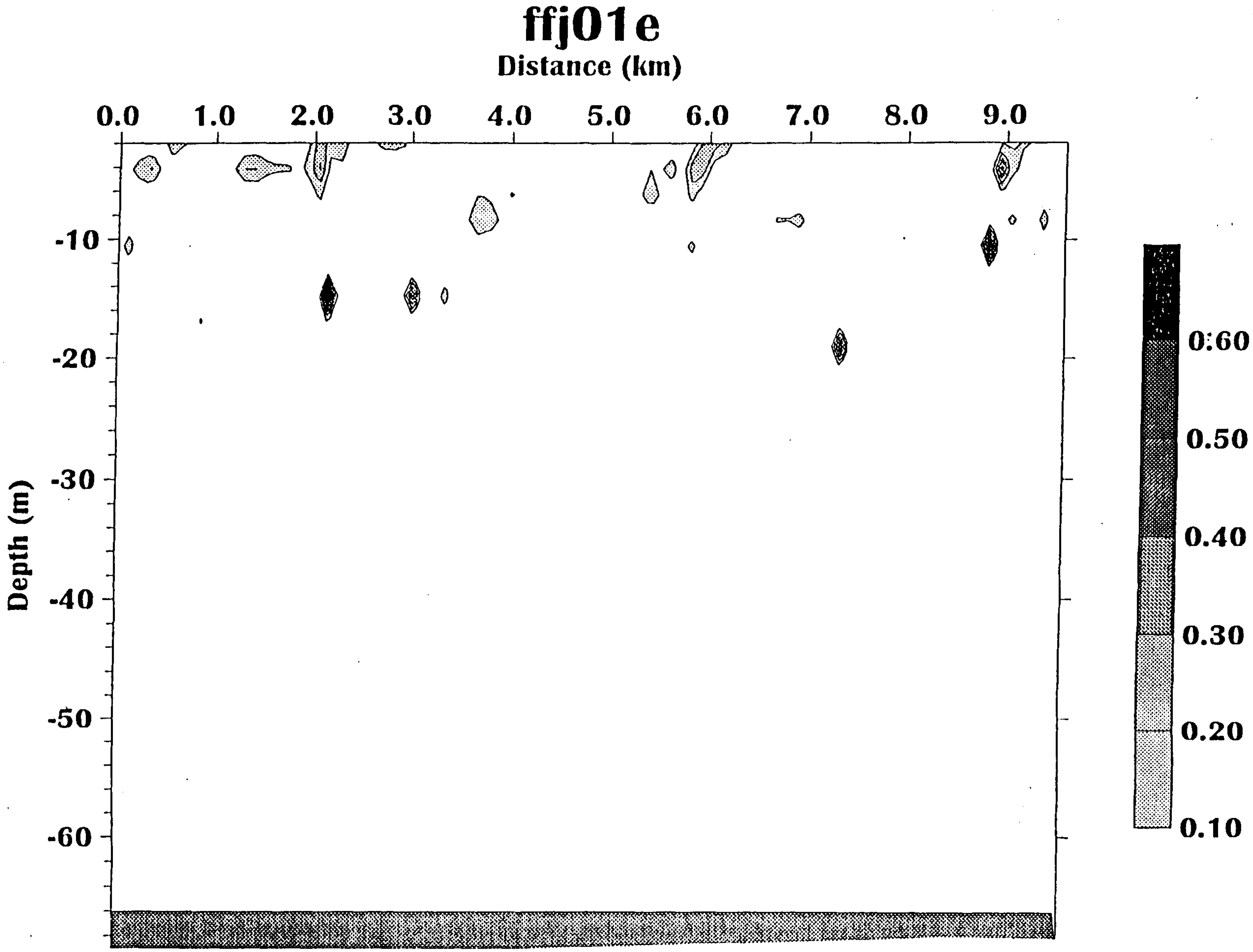

Figure 31. Distribution of biomass on Transect J01A in Knight Island Passage (South area) during the first acoustic survey.

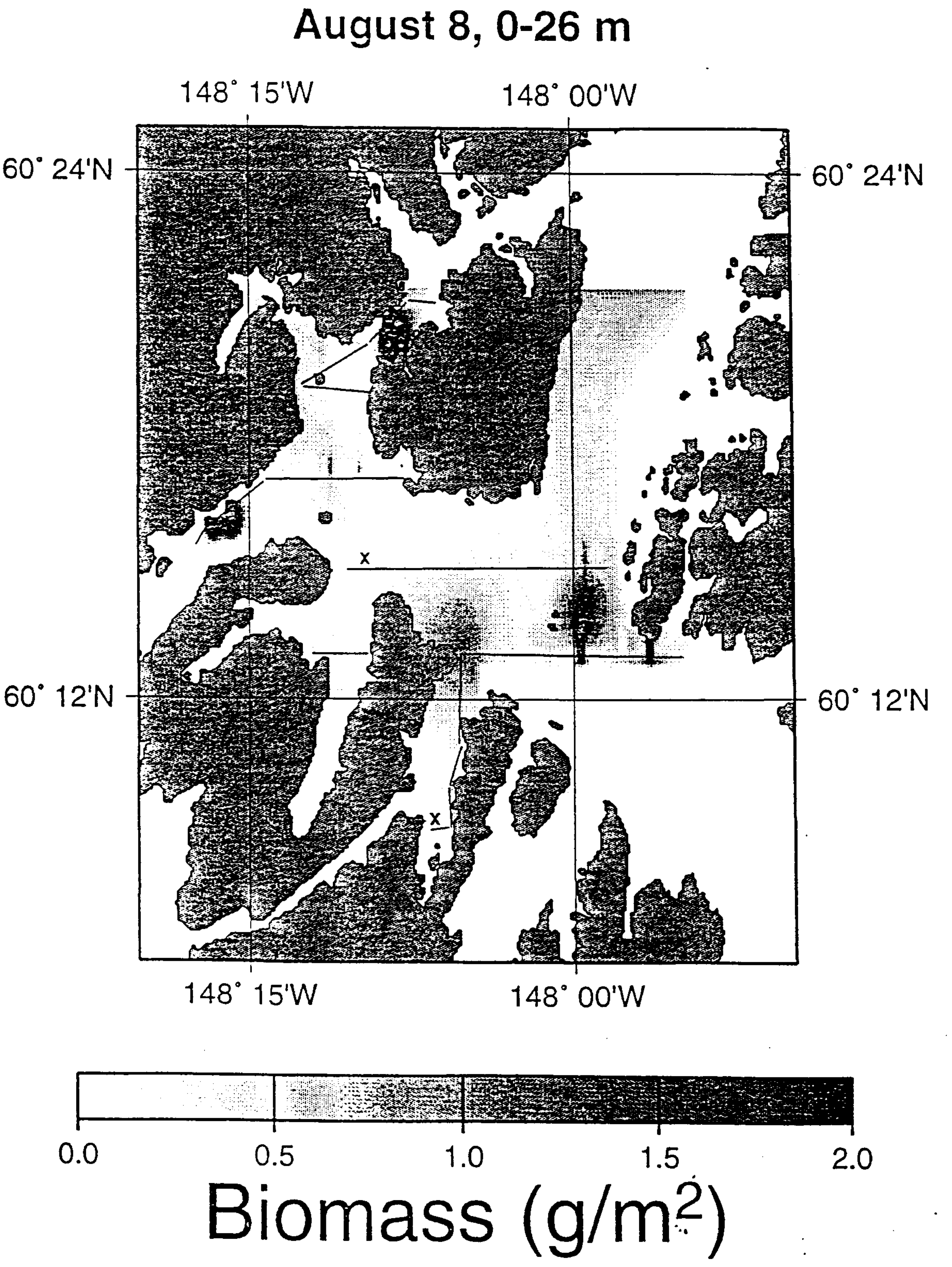

Figure 32. Geographic distribution of biomass in the shallow (<26 m) depth stratum of the South study area during the second acoustic survey.

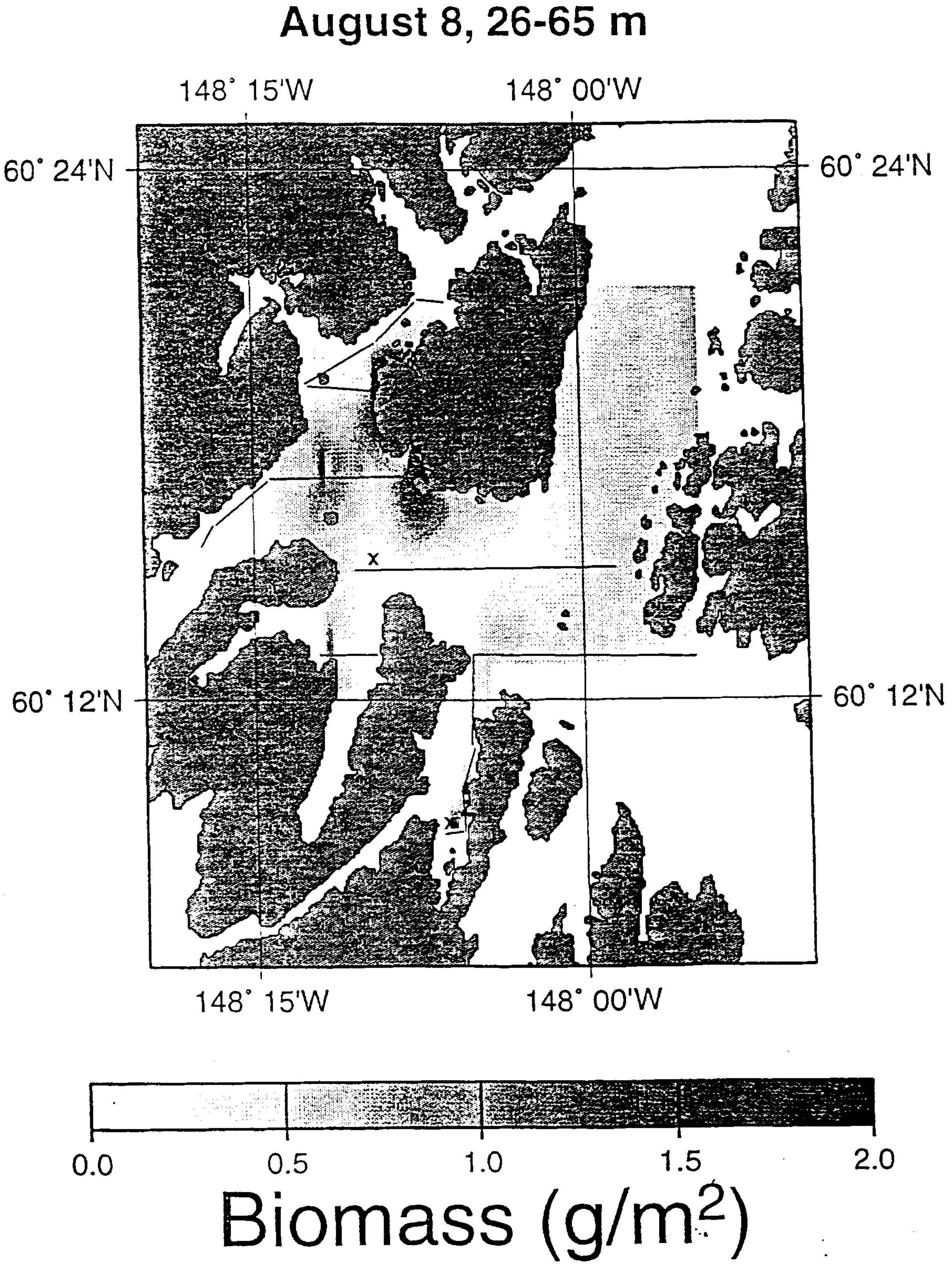

Figure 33. Geographic distribution of biomass in the deep (26 - 65 m) depth stratum of the South study area during the second acoustic survey.

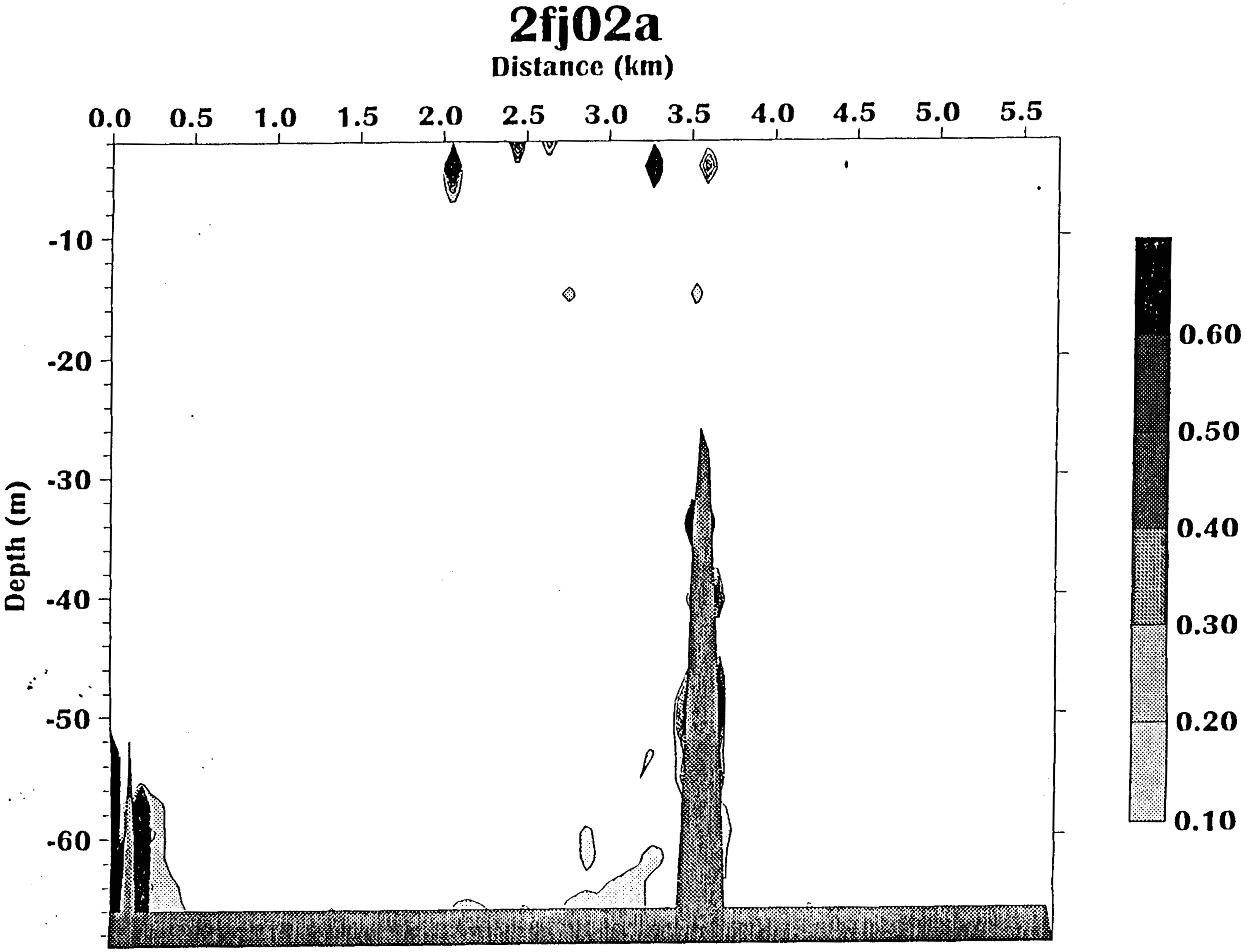

Figure 34. Distribution of biomass on Transect J02A in Dangerous Passage (South area) during the second acoustic survey.

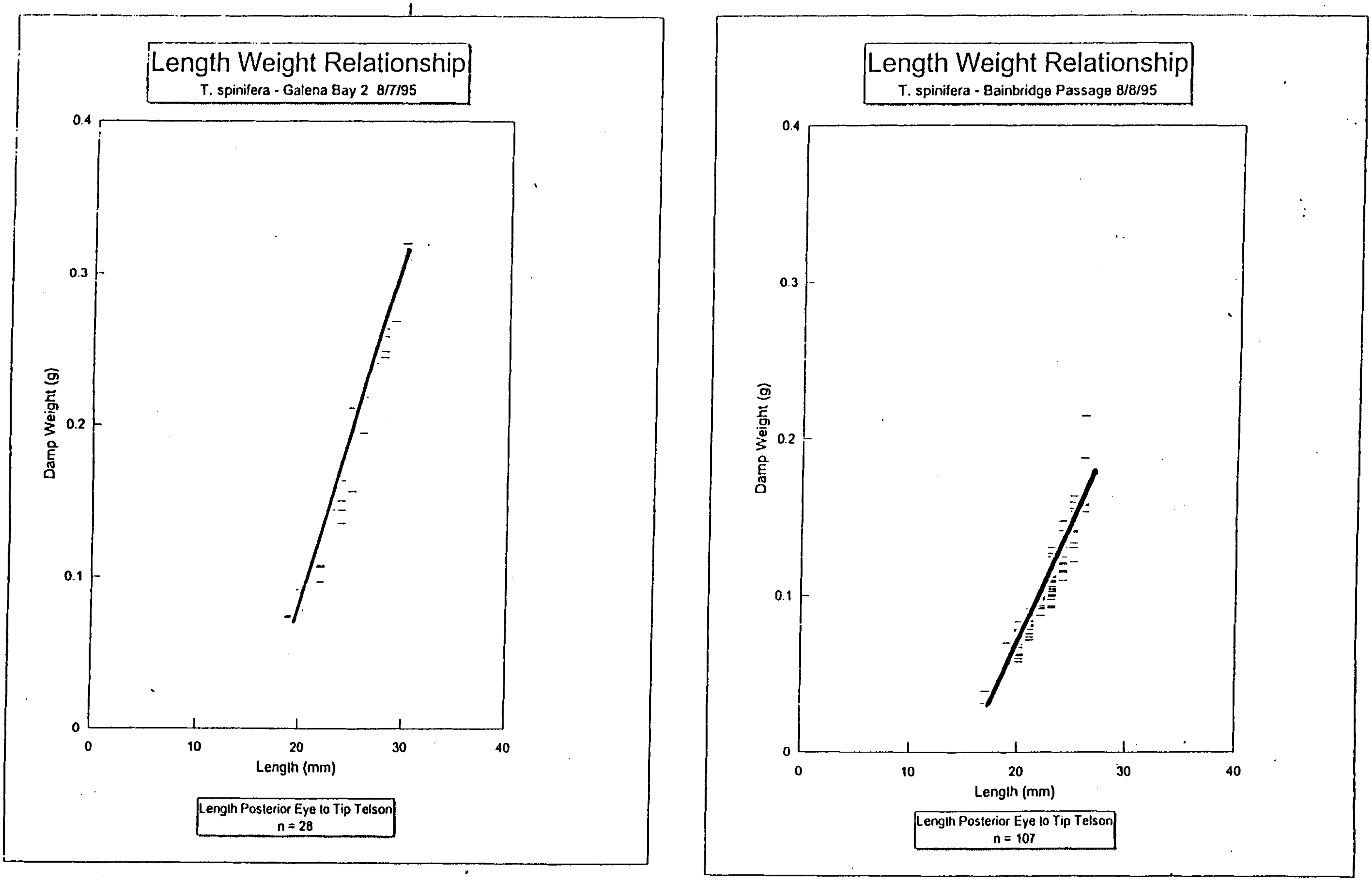

Figure 35. Length (mm)/weight (wet wt. in g) relationships of T. Spinifera from: A. Galena Bay collectod on August 7, 1995 and, B. Bainbridge Passage on August 8, 1995.

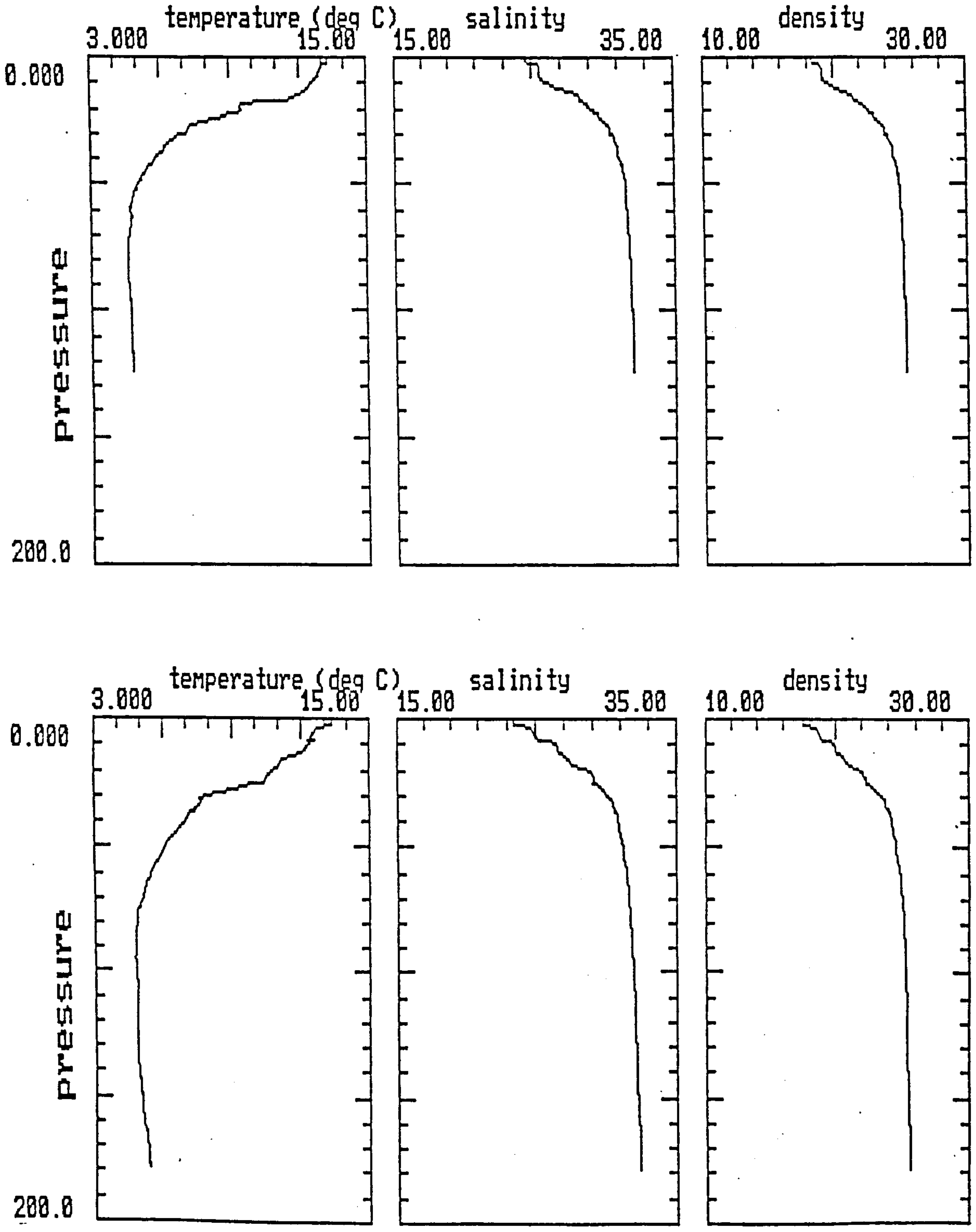

Figure 36. Vertical profiles of temperature, salinity and density (sigma-t) on transect V01A in the North area during the first (26 July) and second (5 August) surveys.

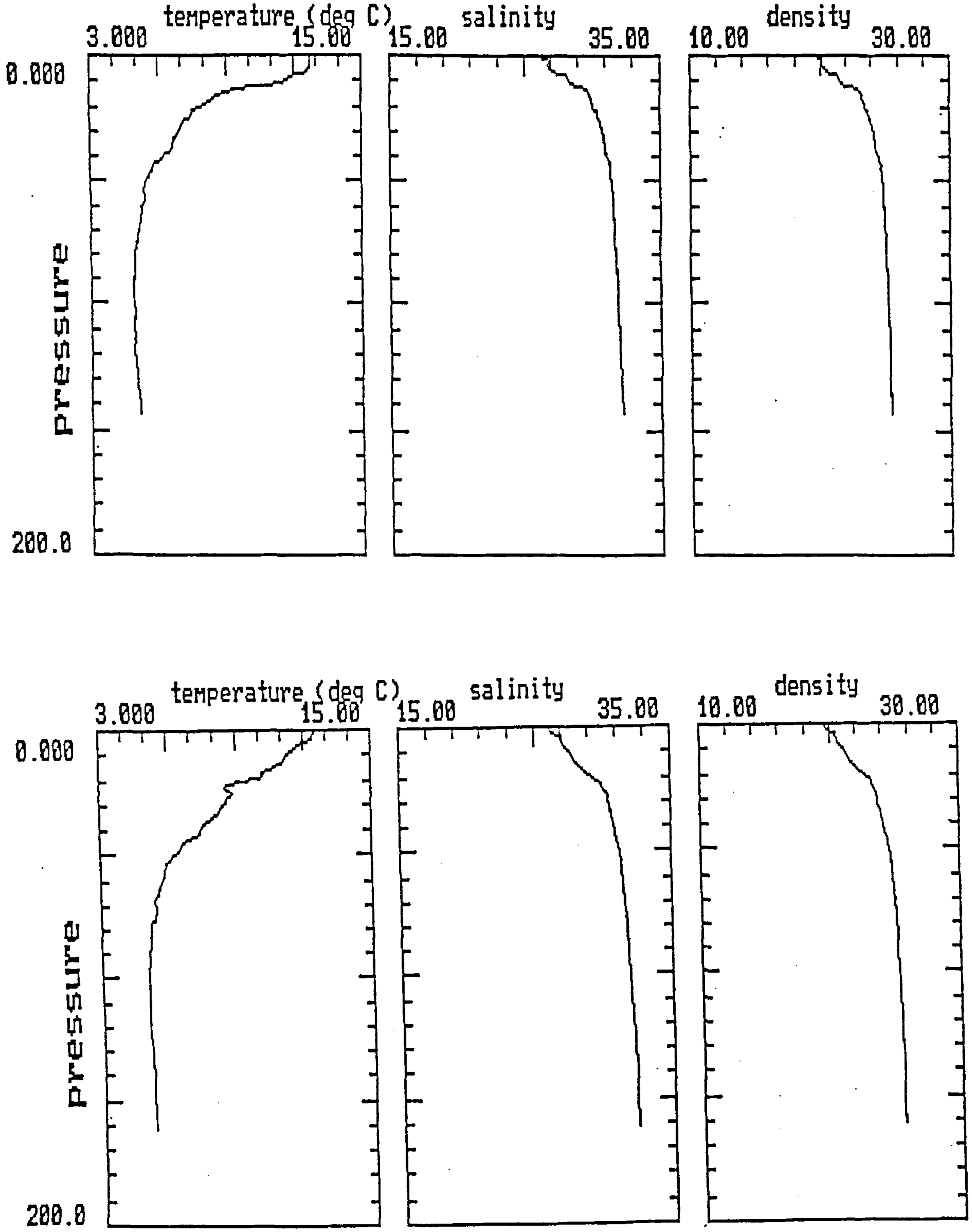

Figure 37. Vertical profiles of temperature, salinity and density (sigma-t) on transect N07A in the Central area during the first (23 July) and second (2 August) surveys.

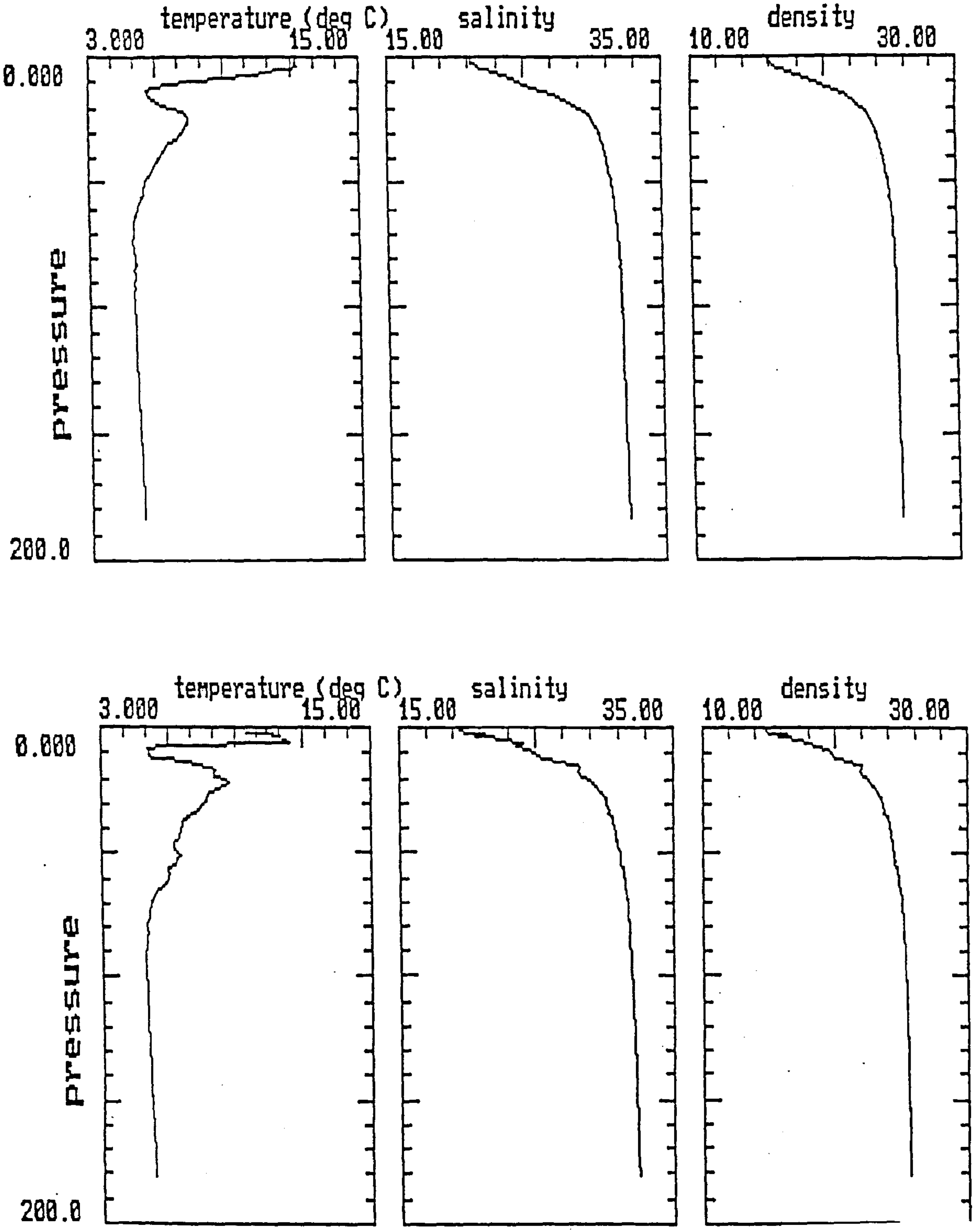

Figure 38. Vertical profiles of temperature, salinity and density (sigma-t) on transect J02A in the South area during the first (30 July) and second (8 August) surveys.

APPENDIX B

APEX: 95163 B

Appendix B-1

APEX: 96163B

SEABIRD/FORAGE FISH INTERACTIONS

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ABSTRACT

We sought to determine if forage fish characteristics and/or interactions among seabirds limit food availability. We monitored seabird/forage fish interactions by conducting systematically arranged transects in three areas of Prince William Sound from 21 July-11 August 1995. The study sites were located at Valdez Arm, Naked and Knight Islands, and Jackpot and Icy Bays. Down- and side-looking hydroacoustic and bird-observation data were collected simultaneously. We collected separate data on foraging behavior and kleptoparasitism on 22 foraging flocks encountered during the survey. Walleye pollock (*Theragra chalcogramma*) made up a high proportion of the forage fish biomass; however, these schools were at depths greater than 15 m and were associated with few seabirds. Black-legged kittiwakes (*Rissa tridactyla*), pigeon guillemots (*Cepphus columba*), and marbled murrelets (*Brachyrampus marmoratus*) were observed in shallow water near (<2 km) shore. Tufted puffins (*Fratercula cirrhata*) and glaucous-winged gulls (*Larus glaucescens*) were observed significantly farther from shore. We attempted to correlate the presence of forage fish schools observed in side viewing sonar with seabirds and found no relationship. Foraging flocks were associated with capelin (*Mallotus villosus*), sand lance (*Ammodytes hexapterus*), and juvenile herring (*Clupea harengus*).

Marbled murrelets and black-legged kittiwakes were positively correlated in foraging flocks suggesting that kittiwakes cue on marbled murrelets as a mechanism which concentrates and drives forage to the surface. Our observations suggest that glaucous-winged gulls' behavior may hinder kittiwake feeding in tightly grouped flocks. Kittiwakes lost 5% of their food catches to intraspecific and 7% to interspecific kleptoparasitism while foraging in mixed species flocks. Pomarine (*Stercorarius pomarinus*) and parasitic jaegers (*S. parasiticus*) attended the largest foraging flocks. Additional data and analysis is needed to determine if kleptoparasitism and aggressive behavior is limiting access to available forage.

Appendix B-2

INTRODUCTION

The T/V *Exxon Valdez* oil spill resulted in extensive mortality of seabirds and damage to other resources in Prince William Sound (PWS) and the Gulf of Alaska (Piatt et al. 1990). Several of these resources had not recovered 5 years after the spill (Agler et al. 1990a&b, Klosiewski and Laing 1994). The APEX project was initiated in 1994 to determine if a shift in the marine trophic structure has prevented the recovery of injured seabirds. Seabirds interact with the marine system principally through foraging; therefore, a study of the seabird/forage fish interactions and foraging behavior is a necessary component of the APEX project.

This is an ongoing study that began with a pilot effort in 1994 to test field methods. In 1995, the study was expanded to look at seabird foraging in several habitats in 3 study sites within PWS. During 1995 we investigated the general supposition that forage fish characteristics and/or interactions among seabirds limit availability of prey. We limited the scope of this hypothesis to 2 working components:

a. Forage fish are unavailable to seabirds because schools are too deep.

b. Aggressive social interactions among seabirds limit access to prey.

METHODS

We collected data from 3 study areas within PWS (Fig. 1). We selected transects systematically with a randomly chosen point of origin. Each study area was sampled twice during 21 July-11 August 1995. We conducted seabird and marine mammal surveys simultaneously with hydroacoustic surveys (hydroacoustic survey methods were described in the report for 95163A) employing techniques similar to those used to conduct population surveys in PWS (Klosiewski and Laing 1994). Seabird data were collected during hydroacoustic sampling. All birds and mammals observed within 100 m of the starboard side of the vessel (that side which was scanned by side-viewing sonar) were identified and recorded. Observers calibrated their ability to estimate distances by viewing a duck decoy tied to the end of a fishing line three times during the survey. Calibrations were done for 100 and 300 meters. Bird observations were made by scanning ahead of the ship with binoculars.

Observations were made before the ship's presence influenced bird behavior. Data were entered when the ship was closest to the point at which the birds were first observed. The perpendicular distance to each bird from the transect line was estimated to the nearest meter. Bird behavior was recorded categorically as: (a) in the air, (b) on a floating object, (c) on the water, (d) following the boat, (e) foraging, or (f) potential foraging. Foraging (e) was defined as actual observation of foraging behavior such as diving for food or holding food in the bill. Potential foraging (f) was defined as >2 associated birds on the water or circling above. Data was directly entered in a computer file. The data entry system was programmed to record time and location of each observation. Locations were recorded directly from a geographical positioning system (GPS). Data were also collected on all foraging flocks on either side of the vessel. Three foraging piscivorous seabirds were used as the threshold number to define a flock. Data on estimated perpendicular distance to the flock, location, time of observation, and number of each species were recorded into a computer file.

We collected additional data on all foraging flocks and the associated fish schools seen while conducting boat surveys. This required diverting from the transect. After data were obtained from foraging sites the transect was resumed from the point of departure. For each sampled flock, hydroacoustic, GPS location, and behavioral data were collected. Flocks were assigned a classification based upon criteria developed by Hoffman et al. (1981). These classifications were: 1) small short duration flocks over tightly clumped prey; 2) larger persistent flocks over more broadly dispersed prey; 3) Flocks associated with sites where forage is concentrated by downwelling or other hydrophysical influence. The influence of structure, for ascribing type 3 classification, was determined by a subjective evaluation of oceanographic features rather quantitative measurement of physical variables. Data were recorded by making auditory notes onto a cassette recorder and by video recording of behavior. Two additional foraging flocks not seen on transect were included in the analysis of behavioral data. Priorities for data collection were: 1) kleptoparasitic and piracy interactions with as much detail as possible; 2) foraging methods used by kittiwakes including number of dives, time between dives, success of dives, inter- and intraspecific interactions; 3) foraging methods of other gulls, or alcids as per #2. After behavioral data were collected, the vessel approached from a direction parallel to the transect to obtain a hydroacoustic profile of the forage. Vessel limitations, however, kept us from sampling many nearshore flocks in this manner. The species of forage fish associated with foraging flocks was determined by dip netting, pair-trawling, or trawling beneath the flocks.

We obtained data on distance to shore and distance to the nearest respective colony for each bird and flock observed with GIS software. We compared the mean distances to shore for black-legged kittiwakes, pigeon guillemots, and marbled murrelets, tufted puffins and glaucous-winged gulls with an analysis of variance (ANOVA) (Zar 1984). The distances to the nearest conspecific colony were also compared with an ANOVA for black-legged kittiwakes, pigeon guillemots, and tufted puffins. The acoustic data set has not yet been analyzed to determine collective or species specific forage biomass; however, qualitative comparisons were made by plotting the acoustic data and making visual observations. We compared acoustic and seabird data by plotting the locations of observed birds with the corresponding plots of hydroacoustic data and then made visual comparisons. Transects for which side-viewing sonar data were available, were partitioned into 10-min segments. We determined the number of piscivorous birds, number of fish schools, and total chord length of schools contained within each 10-min segment. We used Pearson Correlation (Zar 1984) to determine if there was a relationship between the number forage fish schools and the number of birds observed, and between the total chord length of fish schools and the number of birds observed within the 10-min segments.

We also used Pearson Correlation (Zar 1984) to determine the relationship between marbled murrelets and black-legged kittiwakes and between alcids and larids at foraging flocks. To determine differences in behaviors at the foraging flocks we used non-parametric statistics such as chi-square and Fisher's exact test (Zar 1984).

RESULTS

Marbled murrelets, pigeon guillemots, and black-legged kittiwakes were observed significantly closer to shore than were tufted puffins and glaucous-winged gulls ($n = 931$, $P < 0.05$) (Fig. 2). Black-legged kittiwakes were observed significantly farther from the nearest respective colony than were pigeon guillemots and tufted puffins ($P < 0.05$) (Fig. 3). Our visual review of the plots of the hydroacoustic data indicate that walleye pollock made up a large proportion of the biomass of schooling forage fishes (Fig. 4). We examined the graphical representations of the distribution of seabirds and hydroacoustic plots that contained pollock and determined that these schools were at depths greater than 15 m and were associated with few seabirds (Fig. 4). We found that there was no significant relationship between the number forage fish schools and the number of birds observed; and the total chord length of fish schools and the number of birds observed, within the 10-min segments ($P > 0.05$) (Fig. 5 and 6).

During 18 days of running transects, foraging flocks were rarely encountered and ranged in size from 3 to 1065 birds (= 135.8; SD = 291.5; n = 22). In each of the 3 study areas, foraging flocks were located close to shore (= 415 m; SD = 315.0; n = 22) (Figs. 7, 8 & 9). A total of 15 different bird species participated in foraging flocks with 11 species in a single Type II flock. Black-legged kittiwakes (= 56.45; SD = 132.94) and marbled murrelets (= 30.59; SD = 66.07) were predominate species in all three flock types. Kittiwake presence in flocks was positively correlated with murrelet presence (Pearson correlation; r = 0.65; P = 0.011). Furthermore, numbers of all larids were positively correlated with all alcids combined (Pearson correlation; r = 0.75; P < 0.001). Tufted puffins were also a predominant species in Type I and II flocks.

Type I flocks were composed of a mean of 3.3 species (SD = 1.45) and 7 to 174 birds (= 44.87; SD = 42.97; n = 15). Trawls at these flocks revealed that herring (at 4 flocks) were the predominate fish being preyed upon but capelin (at 1 flock) and sand lance (at 1 flock) also appeared in some catches. The fish were held in tight balls for at least part of our observation time in 8 out of 15 Type I flocks by presumably by pursuit-diving birds that dived and resurfaced near the periphery of the flock (Hoffman et al. 1981, Mahon et al. 1992).

We encountered two Type II flocks of 984 and 1065 birds with 11 and 8 different species participating in them, respectively. These were much smaller than the Type II flocks described by Hoffman et al. (1981) who characterized such flocks as ranging in size from 5,000 to 50,000 individuals. However, we considered them Type II flocks because: (1) they were significantly larger than flock types I and III (2 = 1696.1, d.f. = 2, P < 0.001), (2) both of them lasted for at least two days, and (3) they were loosely aggregated assemblages feeding on spawned out male capelin in one case and either capelin or herring in the second case.

Type III flocks were composed of a mean of 4.2 species (SD = 2.68) and 11 to 168 birds (= 53.00; SD = 64.84; n = 5). These flocks were concentrated around points of land or at the entrances to shallow passages. A trawl at one of these flocks disclosed herring of various age groups.

In Type I flocks, where the fish were in a tight ball, glaucous-winged gulls sat on the water above the fish while kittiwakes sat outside the gulls or hovered above. To maintain their position in this flock type, the gulls hop-plunged as opposed to plunge dived. The latter foraging method was used more often in Type II and III flocks (Fisher's exact test; P < 0.0001). Kittiwakes also hop-plunged more often in Type I flocks than in Type II and III flocks (2 = 14.356; P < 0.001). Yet, in all flock types, greater than 78% of their foraging attempts were plunge dives (Figure 10).

Kittiwakes had a foraging success of 80.6% (n = 129) and lost 4.8% of their captures to intraspecific piracy and 6.7% to interspecific piracy (Fig. 11). Kleptoparasitism against kittiwakes was most intense in the tightly aggregated Type I flocks compared to Type II and III flocks (2 = 83.55; P < 0.001).

Interspecific kleptoparasitic attempts by glaucous-winged gulls were directed toward kittiwakes in Type I and II flocks and toward alcids in Type I flocks (Figure 12). Intraspecific kleptoparasitism by kittiwakes was observed most often in Type I flocks while attempts directed against alcids were more commonly seen in Type III flocks (Figure 13). Together, glaucous-winged gulls and black-legged kittiwakes kleptoparasitized alcids less than expected in Type I flocks (2 = 15.32, d.f. = 1, P < 0.001) but not in Type III flocks (2 = 1.780, d.f. = 1, P = 0.182; Table 1). Parasitic and pomarine jaegers preferentially chased kittiwakes in Type II flocks (Figure 14). In flocks where jaegers were present, the number of kleptoparasitic attempts by them increased with the number of larids present in the flock (Figure 15).

DISCUSSION

Black-legged kittiwakes, pigeon guillemots, marbled murrelets were associated with nearshore habitats. These piscivorous species were all arguably injured by the spill (*Exxon Valdez* Oil Spill Trustee Council 1994, Irons, U. S. Fish and Wildl. Serv., Anchorage, Alas., unpublished data); whereas tufted puffins and glaucous winged gulls were located significantly farther from shore and were not classified as injured by the *Exxon Valdez* Oil Spill Trustee Council (1994). These injured seabird share a lifehistory linkage to nearshore habitats with many nonbird species listed as injured by the *Exxon Valdez* Oil Spill (Exxon Valdez Oil Spill Trustee Council 1994). This linkage implies that the major long term impact of the spill has been nearshore and this portion of the ecosystem has not recovered. Alternatively, long term fisheries monitoring of the Gulf of Alaska has demonstrated major trophic shifts that include an increase in walleye pollock abundance (Anderson et al. 1994). It is probable that these shifts also occurred in PWS and that the high proportion of walleye pollock in the total fish biomass is a recent result from these shifts. Wespestad and Fried (1983) demonstrated a negative relationship between herring and pollock biomass in the Bering Sea. Data collected by APEX indicates that pollock and herring school together during the fall (L. Halderson, Univ. of Alas. Fairbanks, unpublished data) and their diets overlap (M. Sturdevant, US Nat. Marine Fish. Ser., unpublished data) suggesting that direct competition does occur and that a negative relationship between the species is probable in PWS. Our data suggest that the injured seabirds are notforaging on walleye pollock and have not adapted to the ecological shift. Had the spill not occurred, a decline in the injured seabird species may have been inevitable. We suggest that the current condition in PWS is the result of both broad scale ecological change and the localized long term impact of the spill. The oil spill may have directly reduced the populations of preferred nearshore prey species giving a competitive edge to an increasing pollock population, thereby exacerbating an on going decline. We suggest that the large scale ecological shift will prevent or delay a recovery of the injured seabirds until the Gulf of Alaska returns to previous conditions.

Our finding of an insignificant correlation between bird and fish abundance is consistent with previous studies that found correlations between seabird and fish abundance became less significant at decreasing scale (Obst 1986, Heinemann et al. 1989, Schneider and Piatt 1986, Erikstad et al. 1990, Hunt et al. 1990, Piatt 1990). We suggest that at smaller scales birds observed loafing and in transit to and from foraging sites confounded the correlation between birds and fish. This has led us to consider reanalyzing our data using fish schools as our sampling unit and examining additional environmental variables to explain resource selection by seabirds. Through a GIS and the down- and side-looking hydroacoustic data we will derive depth of school, total depth of water, and distance to shore. Additionally, we intend to examine the role of time of day, and state of tide. The probability of school selection will be modeled statistically through the use of a multivariate resource selection function (Manly et al. 1993).

In PWS flocks are generally smaller than those encountered in more oceanic regions (e.g. Hoffman et al. 1981, Duffy 1983). Foraging flocks of murrelets, kittiwakes, gulls, puffins, and guillemots fed on schools of herring, capelin, and sand lance that were nearshore. Conspecifics and congeners of these birds have also been found distributed nearshore in other boreal environments (Vermeer et al. 1989, Stone et al. 1995) to obtain easy access to their prey. Our observation of only 22 foraging flocks during 18 days was likely the result of spending a much greater proportion of time on offshore portions of transects.

Seabird prey can be concentrated by upwelling or downwelling in both oceanic and coastal regimes (e.g. Wahl et al. 1989, Schneider et al. 1990, Coyle et al. 1992). Such flow gradients are often found around islands and points of land (Hamner and Hauri 1981, Kinder et al. 1983). In PWS these processes may associated with concentrations of herring that are vulnerable to seabird predation. Sand lance are also common nearshore and in shallow waters that have sandy substrates and relatively high bottom current velocities (Auster and Stewart 1986). These conditions occur around many land masses in PWS. The capelin concentrations discovered nearshore appeared to be post spawning aggregations that are known to attract alcids (Piatt 1990) and many other seabirds (Hoffman et al. 1990). Preliminary analysis of the hydroacoustic data suggests that the predominant concentration of capelin in these schools reside near the bottom of the water column. Alcids appear to be the driving force in Type I flocks where capelin and other forage fish are concentrated in tight balls near the surface and hence become accessible for gulls and kittiwakes (Grover and Olla 1983). In the large Type II flocks individual capelin apparently become confused and swim to near the surface where they are vulnerable to plunge-diving birds.

Research in British Columbia suggested that marbled murrelets may have been the catalyst in the formation of foraging flocks (Mahon et al. 1992). Murrelets may have made forage available to kittiwakes by forcing schools into tight balls and driving them to the surface. This is a likely cause for the strong association between murrelets and kittiwakes at foraging flocks. Our observations of murrelet participation in flocks were consistent with observations made within intercoastal waters of British Columbia (Mahon et al. 1992) and inconsistent with the low murrelet participation in flocks of outside waters (Porter and Sealy 1981, Chilton and Sealy 1987).

Glaucous-winged gulls may deter smaller gulls and kittiwakes from feeding at densely aggregated foraging flocks. Porter and Sealy (1982) observed that smaller California gulls usually hovered over flock and plunge dived while glaucous-winged gulls flew right into the center and hop-plunged or dipped for prey. These behaviors are similar to what we have observed with kittiwakes and gulls in PWS foraging flocks. We encountered one foraging flock that had 12 glaucous-winged gulls sitting on the water over a tight ball of capelin and occasionally plunge diving. Kittiwakes were entirely absent from this flock though many were seen within just a few kilometers. Glaucous-winged gulls are unable to dominate the more loosely aggregated fish at Type II and III flocks. Unfortunately, foraging success is difficult to determine in tightly clumped feeding flocks, therefore comparison with type II and III flocks is not viable. The rates of kittiwake plunge-dives at densely aggregated fish schools with glaucous-winged gulls over them compared to those without glaucous-winged gulls are presently being analyzed.

Densely aggregated Type I flocks promoted kleptoparasitism within the gulls and kittiwakes but did not facilitate piracy by jaegers perhaps because of a low success rate in this flock type (Hoffman et al. 1981). Alcids were also attacked less frequently in Type I flocks because of their ability to dive and resurface around the outer edge of these flocks and avoid the attacking kittiwakes (Hoffman et al. 1981, Chilton and Sealy 1987). The inability to keep fish tightly balled as in Type II and III flocks causes diving birds to resurface randomly. Without the focal point of a tight fish school, kittiwakes may cue on the resurfacing alcids for feeding opportunities.

Parasitic and Pomarine jaegers were most commonly observed in the largest foraging flocks (Type II). Although most studies of jaeger piracy have been conducted near colonies (e.g. Andersson 1976, Birt and Cairns 1987) these birds are not common raiders at colonies in PWS (David Irons, pers. comm.). One large capelin feeding flock had a group of 15 pomarine and 2 parasitic jaegers sitting on the water about 1 km away. They appeared to be making occasional sorties (usually alone) into the foraging flock. Their method of attack in Type II flocks appears to concentrate efforts on kittiwakes that have recently caught a fish (Hoffman et al. 1981). We also observed many cases where jaegers chased kittiwakes with fish visible in the bill. These behaviors may increase the robbing success of jaegers. Kittiwakes may also be preferentially chased over the larger gulls because of size differences or the delayed swallowing of prey or a combination of both. On the St. Lawrence River smaller common terns were chased more often by parasitic jaegers than black-legged kittiwakes and almost half the chased terns had fish dangling from the bill whereas none of the chased kittiwakes had a visible fish (Belisle and Giroux 1995). A review by Furness (1987), however, suggests that the parameters regarding a bird's susceptibility to chase remain equivocal.

Evolutionary-stable kleptoparasitic interactions deprive hosts of about 1% of their food (Furness 1987). We determined the estimated loss of secured prey by kittiwakes to interspecific kleptoparasitism is close to 7%. If our sample of foraging kittiwakes was representative of the PWS population this may be great enough to cause feeding stress in their populations. Puffins robbed of only 4% of their food deliveries to chicks in Iceland during 1973 had unusually poor breeding success that year (Arnason and Grant 1978). A significant change in rates of kleptoparasitism in PWS in the coming years may indicate an unstable ecosystem.

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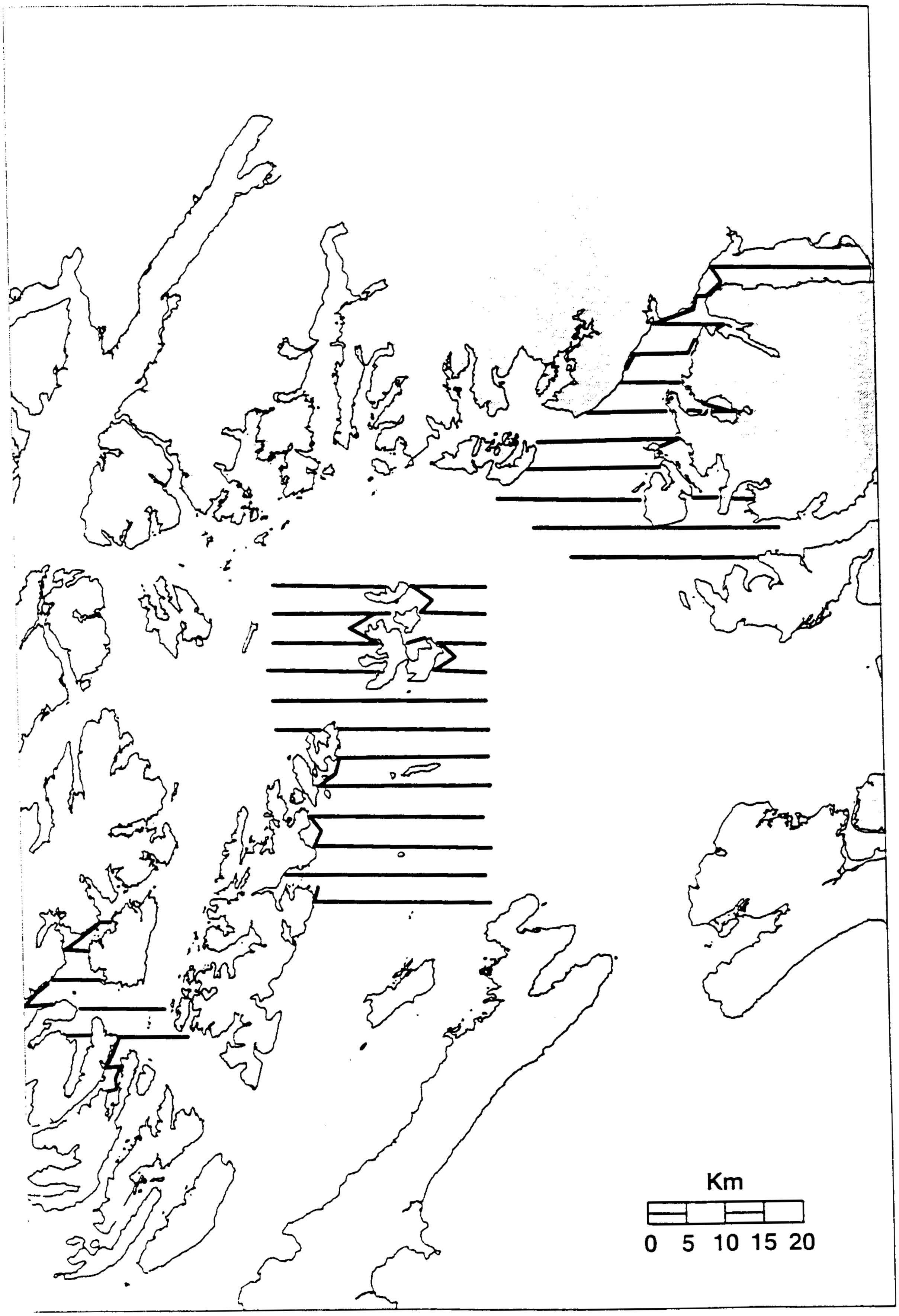
Appendix B-10

Table 1. Relative abundance and observed vs. expected number of chases againstalcids in type I and type III flocks encountered during the 1995 APEX cruise.

Flock Type	Host	total abundance	relative abundance	expected chases	observed chases
I	ALCID	180	0.4286	12.43	2
	BLKI	240	0.5714	16.57	27
III	ALCID	143	0.6272	10.66	8
	BLKI	85	0.3728	6.34	9

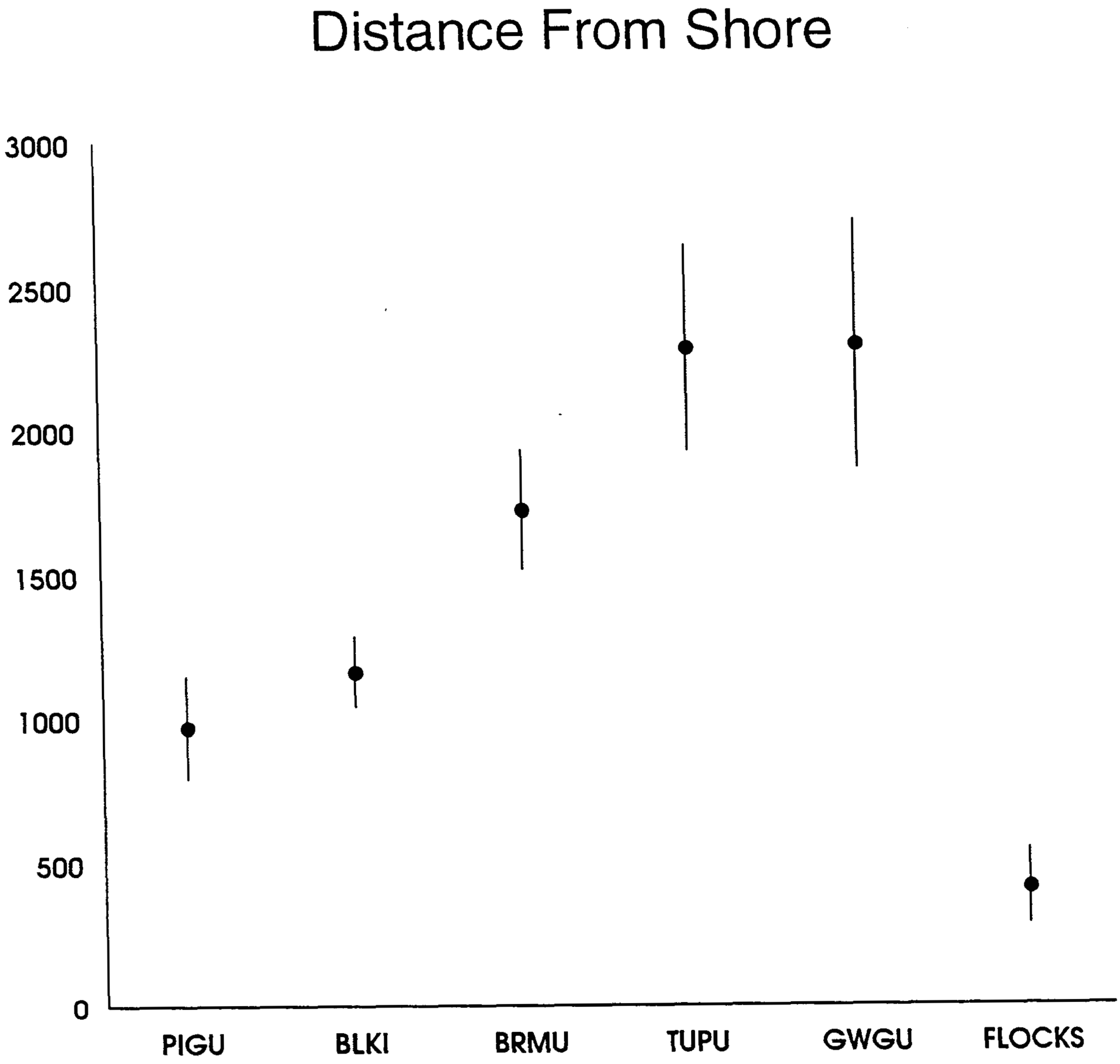
Appendix B-11

Fig. 1. Prince William Sound and the location of transects used in 3 study sights for the 1995 APEX cruise.


Km
0 5 10 15 20

Appendix B-12

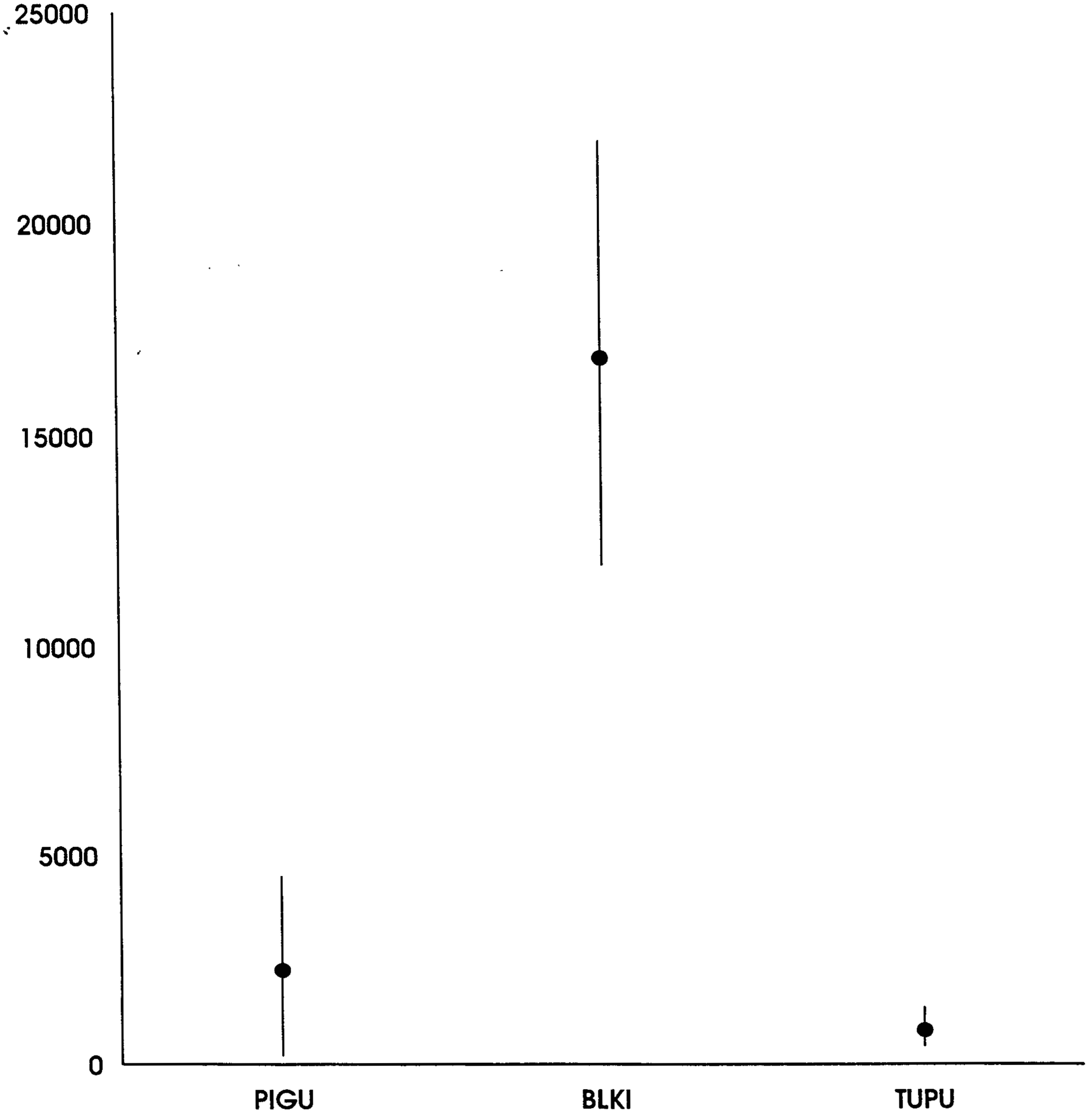
Fig. 2. The mean distance to shore from where seabirds and foraging flocks were observed during the 1995 APEX cruise. Error bars indicate 95% confidence intervals.


Distance From Shore
3000
2500
2000
1500
1000
500
0
PIGU
BLKI
BRMU
TUPU
GWGU
FLOCKS

Appendix B-13

Fig. 3. The mean distance to the nearest respective colony from where seabirds were observed during the 1995 APEX cruise. Error bars indicate 95% confidence intervals.

Distance From the Nearest Colony for Members of Foraging Flocks

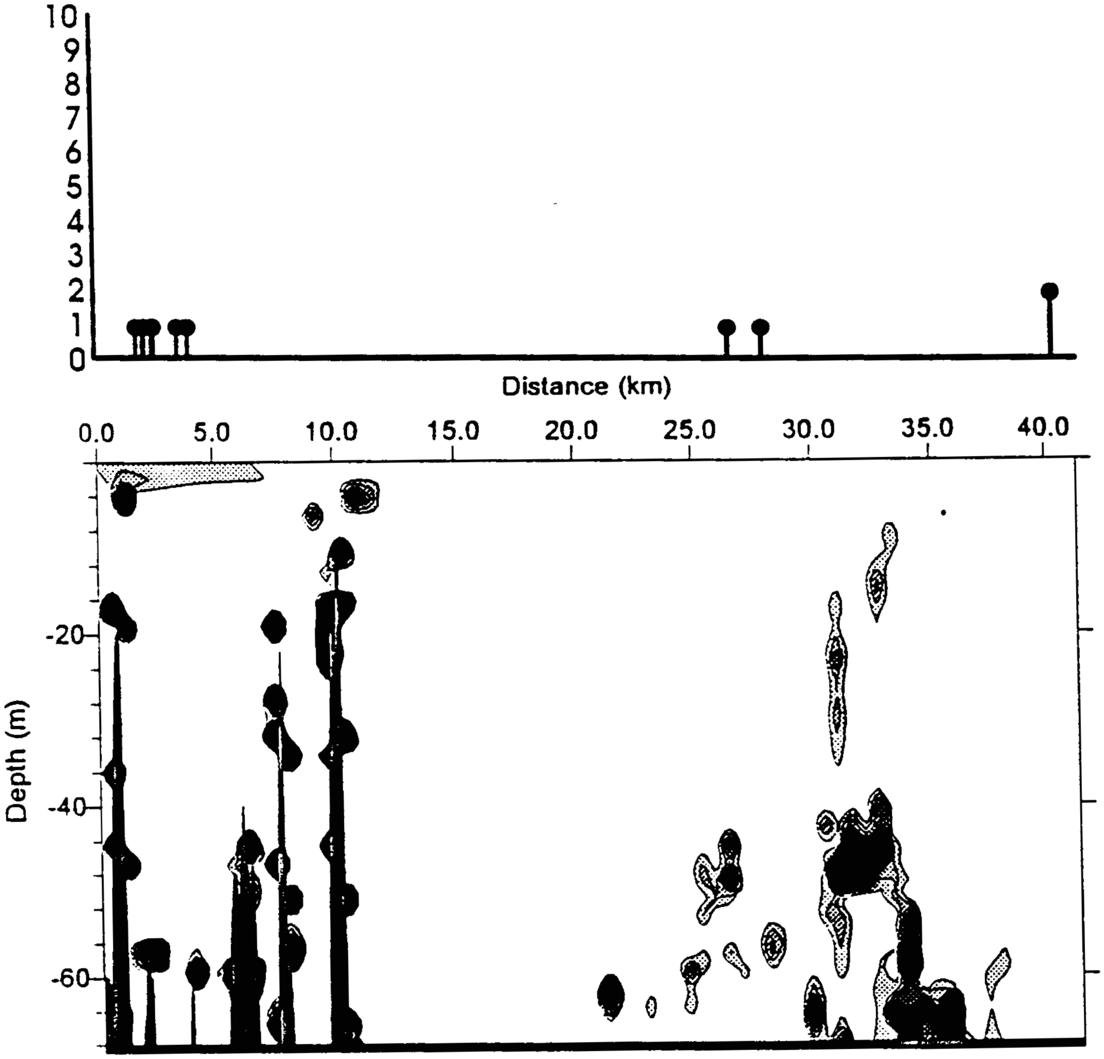


Appendix B-14

Fig. 4. The number of black-legged kittiwakes, marbled murrelets, and pigeon guillemots observed on a representative transect of the central study area is depicted above. The corresponding hydroacoustic data are depicted below. Polygons on the right were determined to be pollock schools. Data were collected during the 1995 APEX cruise.

2F N02A

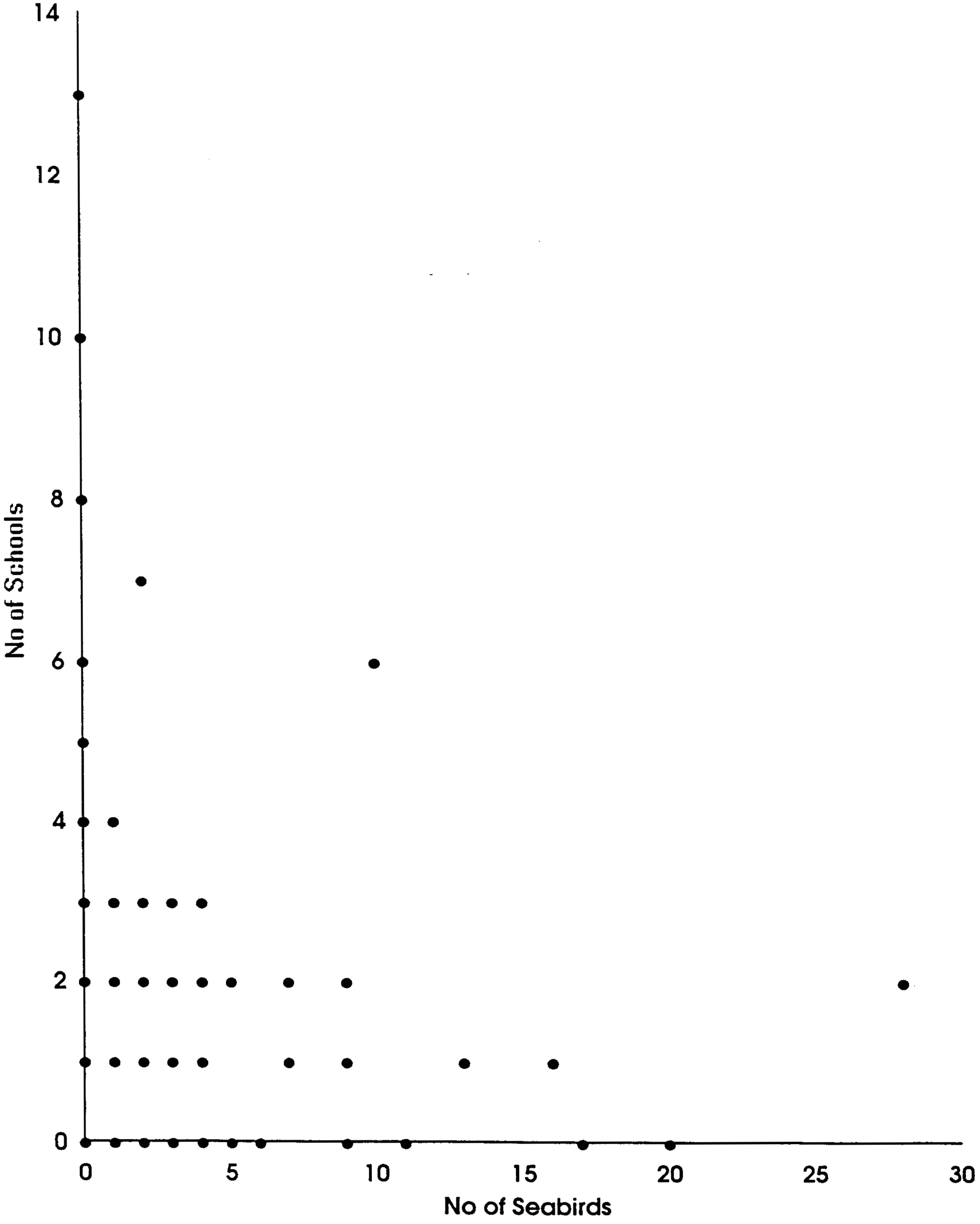
KITTIWAKES, GUILLEMOTS, AND MURRELETS



Appendix B-15

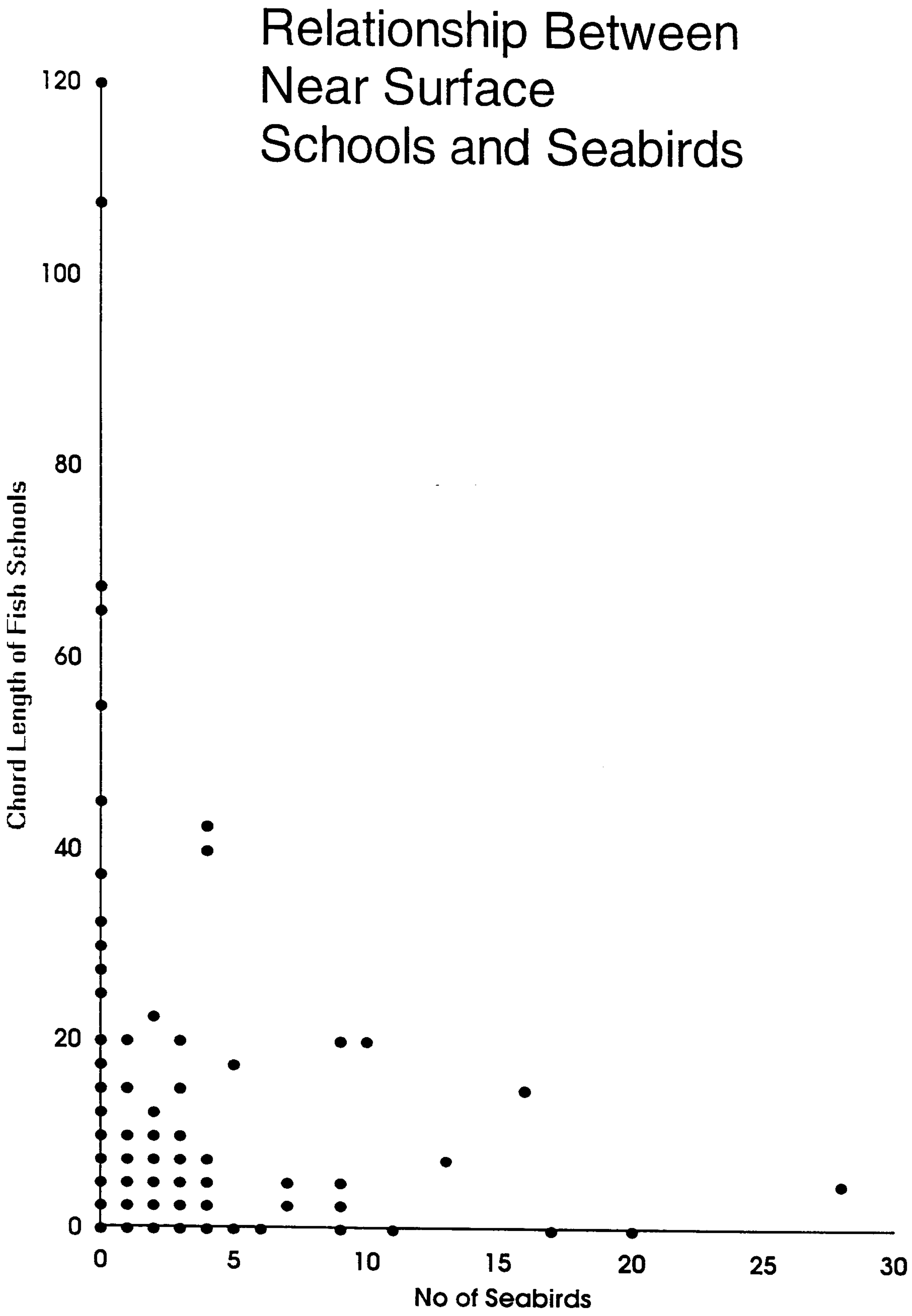
Fig. 5. The lack of correlation between piscivorous seabirds and fish schools observed during 10-min segments in side-looking hydroacoustics during the 1995 APEX cruise.

Relationship Between the No of Near Surface Schools and Seabirds



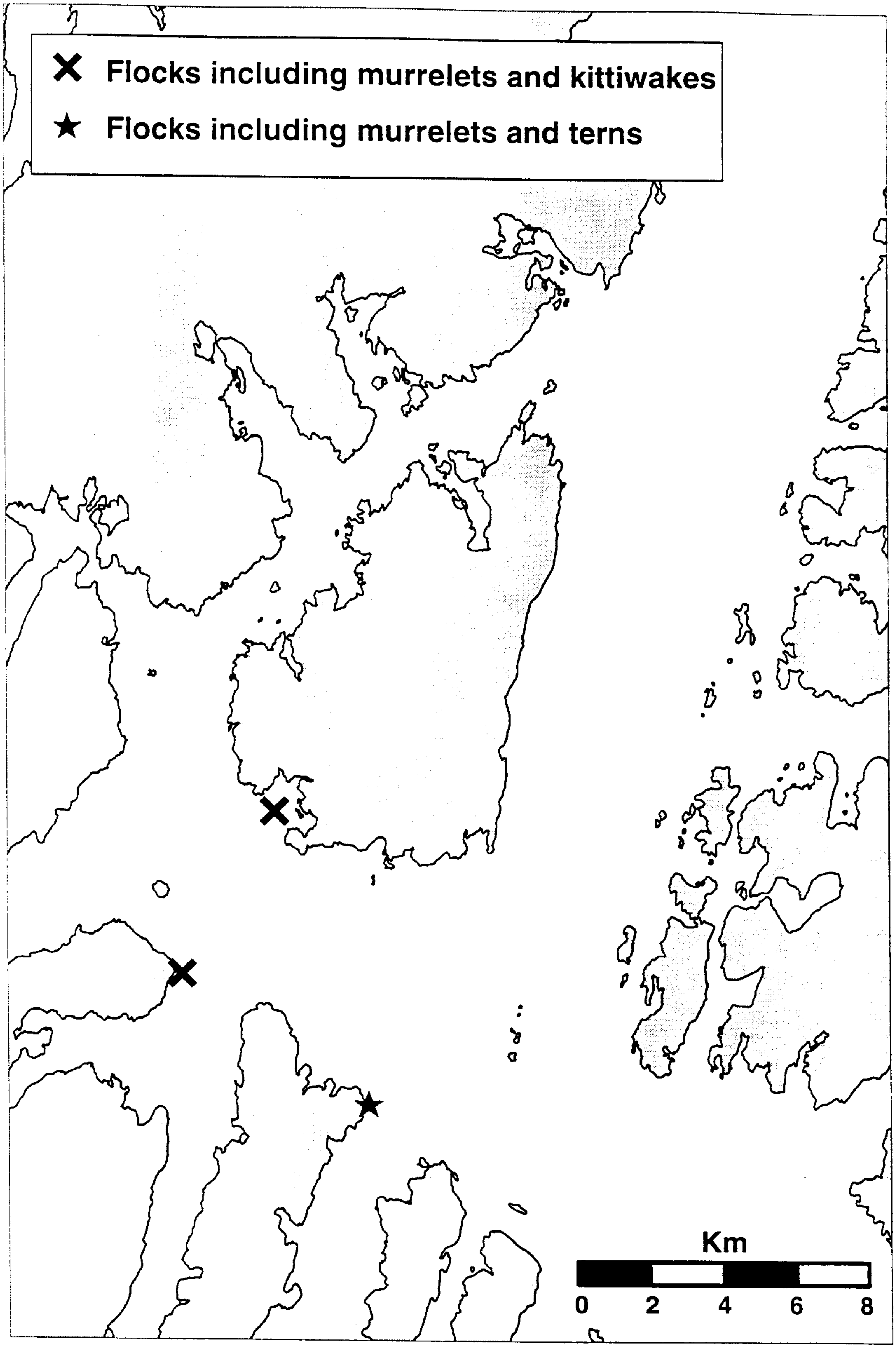
Appendix B-16

Fig. 6. The lack of correlation between piscivorous seabirds and total chord length of fish schools observed during 10-min segments in side-looking hydroacoustics during the 1995 APEX cruise.


Relationship Between Near Surface Schools and Seabirds
120
100
80
60
40
20
0
Chord Length of Fish Schools
0
5
10
15
20
25
30
No of Seabirds

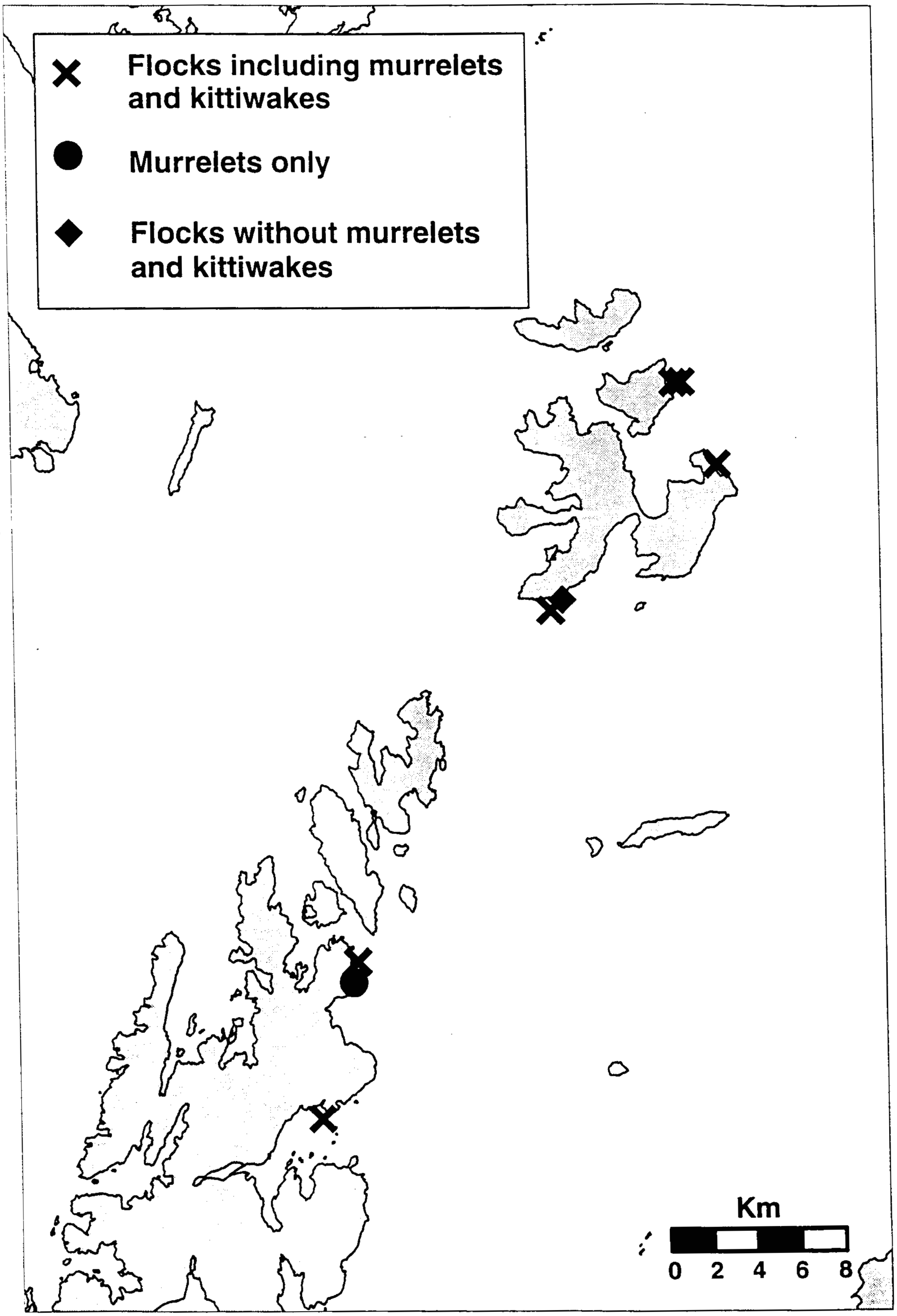
Appendix B-17

Fig. 7. Locations of foraging flocks observed in the Southwestern area during the 1995 APEX cruise.


✕ Flocks including murrelets and kittiwakes
★ Flocks including murrelets and terns
Km
0
2
4
6
8

Appendix B-18

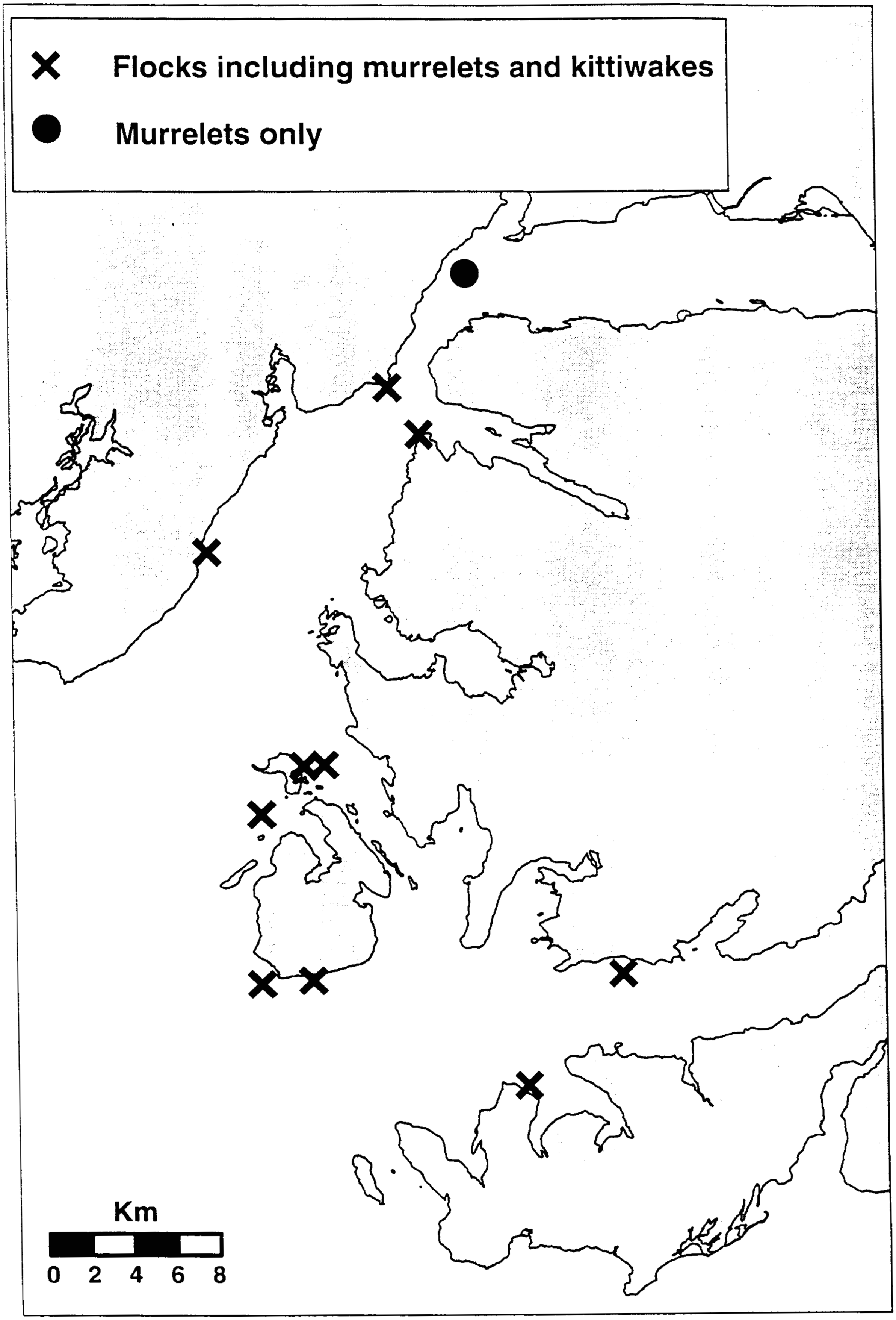
Fig. 8. Locations of foraging flocks observed in the Central area during the 1995 APEX cruise.



× Flocks including murrelets and kittiwakes
● Murrelets only
◆ Flocks without murrelets and kittiwakes
Km
0
2
4
6
8

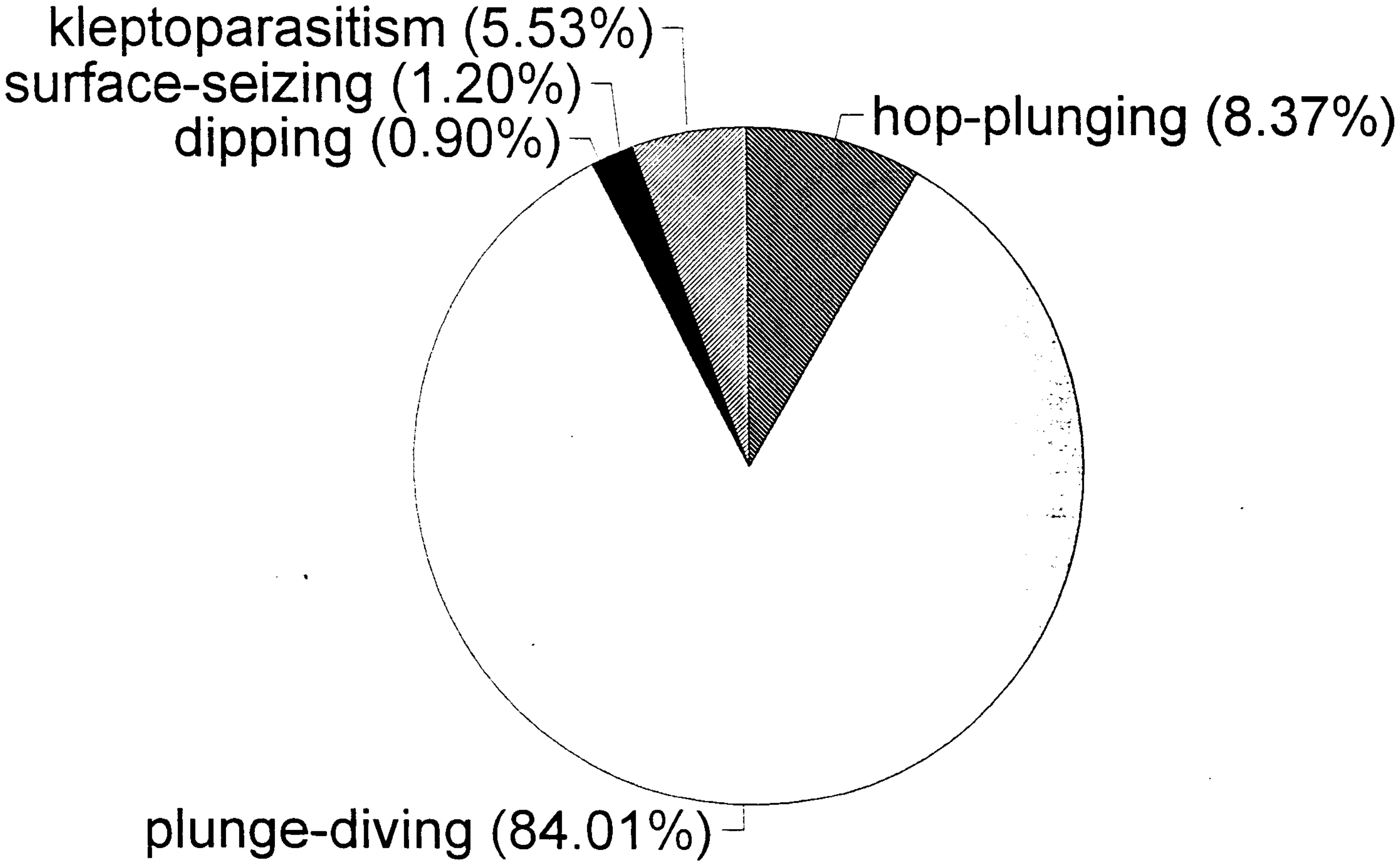
Appendix B-19

Fig. 9. Locations of foraging flocks observed in the Northeastern area during the 1995 APEX cruise.


✕ Flocks including murrelets and kittiwakes
● Murrelets only
Km
0 2 4 6 8

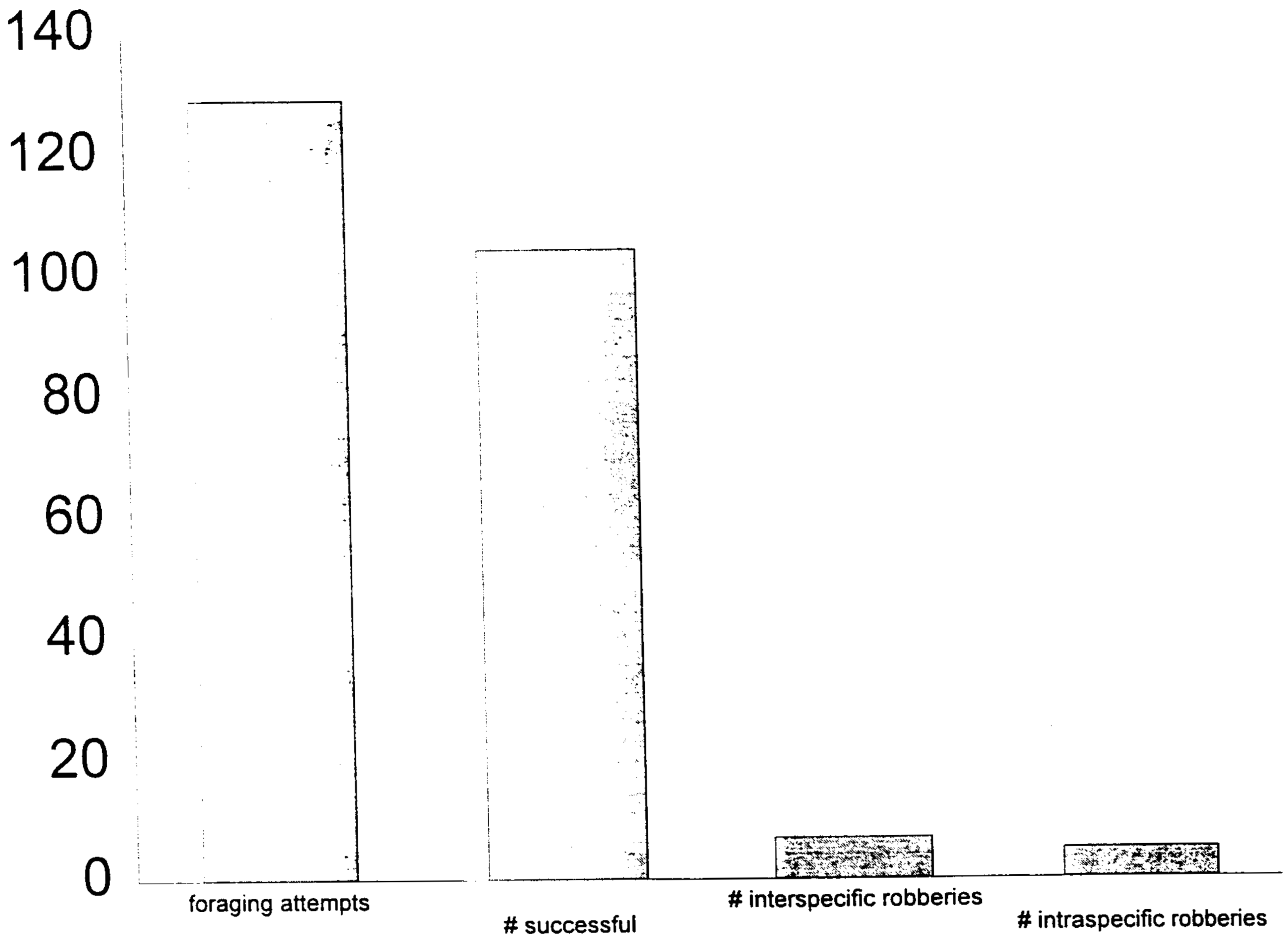
Appendix B-20

Fig. 10. Foraging methods used by black-legged kittiwakes in foraging flocks during the 1995 APEX cruise.


kleptoparasitism (5.53%)
surface-seizing (1.20%)
dipping (0.90%)
hop-plunging (8.37%)
plunge-diving (84.01%)

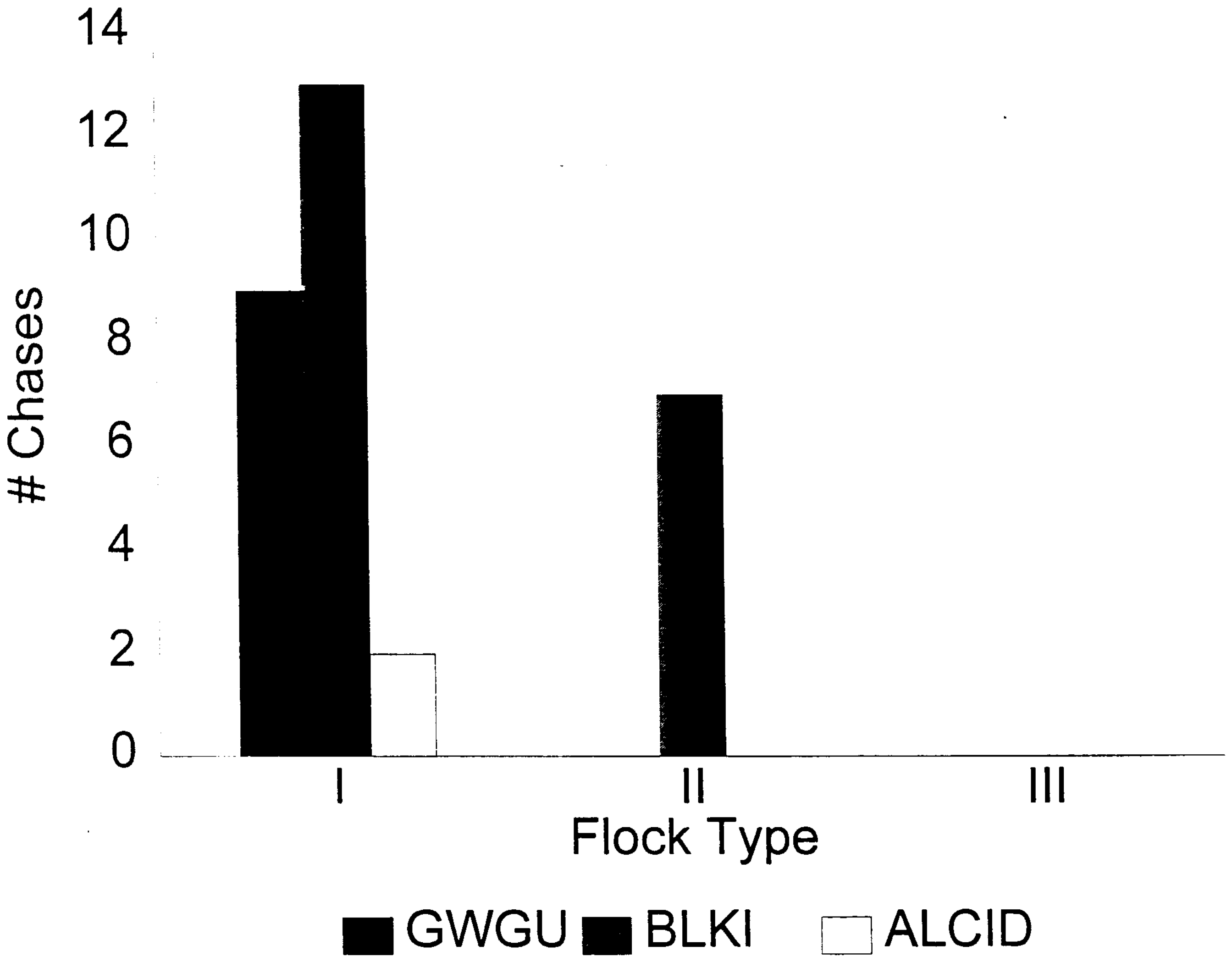
Appendix B-21

Fig. 11. Foraging attempts made by black-legged kittiwakes observed in foraging flocks and the number of successful kleptoparasitic attempts directed against them during the 1995 APEX cruise.


140
120
100
80
60
40
20
0
foraging attempts
successful
interspecific robberies
intraspecific robberies

Appendix B-22

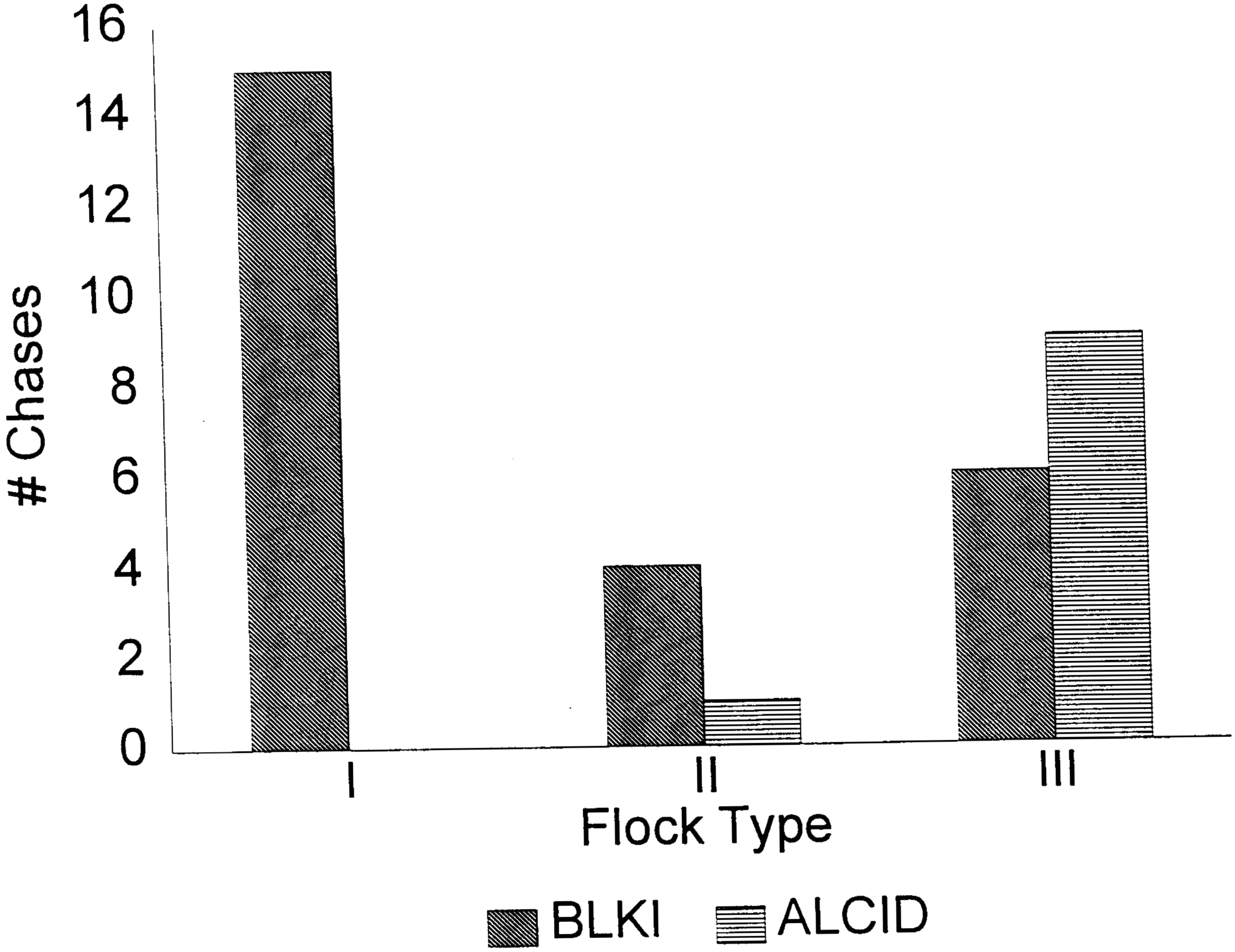
Fig. 12. Victims of kleptoparasitism by glaucous-winged gulls in foraging flocks during the 1995 APEX cruise.



Chases
14
12
10
8
6
4
2
0
I
II
III
Flock Type
GWGU
BLKI
ALCID

Appendix B-23

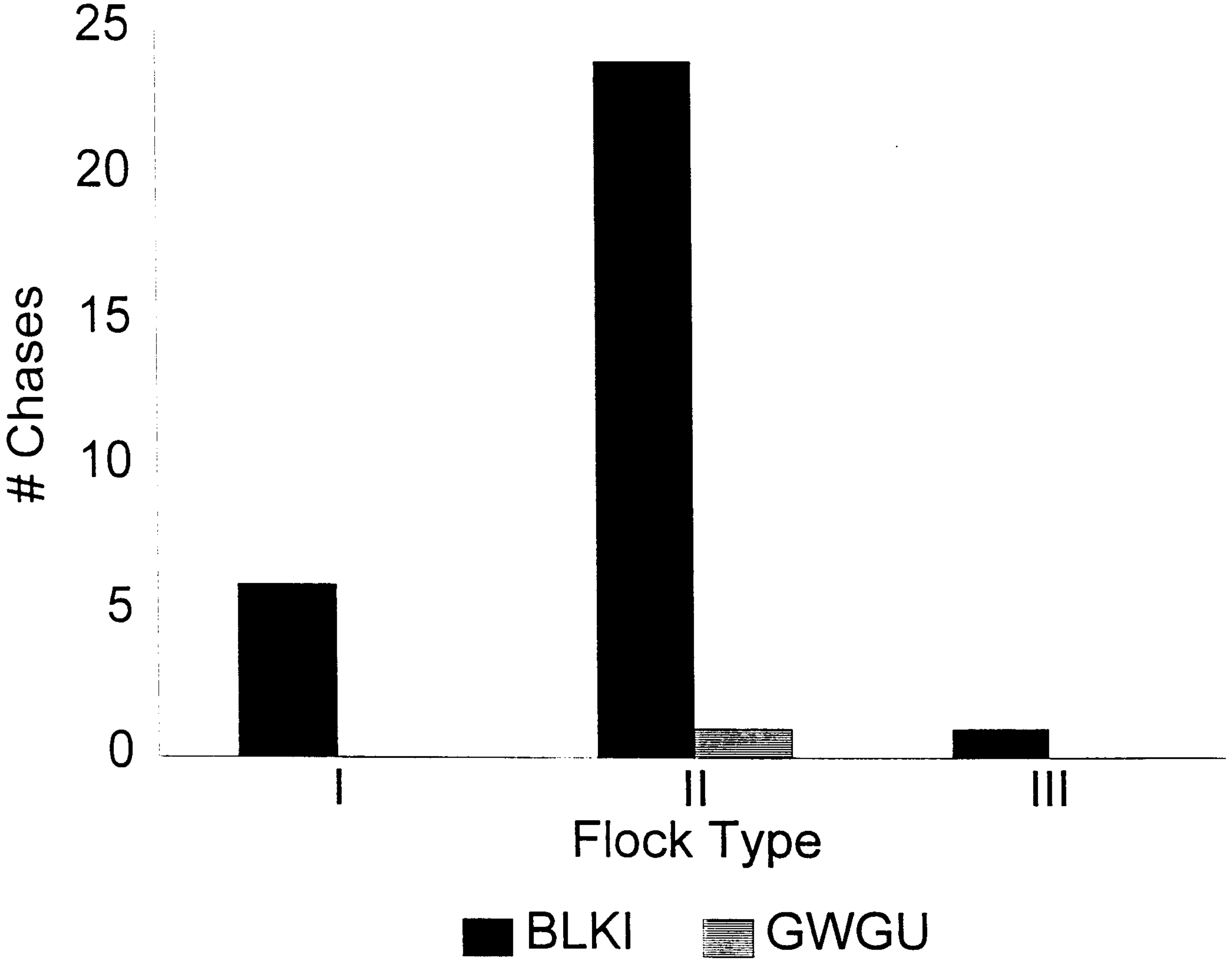
Fig. 13. Victims of kleptoparasitism by black-legged kittiwakes in foraging flocks during the 1995 APEX cruise.



16
14
12
10
8
6
4
2
0
Chases
I
II
III
Flock Type
▨ BLKI
▤ ALCID

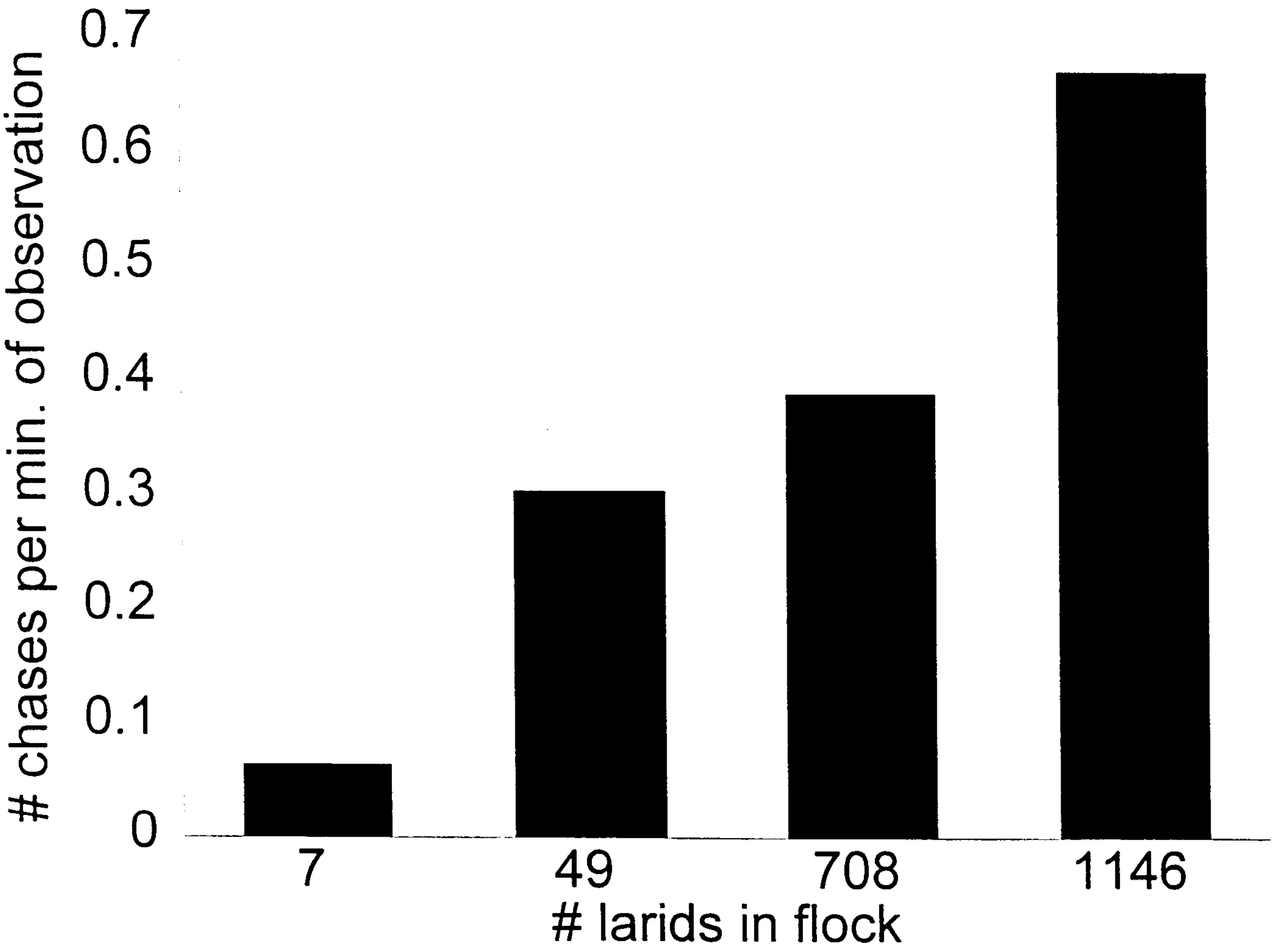
Appendix B-24

Fig. 14. Victims of kleptoparasitism by jaegers in foraging flocks during the 1995 APEX cruise.


25
20
15
10
5
0
Chases
I
II
III
Flock Type
BLKI
GWGU

Appendix B-25

Fig. 15. Number of attempted robberies by jaegers compared with numbers of larids present in the flocks with jaegers during the 1995 APEX cruise.



0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
chases per min. of observation
7
49
708
1146
larids in flock

APPENDIX C

APEX: 95163 C

Appendix C-1

APEX: 96163C

DIET OVERLAP OF FORAGE FISH SPECIES

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ABSTRACT

The food habits of forage fish collected by trawl in Prince William Sound for the Alaska Predator Ecosystem Study (APEX) were examined. The diet study is one of several components of APEX, which is examining trophic interactions of seabirds injured by the Exxon Valdez Oil Spill, (e.g., black-legged kittiwakes and pigeon gillemots), and their forage species. Forage fish diet samples were analyzed from the southern, central and northern regions of PWS from summer, 1995 (n = 80) and fall, 1994 (n = 90). Diets were described for multiple age-classes (as suggested by mean preserved fork lengths (FL)) of herring and pollock and for juvenile sandlance, capelin and eulachon.. Diet composition as percent biomass of pooled prey categories and diet overlap as Percent Similarity Index (PSI) calculated from biomass of prey taxa are presented in these preliminary results.

Most dietary biomass was contributed by few prey categories and differences were observed between seasons, species, age-classes, and areas. In summer, small calanoids were consumed by all except large pollock, forming 29-70% of young-of-the-year (YOY) species and 43% of older herring prey biomass. Hyperiid amphipods comprised 21-23% of YOY prey biomass, while teleosts and barnacle larvae were unique (20% biomass) in YOY pollock and sandlance, respectively. Large calanoids comprised approximately 45% of prey biomass of both older herring and older pollock, while euphausiids (24%) and chaetognaths (20%) were unique in older pollock diets. In the fall, euphausiids were consumed by all species, forming 30-81% of prey biomass. In contrast to summer diets, hyperiids and small calanoids contributed little to YOY fish diets; however, small calanoids remained in older herring diets (33-50% biomass). In southern PWS, YOY pollock diets differed by including 49% biomass from large calanoids and larvaceans combined. Most capelin and eulachon stomachs were empty.

Diet overlap ranged from approximately 32% to 59% PSI between YOY species pairs and for combinations involving herring in both spring and fall. Overlap was highest between pollock and herring collected in the same locations in northern PWS in the fall, and lowest for combinations involving older pollock in summer.

These results suggest that, although the prey resources responsible for the considerable dietary overlap observed change seasonally, competition for food could occur between several species and age classes of forage fish throughout the summer and fall.

Appendix C-2

INTRODUCTION

This report, Diet Overlap of Forage Fish Species, focuses on the trophic interactions of forage fish in Prince William Sound (PWS). The study is one component of the Alaska Predator Ecosystem Experiment (APEX), a multi-disciplinary, a multi-year study designed to examine the PWS food web and its effects on species injured by the *Exxon Valdez* Oil Spill (EVOS).

Investigations of the feeding ecology, distribution, abundance and availability of forage fish consumed by apex predators, the piscivorous marine birds and mammals of the sound, began with an FY94 pilot study, "Forage Fish Influence on Recovery of Injured Species." It was initiated because efforts to restore species injured by the EVOS oil spill, particularly harbor seals, pigeon guillemots, marbled murrelets, and black-legged kittiwakes, have been hampered by a lack of information about the biology and population dynamics of their prey resources, forage fish. Forage fish may include pelagic schooling species in the offshore region of PWS as well as demersal nearshore species. Potential prey in offshore assemblages include Pacific herring (*Clupea harengus pallasi*), Pacific sandlance (*Ammodytes hexapterus*), capelin (*Mallotus villosus*), northern smoothtongue (*Leuroglossus schmidti*), eulachon (*Thaleichthys pacificus*), walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), tomcod (*Microgadus proximus*) and juvenile salmon (*Oncorhynchus* spp.); potential prey in nearshore assemblages may include these and other species, such as Pacific snake pricklebacks (*Lumpenus sagitta*) and daubed shanny (*L. maculatus*).

The high sea bird mortalities associated with EVOS occurred during a period of decline in several sea bird populations (Piatt and Anderson, 1996). While the environmental conditions which contributed to these declines have not been explained, damage assessment studies since the spill have associated continuing sea bird declines with the availability of forage fish prey. Reproductive failures were documented among black-legged kittiwakes from oiled areas (Irons, 1996) and may be associated with food conditions. Greater declines of pigeon guillemots in oiled areas compared to non-oiled areas were associated with reduced deliveries of sandlance, a high energy prey, to their chicks (Oakley and Kuletz, 1996).

At the same time as the health of marine birds and mammals declined in PWS in the last few decades, unexplained, long-term shifts in the relative population abundances of prominent forage species, such as herring, pollock and sandlance, have occurred (Anderson et al., 1994). Enhancement facilities have simultaneously increased production of juvenile salmonids released into the sound. Factors controlling growth and survival of forage fish are not well understood. However, population changes could be reflected in trophic interactions if food availability limits the carrying capacity of PWS. Efforts to understand the ecosystem and estimate the carrying capacity of PWS are restricted by our limited knowledge about forage fish abundance and distribution, planktonic prey production and how prey resources are partitioned (Cooney 1993). Partitioning of prey resources reflects the degree of habitat and diet overlap between species, yet the food habits for many forage fish have not been completely described. This information is needed to characterize trophic niches, determine niche overlap and assess the potential for resource competition between species. Information on the trophic dynamics and environmental variables which determine the nutritional quality and relative availability of forage fish to apex predators is also sparse. The relative availability of high quality forage fish prey can influence the population dynamics of marine bird and mammals. Understanding the trophic interactions between forage fish species may help to explain variability in the food habits and reproductive biology of injured marine birds dependent on them.

"Diet Overlap of Forage Species" was conducted under the general APEX hypothesis that "planktivory is the factor determining abundance of the preferred forage species of seabirds."

Further hypotheses state that the diets of different forage fish species will be different. Evidence supporting the alternative hypothesis, that forage fish diets are similar, suggests that food competition is possible. This hypothesis is being tested by examining the food habits, diet overlap and prey selection of forage fish. Preliminary information about trophic interactions among forage species was reported in "Forage Fish Influence on Recovery of Injured Species: Forage Fish Diet Overlap" (SEA 94163C; Willette et. al, 1995). Analyses are not complete, but substantial diet overlap among forage species pairs was demonstrated for the late summer season. Juvenile herring-pollock and juvenile pink-chum salmon pairs both had relatively high diet overlap, but partitioned available prey resources; small copepods were the principal prey of juvenile herring and pollock, while fish larvae were the principal prey for juvenile salmon.

Collections of a particularly important forage species, sandlance, have been limited in PWS. Although analyses of PWS forage fish diets are not complete, some findings suggest that sandlance trophic interactions could impact several species. Larval sandlance and herring in Port Moller, Alaska shared a diet of various copepod life history stages (McGurk and Warburton, 1992). Willette et al (unpub. data) found that sandlance and pink salmon fry collected together in spring also shared a diet consisting primarily of small copepods, similar to independent observations on these species in other areas (e.g., Craig 1987; Sturdevant et al. 1996). In one net haul, sandlance stomachs contained approximately 10 times the biomass of the pteropod, Limacina helicina, and four times the biomass of small copepods as pink salmon in spring. Trophic interactions between sandlance and other forage species may occur over broad spatial and temporal scales, and this study reports on further investigations.

METHODS

Sample Collection

Samples were collected for "Diet Overlap of Forage Fish Species" during November, 1994 (Forage Fish Cruise 94-02), in July-August, 1995 (APEX Cruise 95-01) and October, 1995 (APEX Cruise 95-02) in conjunction with Project 95163A (Tables 1-3).

Forage fish catch was sorted, identified and enumerated, and size distribution data was obtained on board the vessels. Where possible, at least 10 randomly selected specimens per species/age class combination were designated for stomach analysis from each location sampled. Whole fish were fixed in 10% saltwater-buffered formalin. The abdomens of fish larger than 100 mm forklength (FL) were slit to allow formalin to penetrate the body cavity and fix stomach contents. Since specimens were required for several APEX project components, if hauls did not contain enough specimens of key species, stomach samples were later removed in the laboratory from fish frozen whole for other project needs.

Prey resource samples (two replicates) were collected whenever diet samples were successfully collected, except in the fall of 1994. If samples were limited to frozen fish for other needs, no plankton was collected. Zooplankton samples were collected with a ring-net (0.5 m diameter) towed vertically from the depth where fish were sampled to the surface. In summer, 1995, zooplankton were collected with a net having 303-micron mesh to standardize methods to those used by SEA in 1994. At the beginning of the cruise, samples were collected at three locations using nets having three different mesh sizes to compare prey resources sampled for the purpose of selecting the mesh most appropriate for representing prey used by the fish. In fall, 1995 zooplankton were collected with a net having 243-micron mesh to collect smaller organisms believed to be more representative of the diet. Replicate samples were preserved in 10% buffered formaldehyde solution in individual 500 ml sample bottles. In addition, macroinvertebrates collected in the 0.5 mm mesh cod end of the midwater trawl were preserved for Project 95163A;

this data is available to compare to prey resources utilized by the fish.

Laboratory Methods

Forage fish stomach samples and prey samples were analyzed at the NMFS Auke Bay Laboratory. Laboratory protocols were consistent with 1994 methods for SEA Project 94163C (Forage Fish Diet Overlap).

Fish Samples

Samples were fixed in 10% buffered formaldehyde for a minimum of six weeks to allow shrinkage to stabilize. They were then transferred to 50% isopropanol for preservation. for a minimum of 10 days before analysis. Ten specimens per species/age class were randomly selected for processing from each haul. Whole fish were blotted dry, weighed to the nearest 0.01 g and measured (standard fork length, FL) to the nearest 0.5 mm. Fish stomachs, including the region from the pharynx immediately behind the gills to the pylorus, were excised from the body cavity. The foregut was blotted dry and weighed full to an accuracy of 1.0 mg, the contents were removed, and the empty stomach blotted and weighed again. Total stomach contents wet weight was estimated by subtraction. Stomach fullness and prey digestion were visually assessed and semiquantitative index values recorded. Relative fullness was recorded as: 1=empty, 2= trace, 3=25%, 4=50%, 5=75%, 6=100% full, and 7=distended. The fullness code provides an index of the amount of food consumed relative to the fish's stomach size. The state of digestion was recorded as: 0=fresh, 1=partially digested, 2=mostly digested, 3=stomach empty. These codes provide indications of how recently the fish ate as well as general prey condition, which reflects the level of identification possible.

Prey items in the gut were completely teased apart, identified to the lowest possible taxonomic level and enumerated. Standard subsampling techniques were employed when stomachs were so large and/or full that counting every prey item was not practical. The protocol for subsampling stomach contents was developed during 1994 sample processing and is patterned after general methods (Kask and Sibert 1976). Prey identification efforts were concentrated on identifying copepods to examine prey selection by species, sex and life history stage and within large and small copepod size groups. Where possible, partially digested large copepods which could not be completely identified were distinguished as pristane-manufacturing species (*Neocalanus* spp., *Calanus* spp.) or non-pristane-manufacturing species (e.g.., *Metridia* spp., *Epilabidocera longipedata*). After samples have been processed, gut contents were saved in a labeled vial in 50% isopropanol.

Prey Resources

The composition of available prey resources will be estimated from laboratory analyses of ring net samples. A Hensen-stempel pipette and Folsom plankton splitter will be used to collect at least two random subsamples (1, 5, or 10 ml capacity) from each sample bottle after appropriate dilution. Samples will be diluted to achieve a minimum total count of 500 animals or 200 of the dominant taxon. Zooplankton and epibenthic invertebrates will be identified to the lowest practical taxon and enumerated in each subsample. Total biomass in each taxonomic group will be estimated by the product of average body blotted-dry weight and abundance. Literature values for average blotted-dry wet weight of each species or developmental stage will be used when available. When literature values are not available, mean blotted-dry wet weight will be determined by weighing a sample (ns 50) of intact specimens. The composition of available prey will be described by pooling the data from epibenthic and zooplankton samples standardized to a 1 m2 surface area.

Statistical Methods

Mean preserved fork lengths (FL) for each group of fish used in diet studies were calculated to distinguish between age/size groups. Larger herring and pollock referred to as "older" were not aged. Stomach fullness index was summarized as less than a trace contents, 25-50% full and more than 75% full. The cumulative percent number of fish in a group having each level of fullness was computed. Total stomach contents weight as a percentage of fish body weight was also computed.

For this preliminary report, overall food habits were summarized by pooling specific prey taxa identified into broad prey categories presented as percent total biomass (Figures 5 and 6). Analysis of the complete food habits data set will include prey comparisons based on prey numbers and frequency of occurrence in addition to prey biomass. The Percent Similarity Index (PSI) was used as a measure of diet overlap (Wieser, 1960; Boesch, 1977; Krebs 1989). The PSI is computed by summing the minimum percentage of all prey taxa shared between two species of forage fish :

$$PSI_{jk} = \min(p_{ij}, p_{ik}),$$

where p is the percentage of a given prey taxon in the pooled group of fish species j and k.

The PSI is a simple and conservative estimator of diet overlap, yet is based on the finest resolution identifications available. In addition to PSI as a measure of diet overlap, analyses in final reports will include other overlap measures (Krebs 1989), Principal Components and other multivariate analyses (Johnson and Wichern 1988; Digby and Kempton 1987), and prey selection indices which compare the numbers of taxa consumed by fish to the numbers available in plankton (Ivlev 1961; Krebs 1989; Manly 1986).

RESULTS

This preliminary report summarizes the food habits, prey biomass and diet overlap of forage fish species in several size classes from three areas of PWS in summer, 1995 and fall, 1994 (Figure 1; Tables 1 and 2). Preliminary results are based on prey biomass from all stomach samples available from fall, 1994 collections (n = 90) and a subset of stomach samples from approximately 300 fish collected for diet analyses in summer, 1995 (n = 80). Since the analysis was conducted, approximately 100 additional fish and half of the 70 zooplankton prey resource samples collected in summer, 1995 have been processed. None of the approximately 230 diet samples or 14 zooplankton samples collected in fall, 1995 have been analyzed (Table 3). No zooplankton data or prey selection information from any season is included. Stomach analysis of the remainder of priority samples from 1994 (Willette et al 1995) and 1995 (this report) is expected to be complete by summer, 1996.

Figure 1 shows the sample locations in southern, central and northern regions of PWS from which priority diet samples were analyzed. A complete list of species, samples, locations and other pertinent collection data is given in Tables 1-3 (see also Haldorson et al 1996). Priority samples analyzed from summer, 1995, included YOY pollock (56 mm FL) and adult, post-spawning male capelin (135 mm FL) from the central area and sandlance (90 mm FL), juvenile pollock (181 mm FL), and two age groups of herring (YOY at 76 mm FL and older juveniles at 143 mm FL) from the northern area of PWS. None of the fish analyzed from summer, 1995, sample collections were from southern PWS. The locations represented by the summer diet samples (8 hauls at 8 sites) include Port Fidalgo and Bligh Island in the northern region and Seal, Eleanor, northeast Knight and northwest Montague Islands in the central region. Samples were collected at various depths and times of day and none of the data presented comes from fish species collected in the same hauls (Table 1).

Samples analyzed from fall, 1994 included adult herring (215 mm FL) from the southwest area, two size classes of herring (YOY at 94 mm FL and older juveniles at 170 mm FL) and YOY pollock (105 mm FL) from the northern region, and YOY pollock (111 mm FL) and juvenile eulachon (84 mm FL) from the central region of PWS. None of the fish analyzed from fall, 1994, were from central PWS. The locations represented by the fall diet samples (7 hauls at 5 sites) include Port Gravina and Galena Bay in the northern region and Needles and Icy Bay in the southern region of PWS. Approximately half of the diet samples from trawl hauls in the fall were made in the day, half at night (Table 2). Most of the YOY herring and pollock analyzed from the fall were collected in the same hauls.

Fish used for diet studies were larger in the fall than in the summer. Mean preserved fork lengths (FL) of each species and size group are shown in Figure 2 along with sample sizes analyzed from each area. I assume from their discreet FL's that there were at least three age classes of herring and two of pollock. Comparisons between areas, seasons and size/age groups of fish will be more complete when all samples are analyzed.

Preliminary data suggests differences in the total amount of food consumed by forage fish in the two seasons and possibly between areas and size/age groups. Stomach fullness index and percent body weight for each species and size/age group of forage fish are shown in Figures 3 and 4, respectively. All herring size groups tended to have fuller stomachs in the summer than in the fall (Figure 3) and contents were a higher percentage of body weight (Figure 4). Age-0 herring also tended to have fuller stomachs (mean = 100% full) than older juvenile herring (mean = 50% full) in summer (Figures 3 and 4). Stomachs of all herring age/size groups in the fall, particularly the oldest, contained only trace contents. For pollock, in the summer, stomachs of both 0-age pllock from the central region and older pollock from the northern region were 50% full on average. In the fall, stomachs of 0-age pollock from the northern area were less full (mean = 25%) than those from the southern area (mean = 100% full). Less data is available for the other species represented. Sandlance from the single haul in the northern region in summer averaged 50% full. Adult male capelin from the central region in summer and juvenile eulachon from the northern region in the fall had virtually empty stomachs.

The prey taxa consumed by forage fish species in fall, 1994 and summer, 1995 are shown in Tables 4 and 5, respectively. The species, life history stages and sizes of prey taxa consumed were pooled into 15 taxonomic categories (Figures 5 and 6, pie diagrams. Analyses have not been conducted at the detailed levels of specific taxa and life history stages. Among the prominent categories, the identifiable hyperiid amphipods were primarily juvenile *Parathemisto* spp., euphausiids were primarily juvenile *Thyssanoessa* spp., and gastropods were mainly *Limacina helicina* and, occasionally, pteropods and juvenile snails. Large calanoids, however, were commonly a mixture of several species, including *Calanus pacificus* and *C. marshallae*, Metridia *okhotensis* and *M. pacifica*, *Epilabidocera longipedata* and *Euchaeta elongata*; *Neocalanus* spp. were not common at these times of year. Small calanoids were primarily *Pseudocalanus* and *Acartia* spp. Infrequently-occurring prey taxa, such as harpacticoid copepods, were included the "other" category for this report, but may be prominent dietary components in some forage species in other seasons.

Summer Food Habits

The food habits of all species and size classes of forage fish analyzed to date from summer, 1995 collections are depicted in Figure 5 as percent biomass by prey category. Pie diagrams are arranged to facilitate comparisons between multiple species in young-of-the-year or older size groups or single species in multiple size groups. Small calanoid copepods and hyperiid amphipods dominated the diets of YOY species in the northern and central areas of the sound in summer. Small calanoid copepods formed approximately 29% of prey biomass in YOY pollock, 46% in sandlance and 68% in herring. Hyperiid amphipods formed slightly more than 20% of each diet. Several other categories were present, notably about 20% fish larvae in the YOY pollock from the central area and 20% barnacle larvae in the sandlance collected nearshore by beach seine. Large calanoids were minor components of YOY fish diets.

Two size classes of herring were examined from the northern area of the sound in summer. A large percentage of the dietary biomass for both the YOY and older size class of herring was small calanoids (68% and 46%, respectively). Two size classes of pollock were examined from different areas of the sound in summer, a YOY group from the central area and older fish (181 mm FL) from the northern area. Data is not yet available for diet comparisons between age classes of pollock collected from the same area. Pollock of different sizes had only small percentages of prey biomass in common. The older pollock appeared to switch from small calanoids consumed by younger fish to larger, similar prey, with diets of approximately 45% large calanoids. While YOY pollock consumed small fish larvae (20%), older fish consumed consumed equal proportions of large calanoids (45%) and chaetognaths (16%).

The diet overlap in summer (Figure 6) is presented as a half matrix of PSI values (y-axis) for all possible paired comparisons, with each cell representing a species or size class combination. The right axis lists species representing each row and the x-axis lists the paired group. Combinations involving YOY herring in summer are all in the back row, but cells represented by other species combinations are scattered on the grid. The highest diet overlap values in summer involved combinations with YOY herring : YOY herring with YOY pollock, YOY herring with YOY sandlance, and YOY herring with older herring all had PSI values greater than 50%. Diet overlap for YOY pollock was generally lower, ranging from 22-38%, except for the 53% overlap with YOY herring. Sandlance diet overlapped most with other YOY fish, older herring diet overlapped by close to 50% with both YOY herring and with older pollock, and older pollock diet overlap was greatest, 46%, in combination with older herring.

Fall Food Habits

The food habits of all species and size classes of forage fish analyzed from fall, 1994 collections are depicted in Figure 7. In contrast to summer, euphausiids were the most common prey in fall diets of YOY fish. Euphausiids formed approximately 30% of prey biomass in YOY pollock from the south, 56% in YOY herring from the northern area, and 81% in YOY pollock from the northern area. Only small proportions of the prey categories common in the summer diets, hyperiids and small calanoids, were present in YOY fish in the fall. As in summer, YOYpollock from different areas in the fall consumed different prey, with the exception of euphausiids; large calanoids (19% biomass) and larvaceans (30% biomass) were consumed by pollock only in the southern area.

The three size classes of herring analyzed from fall collections all consumed substantial proportions of euphausiids, 33-57% of the dietary biomass. Small calanoids comprised 33-50% of the older herring's prey biomass in both the northern and southern areas, but were not prominent in diet of YOY herring from the northern sound (8% biomass). The thousands of minute invertebrate eggs in northern YOY herring diets (11% biomass) were probably calanoid eggs consumed during filter-feeding (see Batty et al 1986).

The diet overlap of forage fish in the fall is again presented as a half matrix of PSI values for all possible paired comparisons (Figure 8). The greatest diet overlap in fall again involved herring combinations: YOY herring and YOY pollock from the northern area, most of which were caught in the same 2 hauls, had 59% PSI. Diet overlap for other herring-pollock combinations was usually lower, approximately 35%. The herring size class combinations had overlap values of between 34 % and 52%, and was considerable even when the fish were collected in different areas of the sound. Young-of-the-year pollock from different areas of the sound, north and south, had only 32% overlap.

DISCUSSION

Seasonal, ontogenetic, spatial or temporal partitioning of prey resources may occur among forage fish species inhabiting the same area. A species preferred foraging habitat may change with changing hydrographic conditions and will reflect foraging behaviors that could also change ontogenetically. Species caught in the same area also may have foraged in different levels of the water column. This spatial segregation will be reflected by low dietary overlap. Niche overlap between age-1 herring and capelin, for example, was highest in the spring when both species foraged in the water column; after the water column stratified, herring switched to a surface foraging mode in response to a newly available prey assemblage (Coyle and Paul 1992). Niche overlap between the two species then decreased as capelin continued to feed in the water column. Such trophic shifts also suggest that species which are not competitors during one season or life history stage may become competitors at another time.

Species sharing the same habitat may also partition resources on a temporaral basis, for example by having different diurnal feeding rhythms. For example, juvenile herring are sometimes observed schooling in shallow water at the head of bays (personal observation, APEX 1995). In these conditions, juvenile herring may compete with sandlance or demersal nearshore species for epibenthic or brackish water prey, or perhaps partition resources by feeding at different tidal stages when the suite of available prey changes. Conversely, herring located in pelagic waters offshore may compete with juvenile pollock for planktonic copepod prey.

Sandlance is an important forage species with the potential for food competition with several other species because of its diel behavioral pattern. Pacific sandlance perform a daily migration between feeding grounds, schooling sites and benthic refuge areas in soft substrates, primarily feeding during daylight (Hobson 1986). This transient behavior and the sandlance's attraction to light (Hobson 1986) suggests that sandlance could feed from both epibenthic and pelagic production systems, intermixing with both schooling and demersal fish species at various times during a 24-hour cycle. Calanoid copepods are commonly reported as the majority of prey weight found in the stomachs of several species of sandlance (e.g., Meyer et al 1979; Craig 1987; Field 1988). Meyer et al. observed that American sand lance (*A. americanus*) feed in schools between midwater and the surface, not on the bottom. Pacific sandlance (*A. hexapterus*), however, consumed a variety of prey taxa, with epibenthic taxa more common in diets during fall and winter (Field 1988). Similarly, epibenthic harpacticoid copepods are commonly observed along with other prey in the stomach contents of sandlance in PWS (Sturdevant, unpub. data; Willette et al. 1995). Diet overlap based on numbers of epibenthic prey is likely to be high between sandlance, tomcod (*Microgadus proximus*) and juvenile salmon (*O. gorbuscha* and *O. keta*), the forage species whose stomach contents commonly contained high numbers, but usually low biomass, of these small epibenthic prey (Sturdevant, unpub. data; Sturdevant et al. 1996; Willette 1996).

Information on seasonal changes in diet overlap and food competition among forage species is limited. Craig (1987) observed seasonal changes in the principal dietary components (% biomass) of YOY sandlance on the north Aleutian shelf. Copepods predominated in summer (90%), euphausiids predominated in winter (100%), and a mixture of the two taxa predominated in spring (26% copepods and 40% euphausiids). Although seasonal data were not available for the herring from his study, their diets overlapped with sandlance in summer; the predominant prey of both large (28.2 cm) and small (91 mm) herring in summer were copepods, crustacean larvae, and chaetognaths. Hobson (1986), Field (1988) and McGurk and Warburton (1992) also noted the co-occurrence and similarity in diets of Pacific herring and sandlance during several life stages.

These observations are similar to our preliminary data from APEX collections in the summer of 1995. We found high diet overlap between sandlance and two size classes of herring, largely based on small copepods (Figures 5 and 6). Likewise, we observed high biomass proportions of euphausiids in the diets of both herring and pollock in November (Figure 7), when sandlance were not caught. Euphausiids predominated in sandlance winter diet on the Aleutian shelf (Craig 1987). The best available seasonal data from PWS studies will be provided by our 1994 Forage Fish diet data set (Willette et al 1995). The report (in progress) will cover seasonal diet overlap of forage species from April -September. We do not yet have data to determine if these species diets overlap with sandlance in winter, when food resources are probably at their annual minimum; we have unanalyzed diet samples from the SEA cruise conducted in March, 1996, however.

Although "copepods" are commonly reported in fish diets, specific identifications of the prey are not always made and can be important. *Epilabidocera longipedata,* a surface swarming copepod species (Johnson, 1934), and *Metridia ohkotensis* and *M. pacifica*, diel vertical migrators (Hattori 1989) were consumed by herring and other forage species (Willette et al, unpub. data). The presence of these very different prey organisms in the same spring diets indicates that trophic interactions could occur at several depths in the water column or that oceanographic processes play a large role in determining which prey are available and whether partitioning occurs. The results from analysis of seasonal diet data may also depend on detailed species identifications.

While the APEX project focused on the summer nesting period of marine birds, a complete understanding of the influence of their forage species trophic niche must take into account the fish's entire life history and environment. Ideally, trophic studies should examine seasonal relationships over a broad area, include as many stages of the life history as possible, investigate diel feeding rhythms and behavior, and assess the dynamics of prey resources. These factors may contribute to an explanation of how co-occurring species partition resources and each sustain healthy populations. Competition among species can be inferred from an observed shift in resource use, such as absence from preferred habitat or failure to use a preferred a prey resource (Sogard 1994); the shift is then reflected in some measure of health, such as poor condition or small size. Ultimately, survival may be affected and populations reduced. While a complete investigation of all of these factors is outside the scope of the APEX forage fish diet study, some aspects can be addressed in the 1996 field study.

During the nearshore work scheduled for the 1996 APEX field season, it is likely that a number of additional nearshore benthic and demersal forage species exhibiting substantial diet overlap with sandlance will be collected. Information from APEX and SEA studies of oceanographic processes and fish dynamics will be important for understanding the food observations. Seasonal and tidal oceanographic processes that affect zooplankton and epibenthic prey abundance and distribution could impact trophic interactions (Field 1988; Hobson 1986). Our observation that both same-age classes (fall) and different age classes (summer) of pollock from different areas of PWS had different diets, for example, suggests that the spatial availability of prey in geographic areas may be one factor affecting the amount of diet overlap observed. A number of behaviors could also influence the degree of overlap in diets. Seasonal and/or diel differences in both horizontal and vertical distribution of the fish (and prey) are likely to affect both observations of fullness and prey selection (see Haldorson 1995; Haldorson et al 1996). The prey available may also affect the relative fullness of stomachs, if different size prey are available in different areas. Simultaneous collections of prey samples will be important to determine whether fish are selecting prey from the resources available where they are caught. Furthermore, because mouth gape increases with fish growth, seasonal differences in prey selection from taxa present year round, such as euphausiids, may be a reflection of both fish distribution and their ability to select larger prey specimens. Other aspects of particular species' biology are also important, such as the habit of capelin to stop feeding during the spawning period, which had likely taken place shortly before our summer sampling period.

Systematic collection of diet samples over the diel period will enable us to determine if the preliminary observations of seasonal differences in stomach fullness and the empty stomachs of juvenile eulachon (this report) can actually be attributed to differences in the time of day fish were collected. In addition, the degree of dietary overlap observed among co-occurring species may be explained by other trophic interactions, such as shifts in habitat use like those documented for juvenile cod avoiding predation (sensu Gotceitas et al 1995). A clearer understanding of diel feeding behavior and activity patterns of sandlance and other forage species will be important to explain the simlilarities and differences observed.

SUMMARY AND CONCLUSIONS

Summer diets are of forage fish were primarily small calanoids and hyperiids in the YOY groups, both small and large calanoids in older herring, and large calanoids, euphausiids and chaetognaths in older pollock. No data is shown for capelin because most of them had empty stomachs. Fall diets of all species and age groups included large proportions of euphausiid biomass. Only the older herring consumed substantial proportions of small calanoids, and YOY pollock diets differed between areas of the sound. Eulachon had empty stomachs in the fall. High diet overlap was observed in summer between YOY fish, between herring size classes, and between different species of older fish, the herring and pollock. Similarly, diet overlap in the fall was greatest between YOY herring and YOY pollock and between different size classes of herring.

Preliminary conclusions from this analysis of summer and fall forage fish diets are: 1) that diet overlap is substantial across summer and fall; 2) that the diet composition of forage fish species changes seasonally; and 3) this high diet overlap suggests that competion for food could occur between multiple species and size classes of forage fish and could particularly affect herring condition. While some preliminary information about trophic interactions among forage species has been gained from APEX and its predecessor, efforts in future years will include directed sampling to better address competition. The 1996 forage fish diet component of APEX is designed to examine prey composition and selection, interspecific diet overlap, diel feeding periodicity and potential food competition among forage fish species in PWS. Information obtained from this study will contribute further to an understanding of the mechanisms affecting population and trophic dynamics of forage fish and their availability to apex predators.

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Table 1. Forage fish diet samples collected during the summer, 1995, cruise APEX 95-01 (July 20-August 12, 1995) aboard the F/V Caravelle. Priority samples were processed and data are summarized for this report. Priority: Y = yes, N = no; Area: C = Central, NE = Northeast, SW = Southwest; Gear: T = midwater trawl, M = methot trawl, B= beach seine, D = dipnet, R = pair trawl.

Species	No.	Priority	Area	Location	Station	Haul	Gear	Date	Time	Notes	Plankton#	Depth (m)
Prowfish	1	N	C	NE Montague	1	2	T	07/21/95	16:40:00	-0-	NONE	60
Pink Salmon	27	N	C	NE Montague	1	2	T	07/21/95	16:40:00	-0-	NONE	60
Sculpin	1	N	C	NW Montague	3	1	T	07/22/95	12:23:00	-0-	003P/004P	60
Prowfish	1	N	C	NW Montague	3	1	T	07/22/95	12:23:00	-0-	003P/004P	60
Pink Salmon	1	N	C	NW Montague	3	1	T	07/22/95	12:23:00	-0-	003P/004P	60
Pollock	12	N	C	NW Montague	3	1	T	07/22/95	12:23:00	-0-	003P/004P	60
Pollock	3	N	C	Manning Rocks	4	1	T	07/22/95	-0-	FROZEN	-0-	-0-
Pollock	31	N	C	NW Seal Island	5	2	T	07/22/95	-0-	FROZEN	-0-	-0-
Pollock	3	N	C	East of NE Knight Island	6	2	T	07/23/95	-0-	FROZEN	-0-	-0-
Pink Salmon	1	N	C	SW of Naked Island	11	1	T	07/24/9	10:15:00	-0-	009P/010P	8

Chum Salmon	1	N	C	SW of Naked Island	11	1	T	07/24/95	10:15:00	-0-	009P/010P	8
P. Sandfish	1	N	C	SW of Naked Island	11	1	T	07/24/95	10:15:00	-0-	009P/010P	8
Sculpin	1	N	C	SW of Naked Island	11	1	T	07/24/95	10:15:00	-0-	009P/010P	8
Sandlance	1	N	C	SW of Naked Island	11	2	T	07/24/95	10:53:00	-0-	009P/010P	15
Prowfish	1	N	C	SW of Naked Island	11	2	T	07/24/95	10:53:00	-0-	009P/010P	15
Prowfish	1	N	C	SW tip of Naked Island	11	3	M	07/24/95	11:44:00	-0-	009P/010P	1
Pollock	12	N	C	E. Liljegren Pass	19	1	T	07/25/95	15:37:00	-0-	NONE	50
Prowfish	1	N	C	N. of Montague Pt.	53	1	T	08/01/95	09:17:00	PLANKTON 20 M & 60 M	021P-024P	60
Pollock	12	N	C	N. OF Montague Pt.	53	1	T	08/01/95	0 9:17:00	1 PINK, 1 Capelin FROZEN	021P-024P	60
Pollock	15	N	C	N. of Montague	54	2	T	08/01/95	12:14:00	PLANKTON 20M & 60M	025P-028P	60
Pollock	12	Y	C	Seal Island	56	1	T	08/01/95	15:27:00	PLANKTON 20 M & 80 M	029P-032P	80
Pollock	15	N	C	Seal Island	57	2	T	08/01/95	17:30:00	PLANKTON 20 M & 80 M	033P-036P	80
Pollock	14	Y	C	N. Knight Island	58	2	T	08/02/95	9:25:00	PLANKTON 20 M & 80 M	037P-040P	80
Pollock	12	Y	C	Eleanor Island	62	2	T	08/02/95	15:16:00	PLANKTON 20 M & 60 M	041P-044P	60

Herring		N	C	Eleanor Island	63	1	B	08/02/95	-0-	*4 HERRING, 2 SL FROZEN	-0-	1
Eulachon		N	C	S. Naked Island	65	1	R	08/03/95	-0-	*2 EULACHON FROZEN	-0-	-0-
Capelin	12	N	C	S. tip Naked Island	65	1	R	08/03/95	10:45:00	-0-	NONE	-0-
Pink Salmon	12	N	C	Eleanor Passage	66	2	T	08/03/95	14:49:00	NO PLANKTON #045	046P/047P	8
Prowfish	1	N	C	Eleanor Passage	66	2	T	08/03/95	14:49:00	NO PLANKTON #045P	046P/047P	8
Pink Salmon		N	C	E. of Peak Island	67	1	T	08/03/95	-0-	*1 PINK & LARVAE FROZ EN	-0-	-0
Pollock		N	C	E. of Liljegren Passage	72	1	T	08/04/95	-0-	*1 POLLOCK, 1 COHO & LARVAE FROZEN	-0-	-0-
Pollock		N	C	E. of Liljegren Passage	73	1	T	08/04/95	-0-	*130 POLLOCK, LARVAE, SCULPINS FROZEN	-0-	-0-
Capelin		N	C	E. of Storey Island	94	1	T	08/07/95	-0-	*2 CAPELIN FROZEN	-0-	-0-
Pollock		N	C	N. Hogan Bay	108	1	T	08/08/95	-0-	*22 POLL., 6 CAPELIN, 4 HER. FROZEN	-0-	-0-
Pollock		N	C	E. Discovery Pt. (Snug)	109	1	T	0 08/09/95	-0-	*1 POLL., 1 CAPELIN, 2 LINGCOD FROZEN	-0-	-0-
Herring		N	C	SE Eleanor Island	110	1	B	08/09/95	-0-	*LARVAL HERRING, 1 LINGCOD. GREENLING FROZEN	-0-	-0-
Pollock	12	N	C	S. of Naked Island	112	1	T	08 10/95	13:13:00	PLANKTON 20 M & 80 M	063P-066P	80
Prowfish	1	N	C	S. of Naked Island	112	1	T	08 10/95	13:13:00	PLANKTON 20 M & 80 M	063P-066P	80
Pollock		N	C	E. Naked Island	113	1	T	08 10/95	-0-	*2 POLLOCK FROZEN	-0-	-0-

Capelin	12	Y	C	NW Montague Island	114	1	T	08/10/9	-0-	*16 CAPELIN FROZEN	-0-	-0-
Capelin	12	Y	C	NW Montague Island	114	7	T	08/10/95	20:38:00	*1 POLLOCK FROZEN; PLANKTON DEPTH 20 M	067P-068P	15
Pollock		N	C	NE Montague Pt.	117	1	D	08/10/95	-0-	*1 POLLOCK 1 CAPELIN, 12 STICKLEBACK FROZE	-0-	-0-
Sandlance	151	N	C	Cabin Bay	99	1	B	08/16/95	-0-	Lyndsey's group catch	-0-	-0-
Herring	12	Y	NE	S. of Bligh Island	22	2	T	07/26/95	11:07:00	-0-	015P/016P	20
Prowfish	1	N	NE	S. of Bligh Island	22	2	T	07/26/95	11:07:00	-0-	015P/016P	20
Crested Sculpin	2	N	NE	S. of Bligh Island	22	2	T	07/26/95	11:07:00	-0-	015P/016P	20
Crested Sculpin	3	N	NE	S. of Bligh Island	26	1	T	07/26/95	18:10:00	-0-	NONE	10
Prowfish	1	N	NE	S. of Graveyard, Fidalgo	26	1	T	07/26/95	18:10:00	-0-	NONE	10
Herring	14	Y	NE	S. Graveyard, Fidalgo	27	1	D	07/26/95	19:30:00	-0-	NONE	-0-
Pollock		N	NE	SE of Bligh Island	28	1	T	07/27/95	-0-	*4 pollock frozen	-0-	-0-
Pollock	6	N	NE	W of Bligh Reef	29	1	T	07/27/95	10:57:00	20 & 80 M PLANKTON	017P-020P	80
Crested Sculpin	1	N	NE	Outer Galena Bay	3	51	T	07/28/95	8:45:00	* LARVAE & CRESTED SCULPIN FROZEN	NONE	110
Pollock	12	Y	NE	E. Graveyard, Fidalgo	82	1	T	08/05/95	14:25:00	PLANK. 20M&8OM *ALSO FROZEN LARVAE	051P-054P	100
Crested Sculpin	3	N	NE	S. Bligh Island	84	1	T	08/05/95	17:29:00	105, 243, 303 micron mesh plankton hauls	055P-057P	15
Prowfish	2	N	NE	S. Bligh Island	84	1	T	08/05/95	17:29:00	105, 243, 303 micron mesh plankton hauls	055P-057P	15
Prowfish	1	N	NE	S. Bligh Island	84	1	T	08/05/95	17:29:00	105, 243, 303 micron mesh plankton hauls	055P-057P	15

Fish Larvae		N	NE	Outer Galena Bay	93	2	T	08/07/95		*LARVAL FISH FROZEN	-0-	-0-
Pollock		N	NE	Outer Galena Bay	93	3	T	08/07/95		*LARVAE, LG. POLLOCK, & EULACHON FROZEN	-0-	-0-
Herring	13	N	NE	Port Gravina	116	1	T	08/11/95	12:10:00	PLANKTON 20 M	069P-070P	30
Prowfish	1	N	NE	Port Gravina	116	1	T	08/11/95	12:10:00	PLANKTON 20 M	069P-070P	30
Sandlance	12	Y	NE	Outer Port Gravina	118	1	B	08/11/95	15:30:00	*ALSO 10 HERRING 1 STICKLEB FROZEN	-0-	-0-
Herring		N	SW	Whale Bay (Dual Hd.)	43	1	T	07/30/95	-0-	*HERRING FROZEN	-0-	-0-
Fish Larvae		N	SW	Whale Bay (Dual Hd.)	43	1	T	07/30/95	-0-	*LARVAE FROZEN	-0-	-0-
Fish Larvae		N	SW	NE Pt. Countess	47	1	T	07/30/95	-0-	*LARVAE FROZEN	-0-	-0-
Pollock		N	SW	NE Pt. Countess	50	1	T	07/31/95	-0-	*8 YOY POLLOCK FROZEN	-0-	-0-
Fish Larvae		N	SW	NE Pt. Countess	50	1	T	07/31/95	-0-	*LARVAL FISH FROZEN	-0-	-0-
Fish Larvae		N	SW	NE Pt. Countess	50	2	T	07/31/95	-0-	*LARVAL FISH FROZEN	-0-	-0-
Herring		N	SW	NE Pt. Countess	50	2	T	07/31/95	-0-	*1 HERRING FROZEN	-0-	-0-
Unid. Greenling	4	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Daubed Shanny	4	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Tomcod	8	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Crested Gunnel	2	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Kelp Greenling	5	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Unidentif. Fish	3	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Lingcod	2	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6
Wh. Greenling	6	N	SW	Pt. Countess	51	1	B	07/31/95	11:30:00	*8 FROZEN POLLOCK	NONE	6

Prowfish	1	N	SW	E. Whale Bay (Dual H.)	100	2	T	08/08/95	13:20:00	* 1 HERRING FROZEN	NONE	10
Prowfish	1	N	SW	SO. OF PT.HELEN	107	2	T	08/08/95	20:16:00	PLANKTON 20 M	061P-062P	20
Herring	10	N	SW	SO. OF PT.HELEN	107	2	T	08/08/95	20:16:00	PLANKTON 20 M	061P-062P	20

Table 2. Forage fish diet samples collected by trawl (T)in Prince William Sound during the fall, 1994, cruise FOR94-02 (November 7-13, 1994) aboard the R/V Medeia. All samples have been processed and data are summarized in this report. No zooplankton was collected.

Species	No.	Area	Location	Station	Haul	Gear	Date	Time	Depth (m)
Herring	10	NE	INNER GALENA BAY	6	1	T	11/10/94	22:42:00	20
Pollock	10	NE	INNER GALENA BAY	6	1	T	11/10/94	22:42:00	20
Pollock	15	NE	MOUTH OF PORT GRAVINA	7	4	T	11/12/94	22:32:00	21
Herring	14	NE	MOUTH OF PORT GRAVINA	7	4	T	11/12/94	22:30:00	21
Eulachon	10	NE	MOUTH OF PORT GRAVINA	7	5	T	11/12/94	23:25:00	80
Herring	10	NE	MOUTH OF PORT GRAVINA	8	2	T	11/13/94	15:10:00	36
Herring	12	NE	MOUTH OF PORT GRAVINA	8	3	T	11/13/94	16:15:00	35
Herring	12	SW	NEEDLES	3	1	T	11/07/94	13:25:00	95
Pollock	12	SW	ICY BAY	5	5	T	11/08/94	15:32:00	50

Table 3. Forage fish diet samples collected during the fall, 1995, cruise APEX 95-02 (October 5-14, 1995) aboard the R/V Medeia.
No samples have been processed to date. Area: C = Central, NE = Northeast, SW = Southwest; Gear: T = midwater trawl, M = methot trawl, B= beach seine, D = dipnet, R = pair trawl.

Species	No.	Area	Location	Station	Haul	Gear	Date	Time	Notes	Plankton#	Depth (m)
Fish Larvae	0	C	APPLEGATE-KNIGHT IS.	1	1	N	10/09/95	12:20:00	LARVAE	NONE	
Fish Larvae	0	C	APPLEGATE-KNIGHT IS.	1	2	N	10/09/95	12:56:00	LARVAE	NONE	
Fish Larvae	2	C	NW OF APPLEGATE ROCKS	1	3	T	10/09/95	15:20:00	LARVAE	NONE	
Snailfish	2	C	NW OF APPLEGATE ROCKS	1	3	T	10/09/95	15:20:00	*FROZEN HERRING & POLLOCK	NONE	
Pollock	20	C	APPLEGATE ROCKS	3	1	T	10/11/95	21:00:00	*YOY POLLOCK	003P/004P;	100M
Fish Larvae	20	C	APPLEGATE ROCKS	3	2	T	10/11/95	22:00:00	* LARVAE; 1 SQUID	003P/004P;	100M
Pollock	12	C	APPLEGATE ROCKS	3	2	T	10/11/95	22:00:00	*LARGE POLLOCK	003P/004P;	100M
Pollock	12	C	SMITH ISLAND	4	3	T	10/12/95	21:50:00	*FROZEN YOY POLLOCK	005P/006P;	75M
Snailfish	1	C	SMITH ISLAND	4	3	T	10/12/95	21:50:00	SNAILFISH	005P/006P;	75M
Lanternfish	1	C	SMITH ISLAND	4	3	T	10/12/95	21:50:00	MYCTOPHID	005P/006P;	75M
Fish Larvae	0	C	SMITH ISLAND	4	3	T	10/12/95	21:50:00	LARVAE, 1 SQUID	005P/006P;	75M
Herring	22	C	EAST NAKED ISLAND (3FNZ4S)	5	1	T	10/13/95	11:30:00	YOY HERRING	007P/008P;	80M
Pollock	21	NE	GALENA BAY (OUTER, SOUTH)	6	1	T	10/13/95	21:42:00	YOY POLLOCK	009P/010P;	50M
Prowfish	1	NE	GALENA BAY (OUTER SOUTH)	6	1	T	10/13/95	21:42:00	1 SQUID ALSO	009P/010P;	50M
Herring	21	NE	GALENA BAY (OUTER SOUTH)	6	1	T	10/13/95	21:42:00	YOY HERRING	009P/010P;	80M
Pollock	21	NE	LANDLOCKED BAY-FIDALGO;15M	7	1	T	10/14/95	21:58:00	-0-	011P/012P;	25M
Prowfish	1	NE	LANDLOCKED BAY-FIDALGO; 15M	7	1	T	10/14/95	21:58:00	PROWFISH	011P/012P;	25M
Herring	21	NE	LANDLOCKED BAY-FIDALGO; 15M	7	1	T	10/14/95	21:58:00	HERRING	011P/012P;	25M
Pollock	21	NE	LANDLOCKED BAY-FIDALGO; 60M	7	2	T	10/14/95	23:20:00	* FROZEN SMELT &. POLLOCK	013P/014P;	100M
Fish Larvae	11	NE	GOOSE IS.-GRAVINA	8	1	N	10/15/95	10:42:00	LARVAE	013P/014P;	100M
Pollock	15	SW	WHALE BAY	2	1	T	10/10/95	19:40:00	YOY POLLOCK	001P/002P;	75M
Pollock	13	SW	WHALE BAY	2	1	T	10/10/95	19:40:00	* FROZEN HERRING & LARVAE	001P/002P;	75M
Snailfish	1	SW	WHALE BAY	2	1	T	10/10/95	19:40:00	SNAILFISH	001P/002P;	75M

Table 4. Prey species observed in stomachs of forage fish by area and size/age group in Prince William Sound in fall, 1994. Category refers to taxonomic grouping for prey species. LARGE = large calanoid copepods, SMALL = small calanoid copepods (see text).

Northeast Region

Herring, 0-age

Category	Prey Taxon	Prey Code
BIVALVE	Bivalve, larvae	BVL
EUPHAUSIID	Euphausiid calyptopis	EU3
EUPHAUSIID	Euphausiid furcilia	EU4
EUPHAUSIID	Euphausiid, general unknown	EUP
EUPHAUSIID	Euphausiid, Thysannoessa sp., adult	TH
GAMMARID	Amphipod, Gammarid, unknown, small	GA1
GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
GASTROPOD	Gastropoda, general juvenile (SNAIL)	GST
HARPACTICO	Harpacticoid, Zaus copepodite	HZC
HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
INVERTEGG	Unknown invertebrate egg, large (>0.2mm)	EGL
INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
LARGE	Calanoid, Epilabidocera longipedata, AM	EPM
LARGE	Calanoid, general large (>2.5 mm)	CAL
LARGE	Calanoid, large, Neocalanus/Calanus	CLN
LARGE	Calanoid, Metridia pacifica, AF	MPF
LARGE	Calanoid, Metridia pacifica, AM	MPM
LARVACEA	Larvacea, Oikopleura dioica	OKI
NOTHING	Unidentified item	UNI
OTHER	Chaetognath, species unknown	CHT
OTHER	Isopod, general	ISP
OTHER	Malacostraca, eyes only	MAE
POLYCHAETE	Polychaeta, general, juvenile	PLL

POLYCHAETE	Polychaeta, Pectinariidae	PEC
SMALL	Calanoid, Acartia clausi adult	ACA
SMALL	Calanoid, Centropages abdominalis, AM	CAM
SMALL	Calanoid, general small (<2.5 mm)	CAS
SMALL	Calanoid, Pseudocalanus AF	PSF
SMALL	Calanoid, Pseudocalanus AM	PSM
SMALL	Calanoid, Pseudocalanus copepodids I-IV	PCP
SMALL	Calanoid, Pseudocalanus sp., general	PSA

Northeast Region

Herring, 1-age

BIVALVE	Bivalve, larvae	BVL
EUPHAUSIID	Euphausiid calyptopis	EU3
EUPHAUSIID	Euphausiid furcilia	EU4
EUPHAUSIID	Euphausiid, general unknown	EUP
GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
INVERTEGG	Unknown egg mass	UEM
INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
LARGE	Calanoid, general large (>2.5 mm)	CAL
LARVACEA	Larvacea, Oikopleura dioica	OKI
OTHER	Chaetognath, Sagitta	SGE
OTHER	Copepod, Caligidae, parasitic copepod	PCO
OTHER	Nematode	NEM
SMALL	Calanoid, Acartia clausi adult	ACA
SMALL	Calanoid, Centropages abdominalis, AF	CAF
SMALL	Calanoid, Centropages abdominalis, AM	CAM
SMALL	Calanoid, general small (<2.5 mm)	CAS
SMALL	Calanoid, Lucicutia flavicornis	LUC

SMALL	Calanoid, Pseudocalanus AF	PSF
SMALL	Calanoid, Pseudocalanus AM	PSM
SMALL	Calanoid, Pseudocalanus copepodids I-IV	PCP
SMALL	Calanoid, Pseudocalanus sp., general	PSA
SMALL	Cyclopoid, Oithona similis AF	OSF
SMALL	Cyclopoid, Oithona similis, general	OS

Northeast Region

Pollock, 0-age

EUPHAUSIID	Euphausiid calyptopis	EU3
EUPHAUSIID	Euphausiid furcilia	EU4
EUPHAUSIID	Euphausiid, general unknown	EUP
EUPHAUSIID	Euphausiid, T. raschii females	TRF
EUPHAUSIID	Euphausiid, Thysannoessa sp., adult	TH
GAMMARID	Amphipod, Gammarid, unknown, medium	GA2
GASTROPOD	Gastropoda, Pteropod, unidentified	PTP
HYPERIID	Amphipod, Hyperiid, P. libellula 2-6.9mm	PL2
HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
LARGE	Calanoid, general large (>2.5 mm)	CAL
LARGE	Calanoid, large, Neocalanus/Calanus	CLN
LARGE	Calanoid, Metridia pacifica, AF	MPF
LARGE	Calanoid, Metridia pacifica, AM	MPM
LARVACEA	Larvacea, Oikopleura dioica	OKI
NOTHING	Unidentified item	UNI
OTHER	Chaetognath, species unknown	CHT
POLYCHAETE	Polychaeta, general, juvenile	PLL
SMALL	Calanoid, general small (<2.5 mm)	CAS
SMALL	Calanoid, Pseudocalanus AM	PSM
SMALL	Calanoid, Pseudocalanus sp., general	PSA

ZOEAE	Decapod zoea, general unknown group	DZG
EUPHAUSIID	Euphausiid, general unknown	EUP
OTHER	Malacostraca	MAL

Southwest Region
Herring, 2-age

EUPHAUSIID	Euphausiid, general unknown	EUP
EUPHAUSIID	Euphausiid, T. raschii females	TRF
HYPERIID	Amphipod, Hyperiid, Primno macropa, <2mm	PR1
LARGE	Calanoid, Metridia pacifica, AF	MPF
LARVACEA	Larvacea, Oikopleura dioica	OKI
NOTHING	Unidentified item	UNI
OTHER	Malacostraca, eyes only	MAE
OTHER	Nematode	NEM
SMALL	Calanoid, Acartia clausi adult	ACA
SMALL	Calanoid, general small (<2.5 mm)	CAS
SMALL	Calanoid, Pseudocalanus AF	PSF
SMALL	Calanoid, Pseudocalanus AM	PSM
SMALL	Calanoid, Pseudocalanus sp., general	PSA

Southwest Region
Pollock 0-age

EUPHAUSIID	Euphausiid, general unknown	EUP
EUPHAUSIID	Euphausiid, T. raschii females	TRF
EUPHAUSIID	Euphausiid, T. raschii males	TRM
EUPHAUSIID	Euphausiid, Thysannoessa sp., adult	TH
GAMMARID	Amphipod, Gammarid, unknown, medium	GA2

GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
GASTROPOD	Gastropoda, Pteropod, unidentified	PTP
HYPERIID	Amphipod, Hyperiid, Hyperia sp.	HP
HYPERIID	Amphipod, Hyperiid, P. macropa, 2-6.9mm	PR2
HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
HYPERIID	Amphipod, Hyperiid/Parath. pacifica gen.	PP
HYPERIID	Amphipod, P. pacifica juvenile, 2-6.9mm	PA2
HYPERIID	Amphipod, P. pacifica juvenile, <2mm	PA1
INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
LARGE	Calanoid, Calanus marshallae AF	CMF
LARGE	Calanoid, Calanus pacificus AM	CPM
LARGE	Calanoid, Calanus/Neocalanus copepodids	CPD
LARGE	Calanoid, Euchaeta elongata ad. male	ECM
LARGE	Calanoid, Euchaeta elongata, AF	ECF
LARGE	Calanoid, general large (>2.5 mm)	CAL
LARGE	Calanoid, large, Neocalanus/Calanus	CLN
LARGE	Calanoid, Metridia pacifica, AF	MPF
LARVACEA	Larvacea, Oikopleura dioica	OKI
OTHER	Chaetognath, Sagitta	SGE
OTHER	Nematode	NEM
POLYCHAETE	Polychaeta, general, juvenile	PLL
SMALL	Calanoid, Acartia longiremis AF	ALF
SMALL	Calanoid, Acartia longiremus adult	AL
SMALL	Calanoid, general small (<2.5 mm)	CAS
SMALL	Calanoid, Pseudocalanus AF	PSF
SMALL	Calanoid, Pseudocalanus AM	PSM
SMALL	Calanoid, Pseudocalanus copepodids I-IV	PCP
SMALL	Calanoid, Pseudocalanus sp., general	PSA
SMALL	Cyclopoid, Oithona similis AF	OSF
ZOEAE	Decapod zoea, Shrimp, Crangonidae	DZC

Table 5. Preliminary list of prey species observed in stomachs of forage fish by area and size group in Prince William Sound in summer, 1995. See Figure 2 for mean lengths of fish size groups. Category refers to taxonomic grouping for prey species. LARGE = large calanoid copepods, SMALL = small calanoid copepods (see text).

Central Region

Pollock, 0-age

Area	Species	Size Group	Prey Category	Prey Taxon	Prey Code
C	Pollock	0	BARNACLE	Barnacle, nauplius	BMP
C	Pollock	0	BIVALVE	Bivalve, larvae	BVL
C	Pollock	0	CLADOCERA	Cladocera, General	CLA
C	Pollock	0	CLADOCERA	Cladoceran, Evadne sp.	EVD
C	Pollock	0	CLADOCERA	Cladoceran, Podon sp.	PON
C	Pollock	0	EUPHAUSIID	Euphausiid furcilia	EU4
C	Pollock	0	EUPHAUSIID	Euphausiid, general unknown	EUP
C	Pollock	0	EUPHAUSIID	Euphausiid, Thysannoessa sp., adult	TH
C	Pollock	0	FISH	Fish larvae, general	FSL
C	Pollock	0	GAMMARID	Amphipod, Gammarid, unknown, small	GA1
C	Pollock	0	GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
C	Pollock	0	HYPERIID	Amphipod, Hyperiid, Parathem. sp.2-6.9mm	PS2
C	Pollock	0	HYPERIID	Amphipod, Hyperiid, Parathemisto sp.<2mm	PS1
C	Pollock	0	HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
C	Pollock	0	INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
C	Pollock	0	LARGE	Calanoid, general large (>2.5 mm)	CAL
C	Pollock	0	LARGE	Calanoid, large, Neocalanus/Calanus	CLN
C	Pollock	0	LARGE	Calanoid, Metridia pacifica, AF	MPF
C	Pollock	0	LARGE	Calanoid, Metridia sp., General	MG
C	Pollock	0	LARGE	Calanoid, Metridia sp., general male	MGM
C	Pollock	0	LARVACEA	Larvacea, Oikopleura sp.	OKP
C	Pollock	0	OTHER	Chaetognath, species unknown	CHT
C	Pollock	0	OTHER	Malacostraca, eyes only	MAE
C	Pollock	0	SMALL	Calanoid, Centropages abdominalis, adult	CA
C	Pollock	0	SMALL	Calanoid, general small (<2.5 mm)	CAS
C	Pollock	0	SMALL	Calanoid, Pseudocalanus AF	PSF
C	Pollock	0	SMALL	Calanoid, Pseudocalanus sp., general	PSA

Central Region

Capelin, spawned-out male

Area	Species	Size Group	Prey Category	Prey Taxon	Prey Code
C	Capelin	1	GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ

Northeast Region

Herring, 0-age

NE	Herring	0	BARNACLE	Barnacle, cyprid	BMC
NE	Herring	0	BARNACLE	Barnacle, nauplius	BMP
NE	Herring	0	BIVALVE	Bivalve, larvae	BVL
NE	Herring	0	CLADOCERA	Cladocera, General	CLA
NE	Herring	0	CLADOCERA	Cladoceran, Evadne sp.	EVD
NE	Herring	0	CLADOCERA	Cladoceran, Podon sp.	PON
NE	Herring	0	DECAPOD	Decapod, megalops, Paguridae	DMP
NE	Herring	0	EUPHAUSIID	Euphausiid calyptopis	EU3
NE	Herring	0	EUPHAUSIID	Euphausiid furcilia	EU4
NE	Herring	0	FISH	Fish egg (~1.0 mm)	FSE
NE	Herring	0	GASTROPOD	Gastropod, juv. snail w/ black pigment	GSB
NE	Herring	0	GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
NE	Herring	0	GASTROPOD	Gastropoda, general juvenile (SNAIL)	GST
NE	Herring	0	HARPACTICO	Harpacticoid, general copepodite	HRC
NE	Herring	0	HARPACTICO	Harpacticoid, general eggsac	HEM
NE	Herring	0	HARPACTICO	Harpacticoid, general, unknown stage	HR
NE	Herring	0	HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
NE	Herring	0	INVERTEGG	Unknown invertebrate egg, large (>0.2mm)	EGL
NE	Herring	0	INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
NE	Herring	0	LARGE	Calanoid, general large (>2.5 mm)	CAL
NE	Herring	0	OTHER	Bryozoa, cyphonautes larva	CFN
NE	Herring	0	OTHER	Malacostraca	MAL
NE	Herring	0	OTHER	Malacostraca, eyes only	MAE
NE	Herring	0	OTHER	Unknown nauplius	UNP
NE	Herring	0	SMALL	Calanoid, Acartia clausi adult	ACA
NE	Herring	0	SMALL	Calanoid, Acartia clausi copepodite	ACC
NE	Herring	0	SMALL	Calanoid, Acartia sp.	AC
NE	Herring	0	SMALL	Calanoid, Centropages abdominalis, adult	CA
NE	Herring	0	SMALL	Calanoid, Centropages abdominalis, AF	CAF
NE	Herring	0	SMALL	Calanoid, Eurytemora pacifica AF	EYF
NE	Herring	0	SMALL	Calanoid, Eurytemora pacifica, general	EYT
NE	Herring	0	SMALL	Calanoid, general nauplius	CAN
NE	Herring	0	SMALL	Calanoid, general small (<2.5 mm)	CAS
NE	Herring	0	SMALL	Calanoid, Pseudocalanus AF	PSF
NE	Herring	0	SMALL	Calanoid, Pseudocalanus copepodids I-IV	PCP
NE	Herring	0	SMALL	Calanoid, Pseudocalanus sp., general	PSA

NE	Herring	0	SMALL	Cyclopoid, Oithona similis AF	OSF
NE	Herring	0	SMALL	Cyclopoid, Oithona similis, general	OS
NE	Herring	0	ZOEAE	Decapod zoea, crab, Brachyrhyncha	DZB
NE	Herring	0	ZOEAE	Decapod zoea, general shrimp	SHR
NE	Herring	0	ZOEAE	Decapod zoea, general unknown group	DZG
NE	Herring	0	ZOEAE	Decapod zoea, Shrimp, Pandalidae	PDZ

Northeast Region

Herring, 1-age

NE	Herring	1	BARNACLE	Barnacle, cyprid	BMC
NE	Herring	1	BIVALVE	Bivalve, larvae	BVL
NE	Herring	1	CLADOCERA	Cladocera, General	CLA
NE	Herring	1	CLADOCERA	Cladoceran, Evadne sp.	EVD
NE	Herring	1	CLADOCERA	Cladoceran, Podon sp.	PON
NE	Herring	1	DECAPOD	Decapod, megalops, Lithodidae	DML
NE	Herring	1	EUPHAUSIID	Euphausiid furcilia	EU4
NE	Herring	1	EUPHAUSIID	Euphausiid, general unknown	EUP
NE	Herring	1	GASTROPOD	Gastropod, juv. snail w/ black pigment	GSB
NE	Herring	1	GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
NE	Herring	1	GASTROPOD	Gastropoda, general juvenile (SNAIL)	GST
NE	Herring	1	HYPERIID	Amphipod, Hyperiid, Parathem. sp.2-6.9mm	PS2
NE	Herring	1	HYPERIID	Amphipod, Hyperiid, Parathemisto sp.<2mm	PS1
NE	Herring	1	HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
NE	Herring	1	HYPERIID	Amphipod, P. pacifica juvenile, 2-6.9mm	PA2
NE	Herring	1	INVERTEGG	Unknown invertebrate egg, large (>0.2mm)	EGL
NE	Herring	1	INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
NE	Herring	1	LARGE	Calanoid, Epilabidocera longipedata, AF	EPF
NE	Herring	1	LARGE	Calanoid, Epilabidocera longipedata, AM	EPM
NE	Herring	1	LARGE	Calanoid, Epilabidocera longipedata, gen	EPI
NE	Herring	1	LARGE	Calanoid, general large (>2.5 mm)	CAL
NE	Herring	1	LARGE	Calanoid, large, Neocalanus/Calanus	CLN
NE	Herring	1	LARVACEA	Larvacea, Oikopleura sp.	OKP
NE	Herring	1	OTHER	Malacostraca	MAL
NE	Herring	1	OTHER	Malacostraca, eyes only	MAE
NE	Herring	1	OTHER	Unknown nauplius	UNP
NE	Herring	1	POLYCHAETE	Polychaeta, general, juvenile	PLL
NE	Herring	1	SMALL	Calanoid, Acartia longiremis , General	ALG
NE	Herring	1	SMALL	Calanoid, Acartia sp.	AC
NE	Herring	1	SMALL	Calanoid, Centropages abdominalis. adult	CA
NE	Herring	1	SMALL	Calanoid, Centropages abdominalis, AF	CAF

NE	Herring	1	SMALL	Calanoid, general small (<2.5 mm)	CAS
NE	Herring	1	SMALL	Calanoid, Pseudocalanus AF	PSF
NE	Herring	1	SMALL	Calanoid, Pseudocalanus copepodids I-IV	PCP
NE	Herring	1	SMALL	Calanoid, Pseudocalanus sp., general	PSA
NE	Herring	1	SMALL	Cyclopoid, Oithona similis, general	OS
NE	Herring	1	ZOEAE	Decapod zoea, Anomuran, Lithodidae	LIZ
NE	Herring	1	ZOEAE	Decapod zoea, crab, Brachyrhyncha	DZB
NE	Herring	1	ZOEAE	Decapod zoea, general shrimp	SHR
NE	Herring	1	ZOEAE	Decapod zoea, general unknown group	DZG
NE	Herring	1	ZOEAE	Decapod zoea, Shrimp, Hippolytidae	HIE
NE	Herring	1	ZOEAE	Decapod, Brachyura general, zoeae	DGB

Northeast Region

Pollock, 2-age

NE	Pollock	2	DECAPOD	Decapod, Brachyuran megalops	DMG
NE	Pollock	2	DECAPOD	*Shrimp, general unknown juv./adult*	SHP
NE	Pollock	2	EUPHAUSIID	Euphausiid, general unknown	EUP
NE	Pollock	2	EUPHAUSIID	Euphausiid, T. longipes	TL
NE	Pollock	2	HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
NE	Pollock	2	INVERTEGG	Unknown egg mass	UEM
NE	Pollock	2	LARGE	Calanoid, general large (>2.5 mm)	CAL
NE	Pollock	2	LARGE	Calanoid, large, Neocalanus/Calanus	CLN
NE	Pollock	2	LARVACEA	Larvacea, Oikopleura sp.	OKP
NE	Pollock	2	OTHER	Chaetognath, species unknown	CHT
NE	Pollock	2	OTHER	Malacostraca, eyes only	MAE
NE	Pollock	2	SMALL	Calanoid, general small (<2.5 mm)	CAS

Northeast Region

Sandlance, 0-age

NE	Sandlance	0	BARNACLE	Barnacle, cyprid	BMC
NE	Sandlance	0	BIVALVE	Bivalve, larvae	BVL
NE	Sandlance	0	CLADOCERA	Cladoceran, Evadne sp.	EVD
NE	Sandlance	0	CLADOCERA	Cladoceran, Podon sp.	PON
NE	Sandlance	0	GASTROPOD	Gastropod, Pteropod, Limacina helicina J	LMJ
NE	Sandlance	0	GASTROPOD	Gastropoda, general juvenile (SNAIL)	GST
NE	Sandlance	0	HARPACTICO	Harpacticoid, general copepodite	HRC
NE	Sandlance	0	HARPACTICO	Harpacticoid, general, unknown stage	HR

NE	Sandlance	0	HARPACTICO	Harpacticoid, Laophontidae, adult	LAO
NE	Sandlance	0	HARPACTICO	Harpacticoid, Laophontidae, copepodite	LAC
NE	Sandlance	0	HARPACTICO	Harpacticoid, Tisbe copepodite	TSC
NE	Sandlance	0	HARPACTICO	Harpacticoid, Zaus copepodite	HZC
NE	Sandlance	0	HYPERIID	Amphipod, Hyperiid, unknown juvenile	HYP
NE	Sandlance	0	INVERTEGG	Unknown invertebrate egg, small (<0.2mm)	EGG
NE	Sandlance	0	LARVACEA	Larvacea, Oikopleura sp.	OKP
NE	Sandlance	0	SMALL	Calanoid, Centropages abdominalis, adult	CA
NE	Sandlance	0	SMALL	Calanoid, general small (<2.5 mm)	CAS

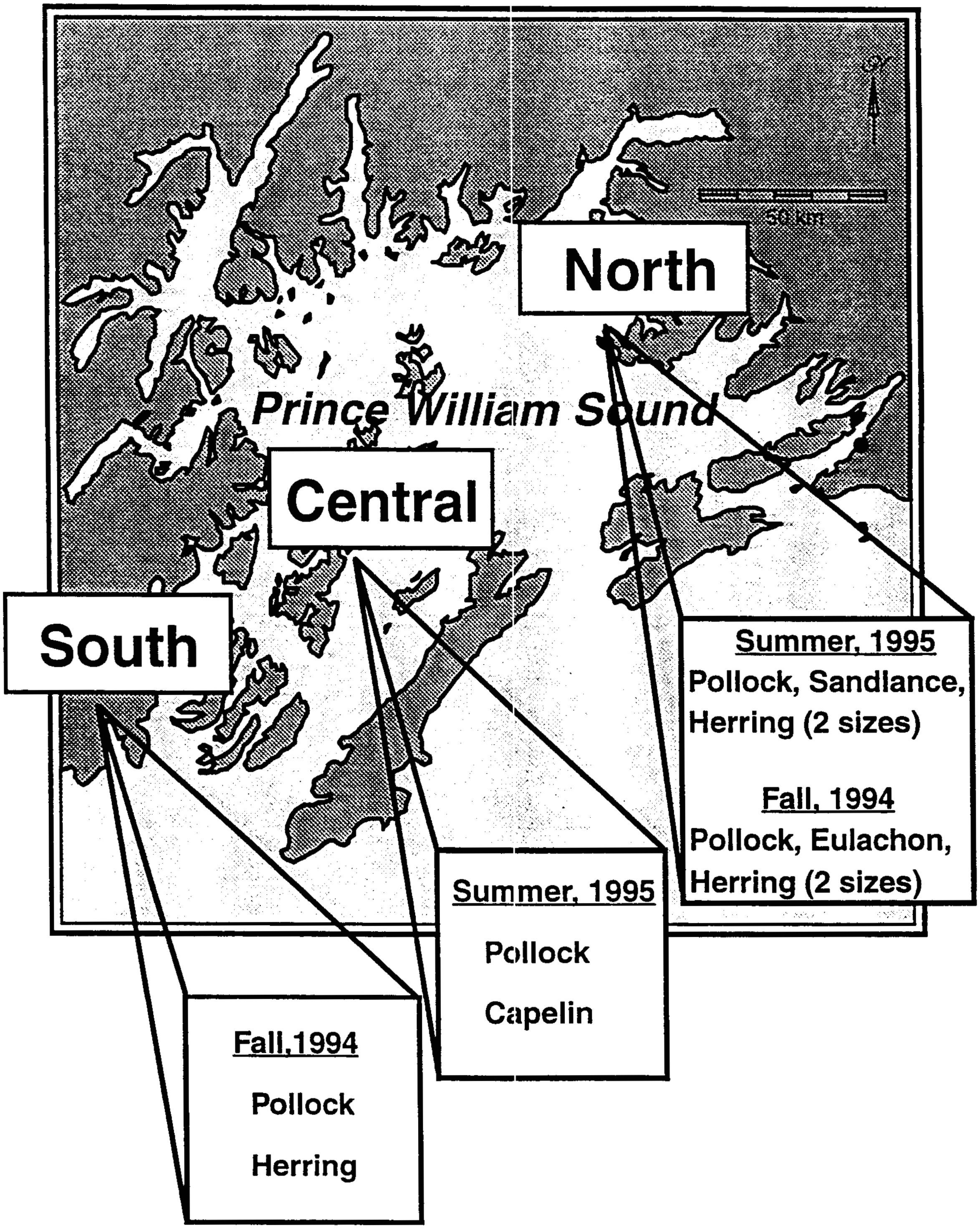

Figure 1 . Map of APEX sampling areas and species of forage fish represented in preliminary diet analyses for fall, 1994 and summer, 1995, in Prince William Sound, Alaska.

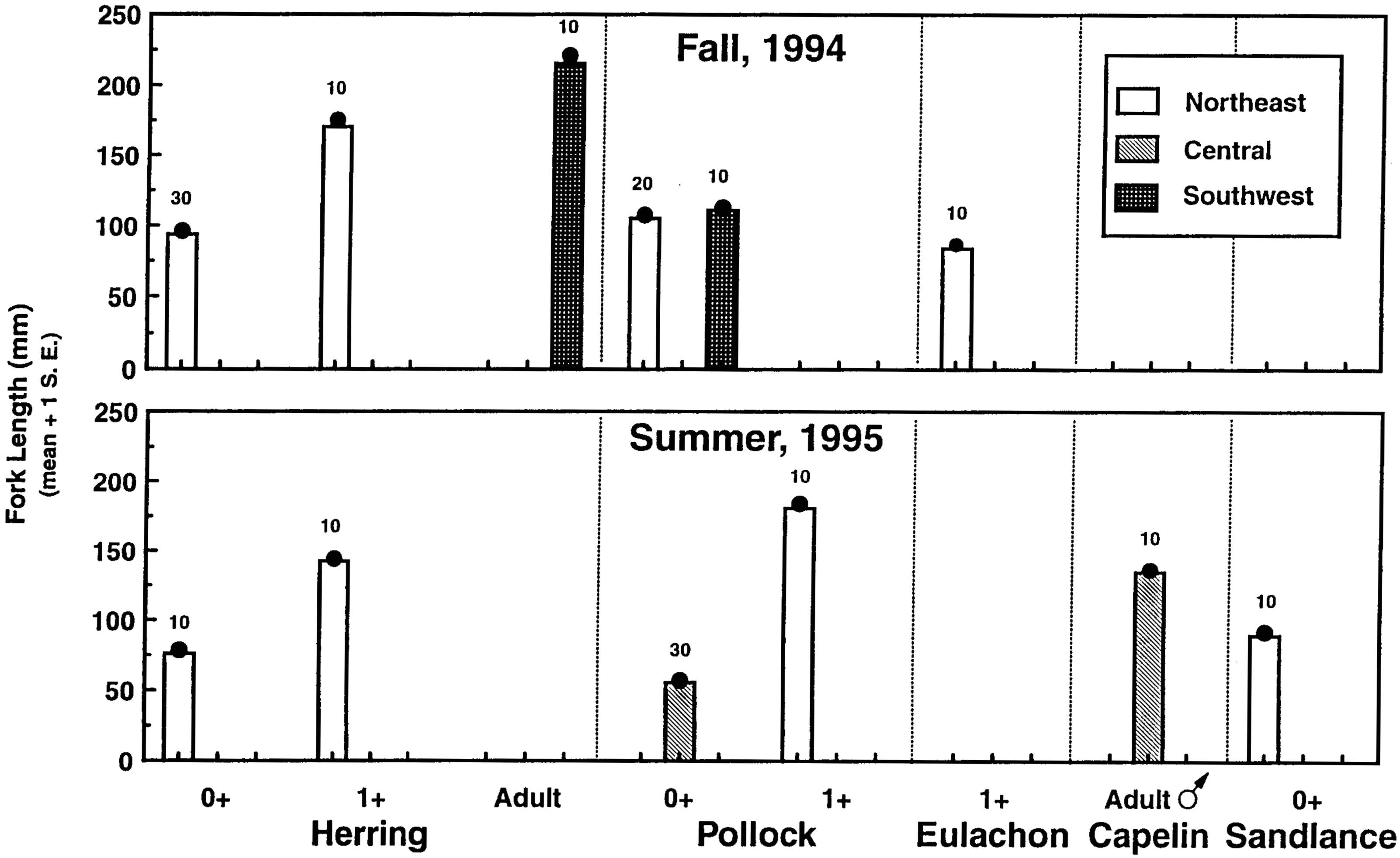

Figure 2. Size of forage fish used in APEX 95163C preliminary diet analyses, by season and area collected in Prince William Sound, fall, 1994 and summer, 1995. The number of preserved specimens analyzed is shown above each bar.

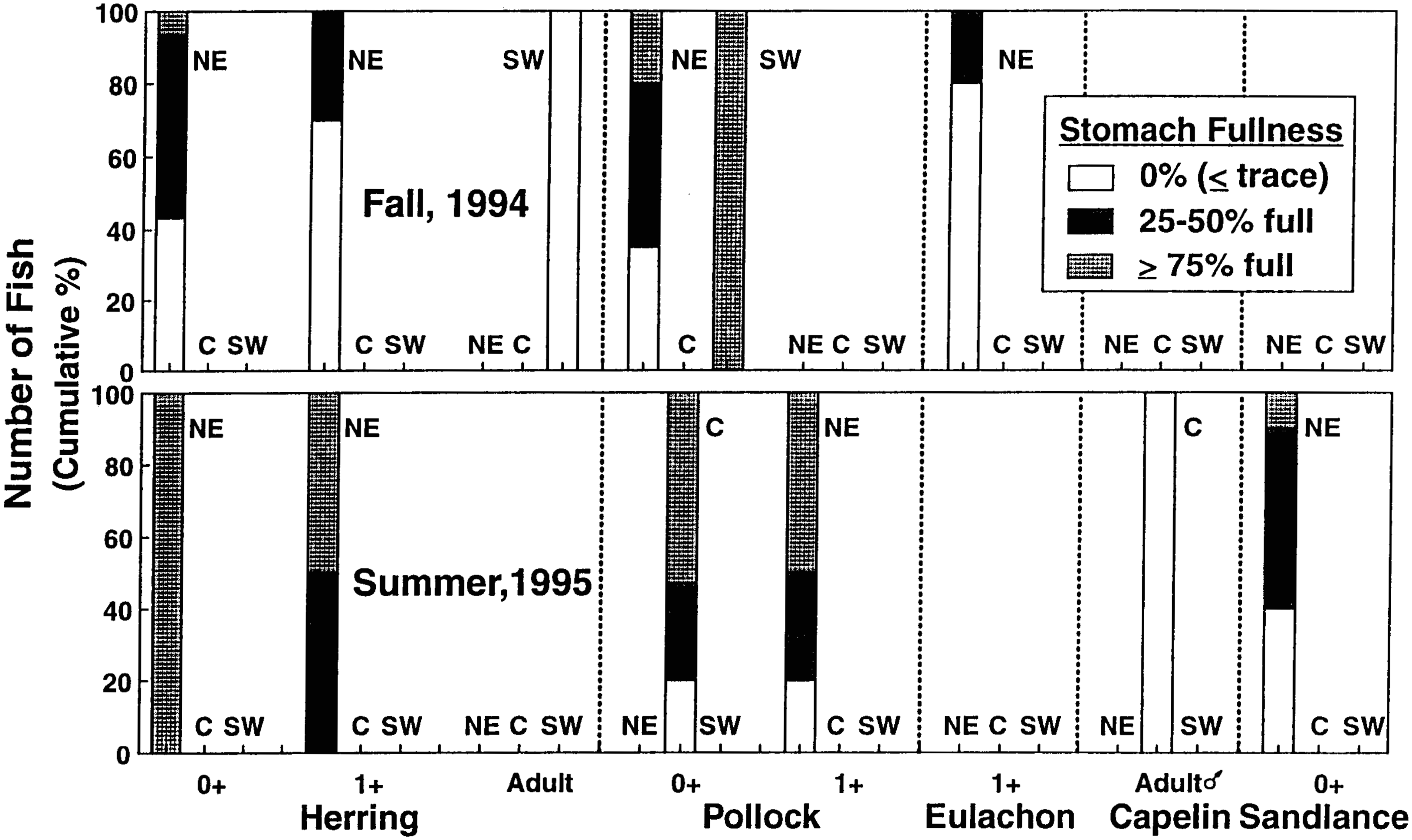

Figure 3. Percent number of forage fish with stomachs containing trace amounts of prey, 25-50% full, and greater than 75% full, from APEX preliminary diet analyses for fall, 1994 and summer, 1995.

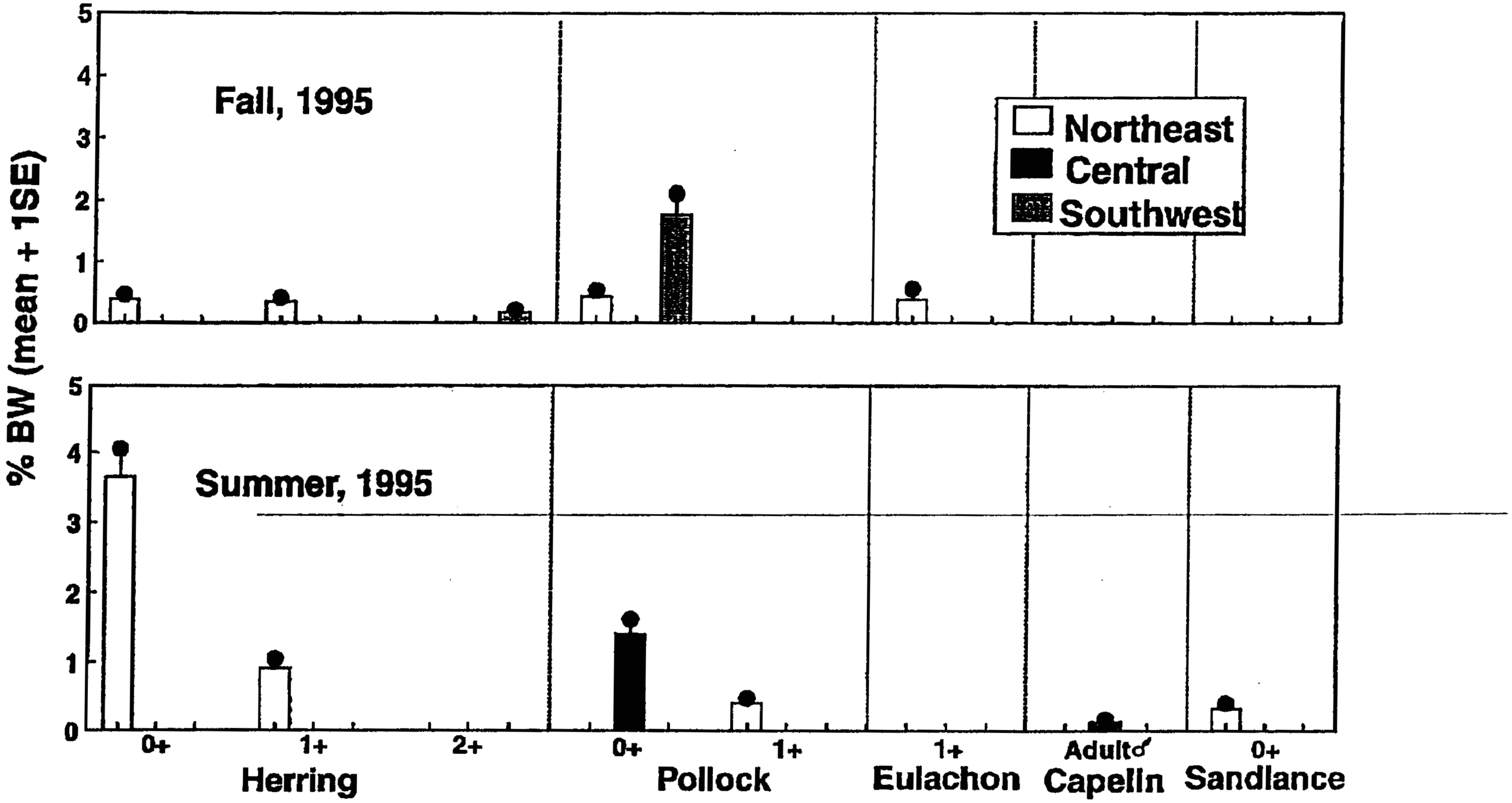

Figure 4. Stomach content as percent body weight for forage fish used in APEX preliminary diet analyses for fall, 1994 and summer, 1995.

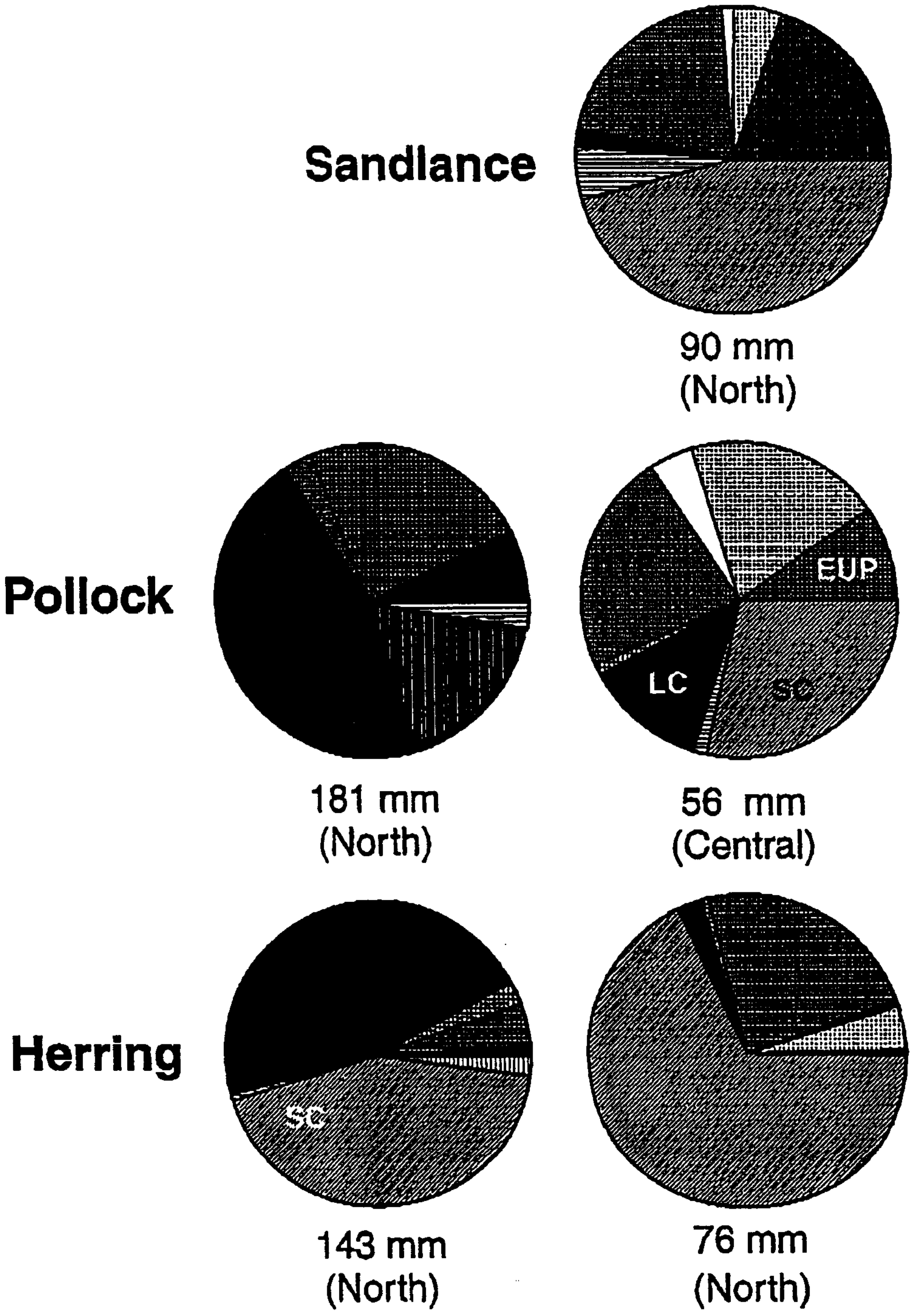

Figure 5 . Diet composition of forage fish collected in Prince William Sound in summer, 1995, as percent biomass of 15 prey categories, with mean FL and area collected. Preylegend is the same as in Figure x.

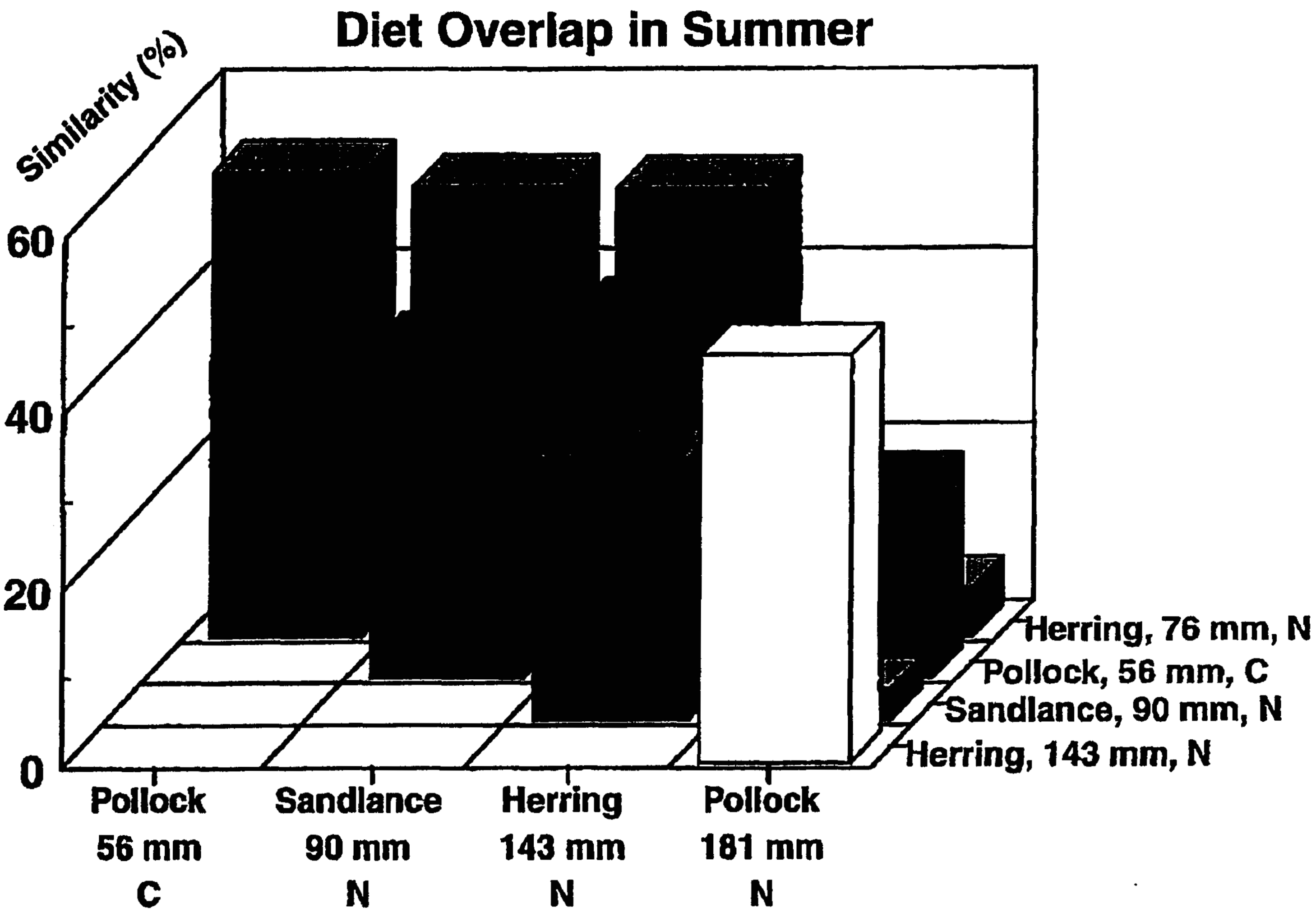

Figure 6 . Diet overlap (Percent Similarity Index) for forage fish collected in Prince William Sound in summer, 1995, with mean FL and area collected.

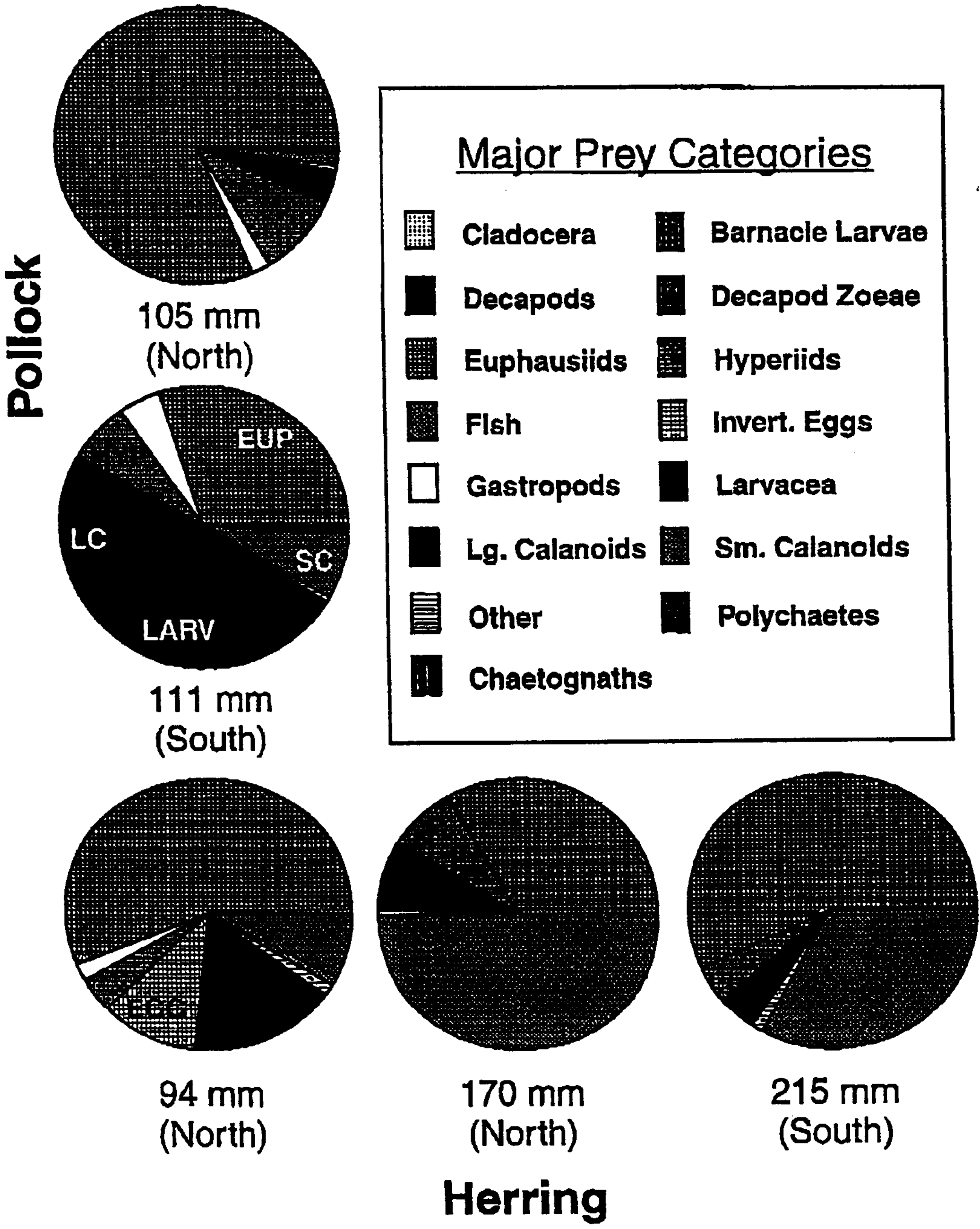

Figure 7. Diet composition of forage fish collected in Prince William Sound in fall, 1994,, as percent biomass of 15 prey categories, with mean FL and area collected. Prey category legend is the same as in Figure x.

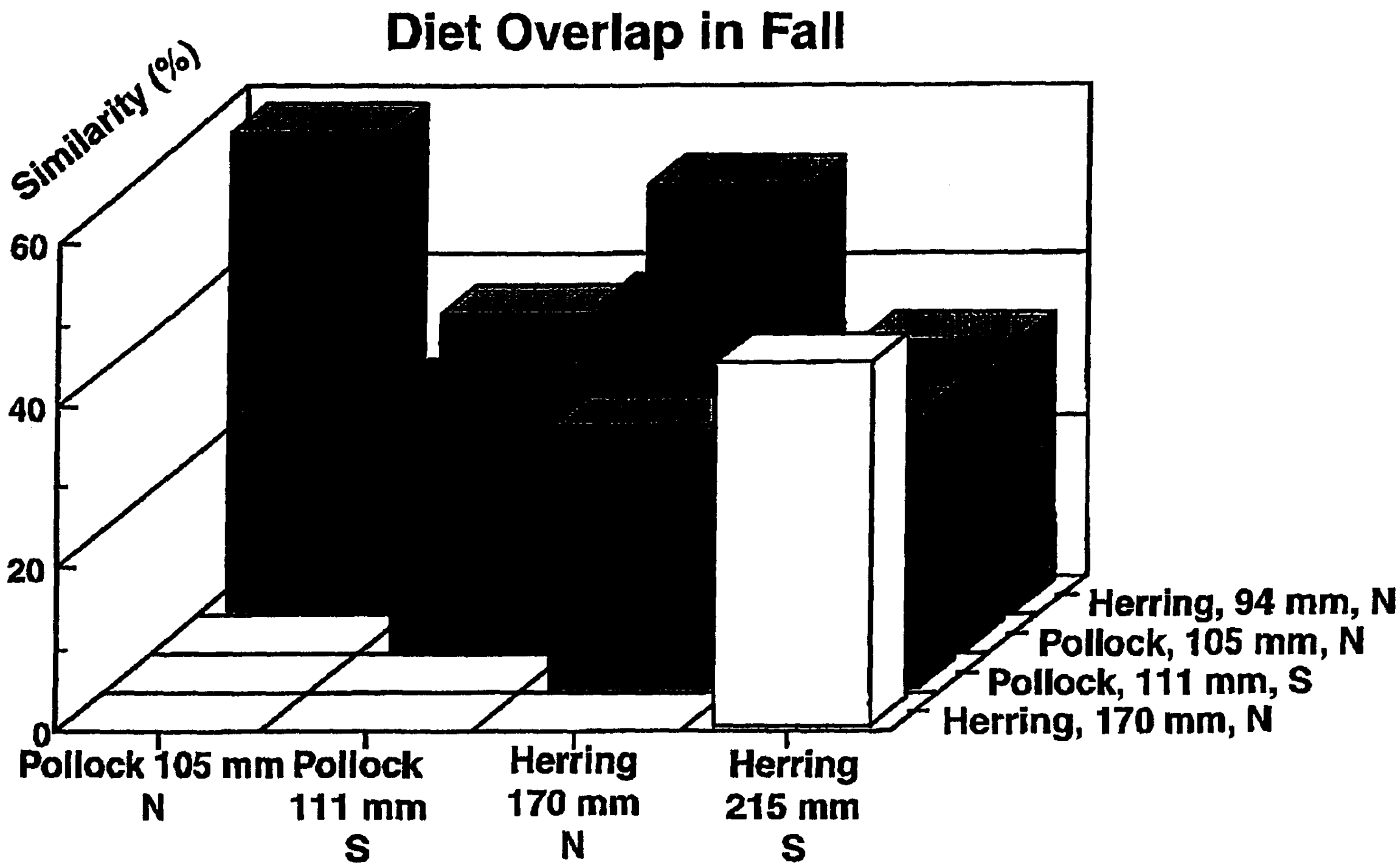

Figure 8. Diet overlap (Percent Similarity Index) for forage fish collected in Prince William Sound in fall, 1994, with mean FL and area collected.

APPENDIX D

APEX: 95163 D

APEX 95163D

TO BE PROVIDED AT A LATER DATE

APPENDIX E

APEX: 95163 E

Appendix E-1

APEX: 95163E

KITTIWAKES AS INDICATORS OF CHANGE IN FORAGE FISH

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ABSTRACT

In 1990, the year following the *T/V Exxon Valdez* oil spill, productivity (fledglings/nest) of Black–legged Kittiwakes in Prince William Sound (PWS) decreased and has not recovered. Studies during this period indicated the decline in productivity resulted from decreased food availability and increased predation. Kittiwake productivity for 1995 was average at Shoup Bay, Eleanor Island, and Seal Island colonies, but overall productivity for kittiwakes in PWS (26 colonies) was low.

While foraging, kittiwakes from Shoup Bay traveled four times the distance and twice the duration of kittiwakes from Eleanor Island and still maintained productivity and chick growth rates similar to Eleanor Island. These results were similar to data collected in 1989 and indicated the potential for adult kittiwakes to buffer their chicks against variability in prey resources, although data from 1990 indicated a certain threshold point exists, beyond which adults can no longer buffer chicks.

Walleye pollock located offshore were a large portion of the forage fish biomass in PWS (APEX component A), however, adult kittiwakes foraged near shore (< 1 km) and fed their chicks primarily Pacific herring and Pacific sand lance (species of greater energy density than walleye pollock; APEX component G).

Surprisingly, kittiwakes often (> 50% of foraging) did not feed in foraging flocks and exhibited foraging site fidelity. These foraging behaviors are important in testing hypotheses of the APEX project.

Data collected during this study and Irons (1992) will allow us to model the relationship of prey availability, foraging effort, and productivity, and 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 effortand 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 of food supply changes 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 (*Rissa tridactyla*), 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 increases their 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 nesting season, productivity, chick diets, and foraging of kittiwakes were monitored at three colonies in PWS and compared to data from a colony in lower Cook Inlet (the Barren Islands, APEX component K). Additionally, data were compared to previous years (Irons 1992 and USFWS unpubl. data). We addressed two 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.

Appendix E-3

METHODS

This study was conducted in PWS, a 10,000 km^2 inland marine/estuarine waterway located along the north coast of the Gulf of Alaska (Fig. 1). Prince William Sound has heterogeneous bathymetry and large tide height variation causing eddies and upwelling which likely affect the distribution of forage fishes and their availability to seabirds. Primary Black–legged Kittiwake colonies studied during the 1995 nesting season in PWS were located near Shoup Bay, Eleanor Island, and Seal Island. In 1995, Shoup Bay was the largest kittiwake colony (5628 nests, an increase of 4197 nests since 1984) in PWS, Eleanor Island was a relatively small colony (159 nests, relatively stable since 1984), and Seal Island was relatively small but increasing in size (270 nests, an increase of 185 nests since 1994). The Black–legged Kittiwake colony at the Barren Islands (Fig. 1) was much larger (> 10,000 nests) than colonies in PWS.

Between 6 June and 23 August, the contents of Black–legged Kittiwake nests were recorded every three to seven days at colonies located near Shoup Bay (206 nests in 12 plots), Eleanor Island (159 nests, entire colony), and Seal Island (270 nests; entire colony). Only nests built before 20 June were included in the plots. Plots also were established and included nearly all nests at the Bay of Isles, Naked Island, and Eaglek Bay kittiwake colonies. Productivity for all kittiwake colonies in PWS ($n = 26$ colonies) was determined by conducting nest counts in mid June and chick counts in early August.

To determine growth rates, measurements of chicks were recorded every three to seven days from hatching to fledgling. Recorded measurements included length (± 0.1 mm) of culmen, headbill, tarsus, length (± 1 mm) of wingchord, fifth and tenth primaries, and total mass (g) of bird. Growth was calculated as weight 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 preserved in 70% ethyl alcohol or frozen. Typically, no more than one sample was collected per chick. Prey were identified using otoliths (all species) and scales (Pacific herring; *Clupea pallasi*).

Adult Black–legged Kittiwakes were captured at their nests using a noose pole and radio transmitters (Advanced Telemetry Systems, Inc (ATS), 166 – 167 MHz, 10 g) were attached to 23 birds at Shoup Bay, 18 birds at Eleanor Island, and 11 birds at Seal Island. Three transmitters for each frequency were differentiated by pulse widths of 145, 185, and195 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, Rhodomine B, and Malachite Green Oxalate) one of three unique color combinations corresponding to the pulse width of the transmitter. 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 Seal Island colonies. A RRS consisted of an ATS data collection computer (DCC) connected to an ATS receiver and a two element "H" antenna. 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 continuously scanned each frequency for one minute every ten minutes. Data from the RRS's were useful in determining changes in foraging trip duration related to time of day, tides, and nest contents (eggs, chicks, fledglings, no nest).

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 (strait 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 withsearching 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 (≥ 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 (≥ 2 birds foraging in an area > 10 m and < 500 m), and 3) potential foraging flock (≥ 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.

Reproductive parameters at all kittiwake colonies in PWS and diets of chicks at Shoup Bay for 1995 will be compared to historical data (1985 – 1994; U.S. Fish and Wildlife Service unpubl. data). Foraging parameters for kittiwakes at Shoup Bay and Eleanor Island colonies in 1995 will be compared to data collected in 1989 and 1990 (Irons 1992).

RESULTS

Analyses of data collected in 1995 are not complete and considered preliminary. Final results will be subjected to statistical analyses.

Productivity (fledglings/nest) was greater at Shoup Bay and Barren Islands than Eleanor and Seal Islands (Fig. 2a). Laying success (80 to 96% of nest structures had ≥ 1egg) and mean clutch size (1.5 to 1.8 eggs) were similar among sites , therefore, reduced productivity at Eleanor and Seal Islands resulted from greater egg and chick mortality. Brood reduction (percent of two–chick broods reduced to one chick broods) was greater at Eleanor Island (57%) and Seal Island (44%) compared to Shoup Bay (36%). Mean chick growth rates were similar among sites in PWS and slightly greater at the Barren Islands (Fig. 2b). Overall productivity for kittiwakes in PWS was 0.19 fledglings/nest, continuing the trend of reduced productivity since 1990 (Fig. 3). Decreased productivity resulted in part from increased failure (≤ 0.10 fledglings/nest) of kittiwake colonies in PWS during 1990 to 1995 (mean = 50%, range = 46% – 54%) compared with 1985 to 1989 (mean = 79%, range = 63% – 89%), rather than low productivity throughout PWS.

Chick diets in 1995 were primarily Pacific herring and Pacific sand lance (*Ammodytes hexapterus*) at Shoup Bay, Pacific herring at Eleanor Island and Seal Island, and capelin (*Mallotus villosus*) and Pacific sand lance at the Barren Islands (Fig. 4). Walleye pollock (*Theragra chalcogramma*) was a small portion (≤ 9%) of chick diets at all locations. Diets of kittiwake chicks from 1988 to 1995 at Shoup Bay also were dominated by Pacific herring and Pacific sand lance; two prey species that, except for 1988, alternate in greatest percent occurrence among years (Fig. 5).

Mean foraging trip duration was two times greater and distance was seven times greater for kittiwakes from Shoup Bay compared with Eleanor Island (Fig. 6). Foraging trip time budgets indicated the duration of travel, search, and rest for kittiwakes from Shoup Bay was at least twice that of kittiwakes from Eleanor Island (Fig. 7). Mean number of feeding attempts per foraging trip was greater for kittiwakes from Shoup Bay (mean = 22 attempts;SE = 5.35) than kittiwakes from Eleanor Island (mean = 10 attempts; SE = 3.05). Mean distance to shore of foraging locations for kittiwakes from Shoup Bay was 0.90 km (SE = 0.24; Fig 8a), 0.24 km (SE = 0.04; Fig 8b) for kittiwakes from Eleanor Island, and 0.28 km (SE = 0.09; Fig 8c) for kittiwakes from Seal Island. Forty–seven percent of feeding attempts of kittiwakes were not associated with foraging flocks when foraging flocks were present.

DISCUSSION

Reduced productivity of kittiwakes at Eleanor and Seal Islands compared to kittiwakes at Shoup Bay and the Barren Islands resulted from egg and chick mortality, possibly due to predation and weather (Seal and Eleanor Island colonies are more exposed to extreme swell and tide conditions than Shoup Bay). Brood reduction also was greater at Eleanor Island and Seal Island colonies than Shoup Bay, a potential indicator of decreased food availability near Eleanor and Seal Islands (Braun and Hunt 1983; Irons 1992). Brood reduction at Eleanor Island and Seal Island in 1995 was mid–way between brood reduction at Shoup Bay in 1989 (33 %, similar to 1995) when productivity and chick growth were average and 1990 (77%) when productivity and chick growth were reduced because of limited food availability (Irons 1992). These results indicated the potential for food to have been a greater limitation to productivity of kittiwakes at Eleanor Island and, to a lesser extent, Seal Island than at Shoup Bay.

Although kittiwakes from Shoup Bay traveled four times the distance and twice theduration while foraging compared with kittiwakes at Eleanor Island, productivity was greater at Shoup Bay and chick growth rates were similar. These results were consistent with data collected at the same colonies in 1989 (Irons 1992) and indicated the potential for adult kittiwakes to buffer their chicks against variability in prey resources. The ability of adults to buffer chicks against variable prey resources has also been reported for Common Murres (*Uria aalge*; Burger and Piatt 1990). Increased foraging trip duration and decreased chick growth for kittiwakes from Shoup Bay in 1990 compared to 1989 and 1995, however, indicated a threshold beyond which adults cannot buffer chicks (Irons 1992).

If decreased food availability did cause increased brood reduction at the Eleanor Island colony, it is interesting that kittiwakes did not increase foraging effort to the extent that kittiwakes at Shoup Bay were capable of maintaining. Irons (1992) reported kittiwakes nesting at Shoup Bay exhibited foraging site fidelity and suggested that predictable locations for finding food were learned, which is a possible explanation for low reproductive success of young kittiwakes compared with older, more experienced birds. Kittiwakes at Eleanor Island may not greatly change foraging effort unless there is a significant reduction in food due to foraging site fidelity and their reliance on locations of predictable (historically) food resources. There may be a range of food availability over which adult kittiwakes will not change their foraging effort if they can successfully raise at least one young. As with foraging effort and productivity, foraging effort and prey availability may not be a linear relationship. Data collected during this study and Irons (1992) will allow us to model the relationship of prey availability, foraging effort, and productivity, and predict the effects of changes in oceanographic conditions and forage fish availability on population dynamics ofkittiwakes in PWS.

Cairns (1987) suggested that activity budgets may be better than reproductive parameters as indicators of changes in food availability. In addition to prey availability, predation is a significant factor affecting productivity of kittiwakes in PWS (Irons pers. obs.). Although foraging activity indicates changes in prey availability, the relationship to productivity is complicated by the effect of predation. Therefore, it is important to collect data on foraging activity and measures of productivity that are mostly independent of predation (e.g. brood reduction, chick growth rates, chick weight at fledging, adult body condition) to more accurately determine the relationship of prey availability to productivity.

For the past seven years at the Shoup Bay colony, Pacific herring and Pacific sand lance dominated chick diets and alternated annually in greatest percent occurrence. Kittiwake chick diets from the Barren Islands, Eleanor Island and Seal Island colonies in 1995 also indicated the importance of Pacific herring, Pacific sand lance, and capelin as prey items; all species of greater energy density than walleye pollock (APEX component G) which was a large portion of the forage fish biomass n PWS (APEX component A).

Kittiwakes primarily foraged within 1 km of shore indicating the importance of the natural history of forage fishes and nearshore oceanographic processes in affecting the availability of primary forage species. These results are consistent with locations of mixed species foraging flocks located by Ostrand (APEX component B)

Results of this study and Irons (1992) indicated kittiwakes, which have been thought to generally feed in flocks, often (> 50% of the time) fed alone, signifying the importance of considering foraging site fidelity when evaluating changes in foraging effort among sites and among years.

ACKNOWLEDGMENTS

Kirk Lenington supervised field work at Shoup Bay in 1995. For their hard work we thank the 1995 field crews at Shoup Bay (Jared Gerstein, Cynthia Restrepo, Sean Wolfe) and Eleanor Island (Teresa Sauer, John Ryder, Kyle Payton). Kim Raum-Suryan assisted with field work and data analyses. Greg Golet conducted productivity surveys of kittiwake colonies in PWS and identified prey in chick diet samples from PWS. David Roseneau and Arthur Kettle provided data from Black-legged Kittiwakes nesting at the Barren Islands.

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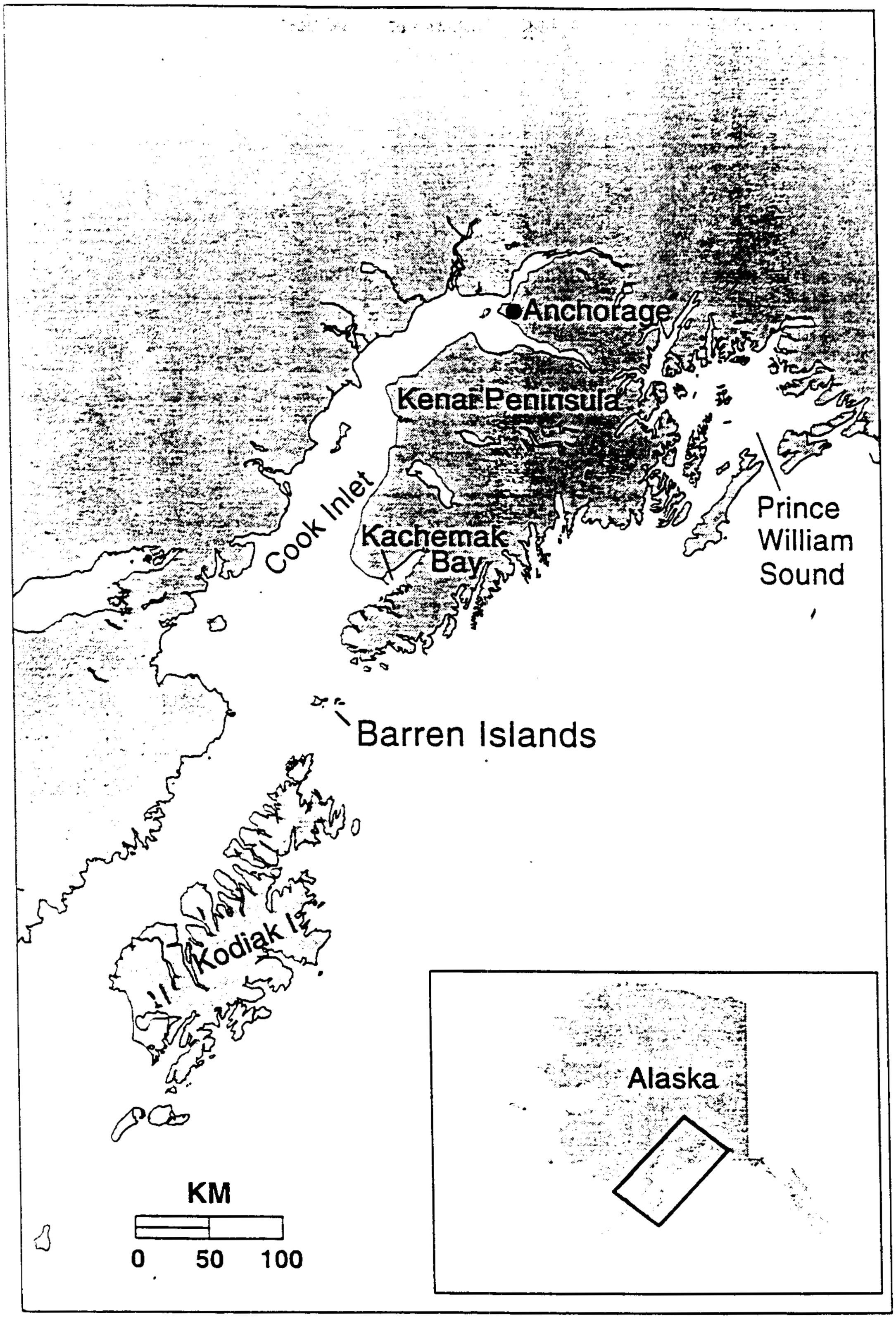


Figure 1. Location of Prince William Sound and the Barren Islands, Alaska.

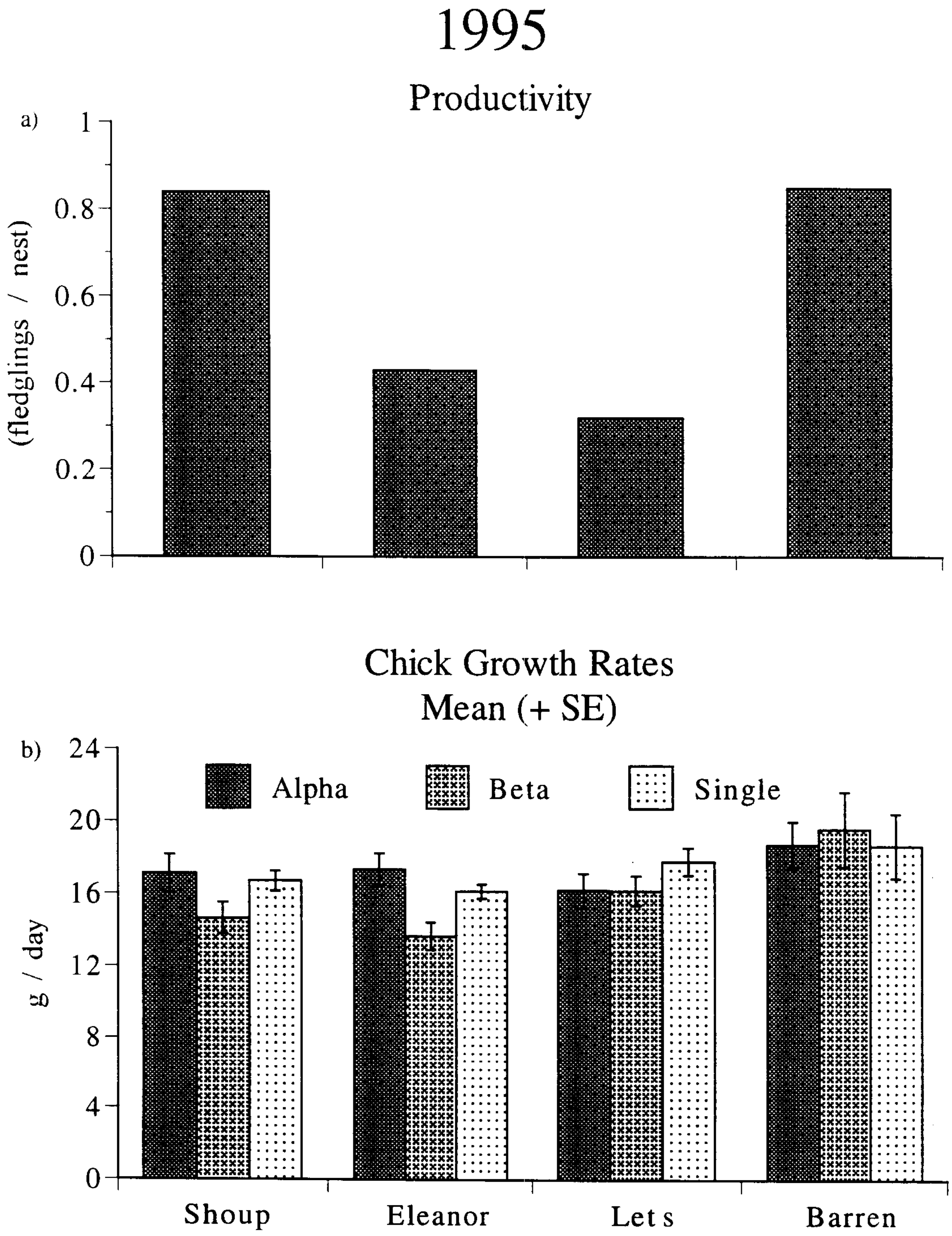


Figure 2. Productivtiy (a; fledglings/nest) and mean chick growth rates (b; ± SE; g/day; alpha, beta, and single chicks) for Black-legged Kittiwakes nesting at Shoup Bay, Eleanor Island, and Seal Island, Prince William Sound and the Barren Islands, lower Cook Inlet, Alaska, June - August 1995.

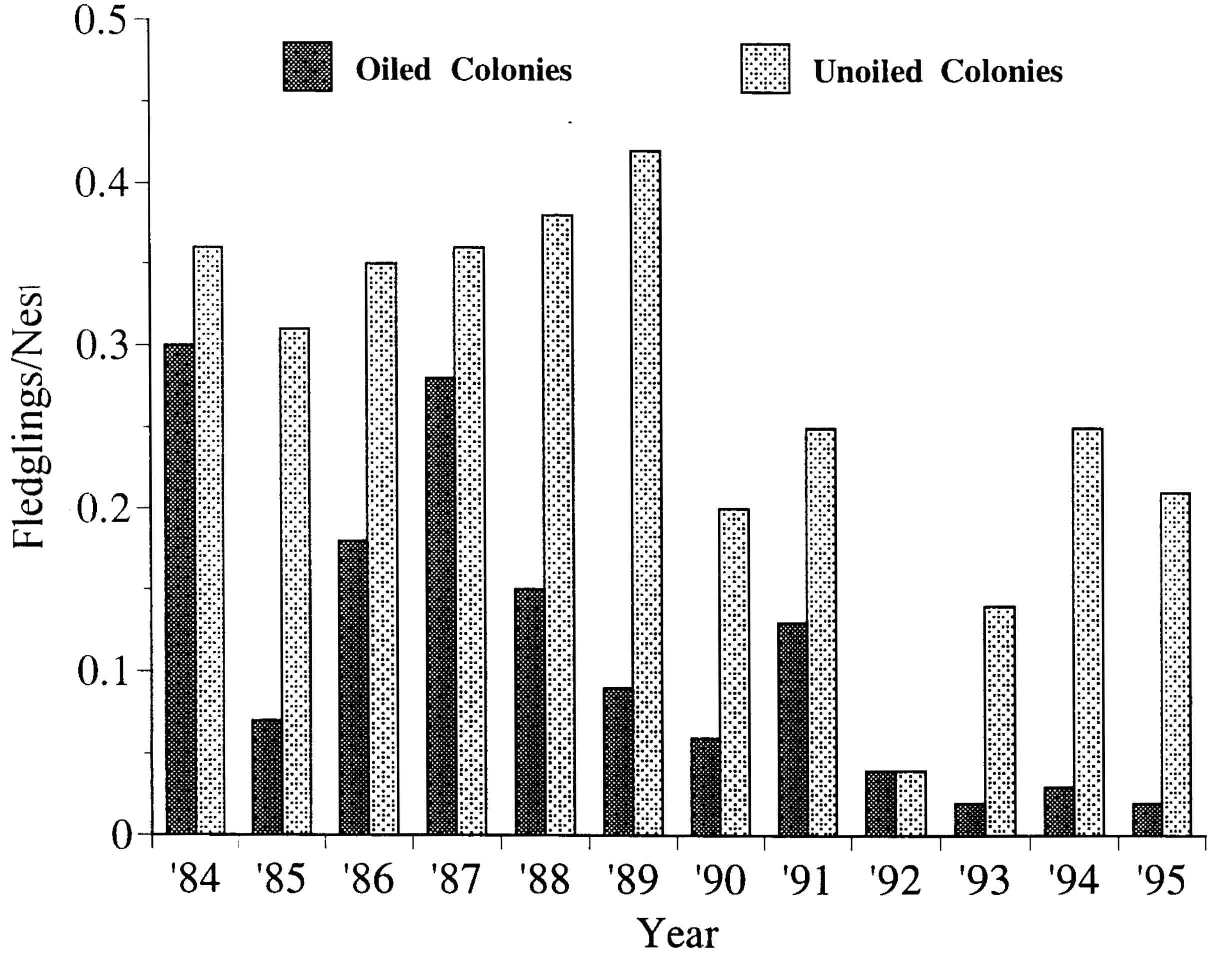


Figure 3. Productivity (fledglings/nest; 1984 to 1995) of Black-legged Kittiwakes at colonies where foraging ranges contained oil or were not oiled by the T/V Exxon Valdez oil spill, 24 March 1989, in Prince William Sound, Alaska.

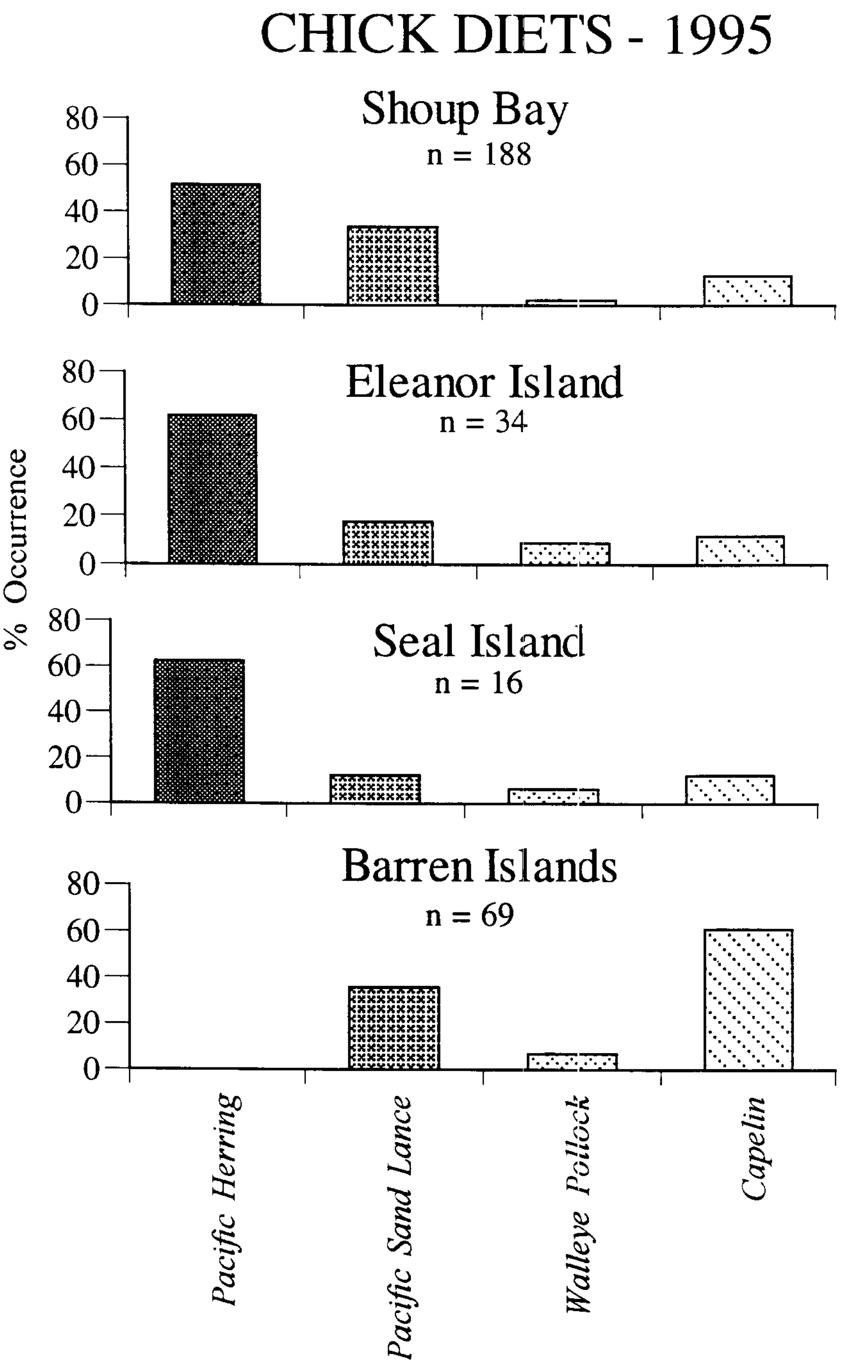


Figure 4. Percent occurrence of primary prey in Black-legged Kittiwake chick diet samples collected during 1995 at Shoup Bay, Eleanor Island, and Seal Island, Prince William Sound, and the Barren Islands, Lower Cook Inlet, Alaska.

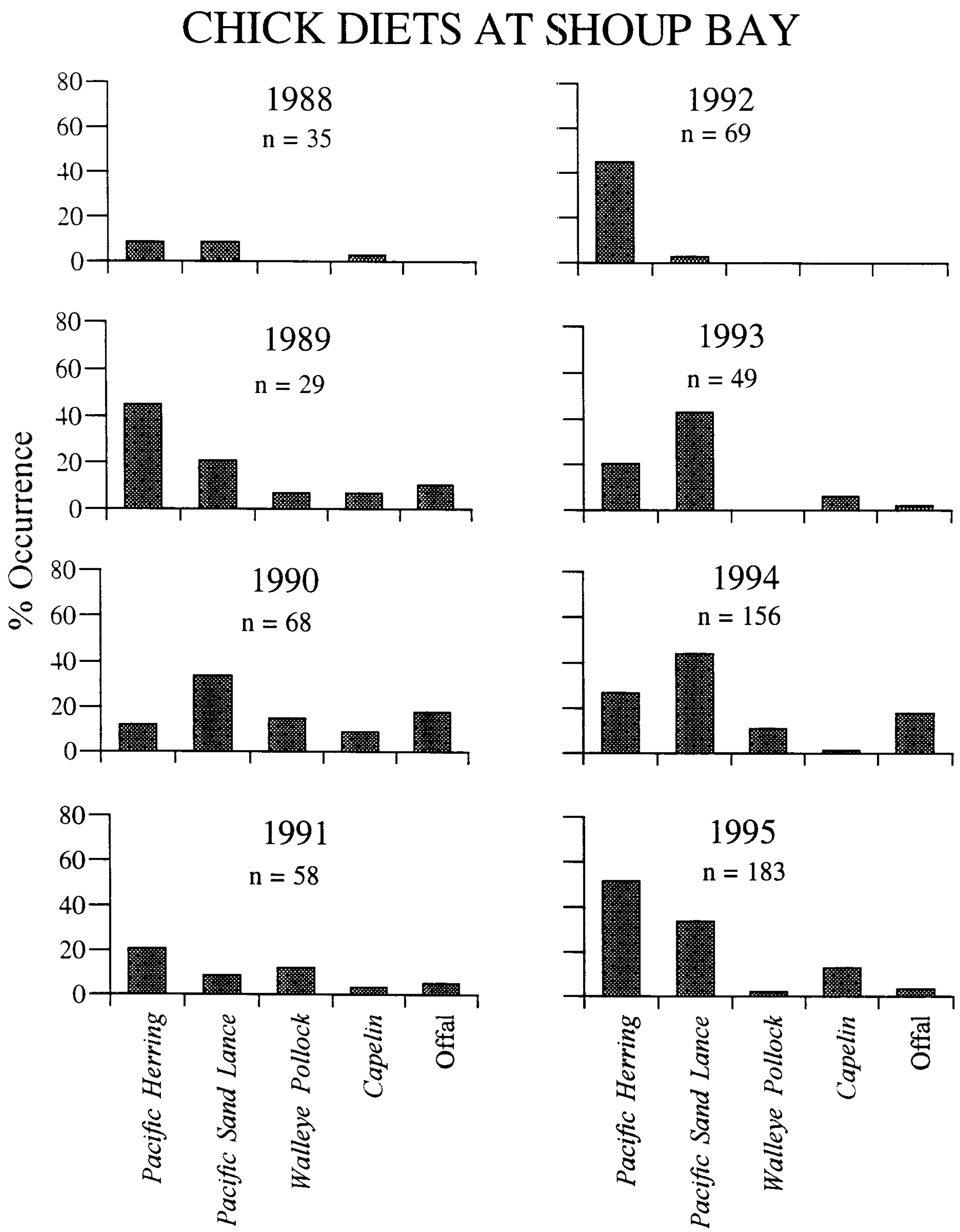
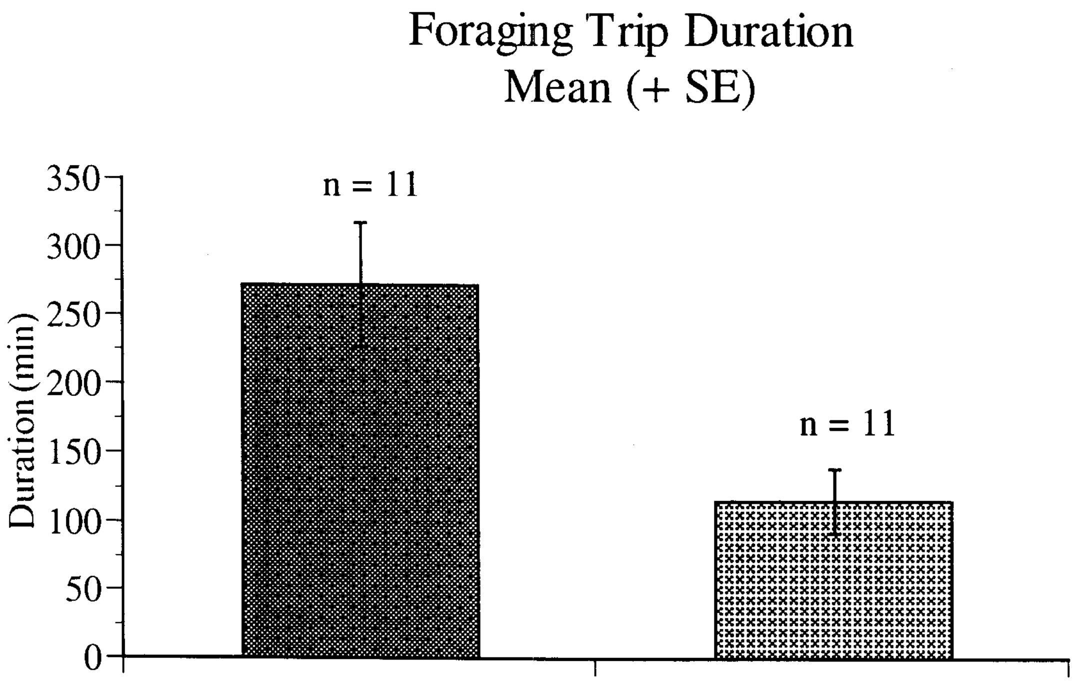


Figure 5. Percent occurrence of primary prey in Black-legged Kittiwake chick diets from 1988 to 1995 at the Shoup Bay colony, Prince William Sound, Alaska.



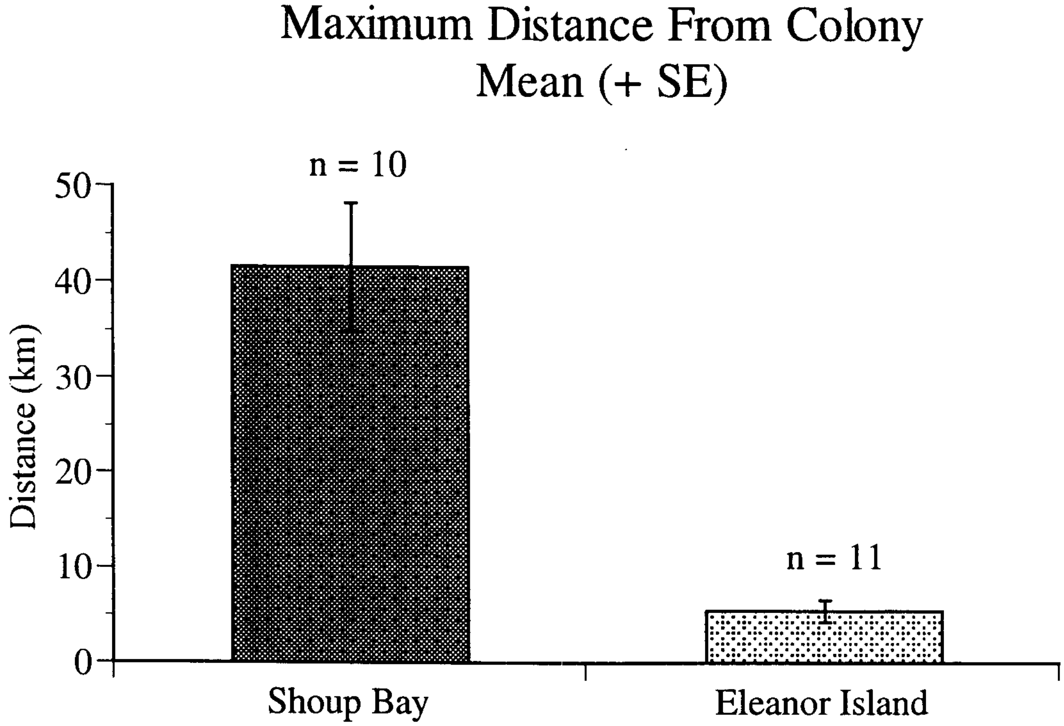


Figure 6. Mean foraging trip duration and mean maximum foraging trip distance for Black-legged Kittiwakes nesting at Shoup Bay and Eleanor Island colonies, Prince William Sound, Alaska, in 1995.

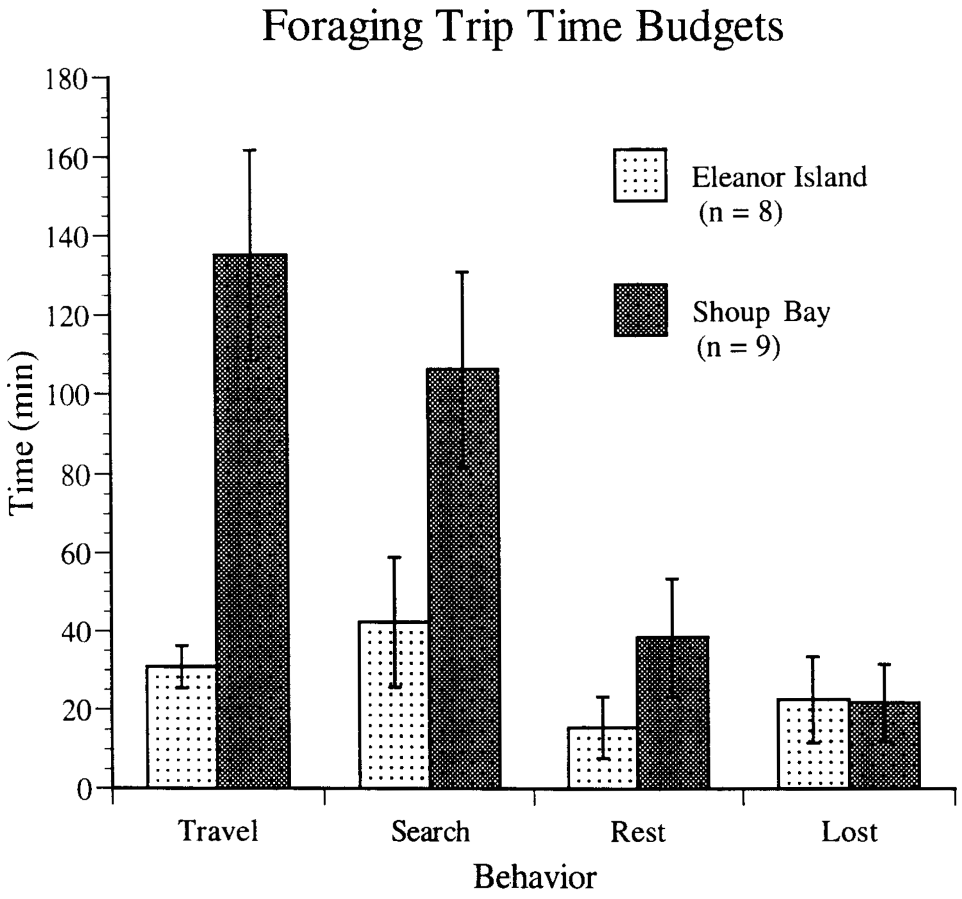


Figure 7. Mean (+ SE) duration of travel, search (including pursuit and handling times), rest, and lost from observer's sight during foraging trips of radio-tagged Black-legged Kittiwakes from Eleanor Island and Shoup Bay, Prince William Sound, Alaska, 1995.

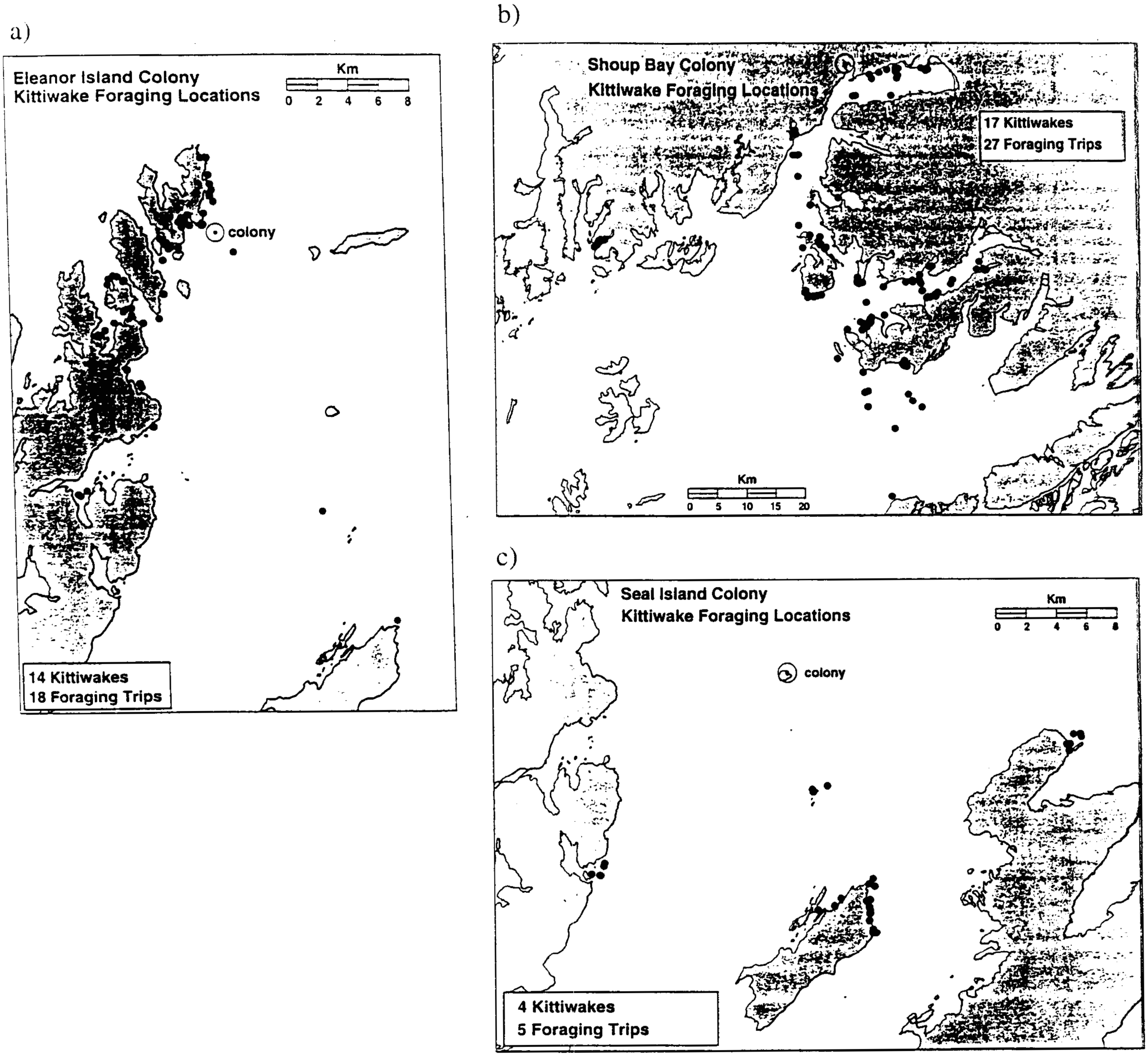


Figure 8. Foraging locations of adult Black-legged Kittiwakes (with 1 or 2 chicks) at colonies located near Shoup Bay (a), Eleanor Island (b), and Seal Island (c) during the 1995 nesting season in Prince William Sound, Alaska.

APPENDIX F

APEX: 95163 F

Appendix F-1

APEX:95163F

A COMPARISON OF THE BREEDING AND FEEDING ECOLOGY OF PIGEON GUILLEMOTS AT NAKED AND JACKPOT ISLANDS IN PRINCE WILLIAM SOUND

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STUDY HISTORY

The field work for Restoration Project 95163F was conducted during the summer of 1995. A similar effort was made in 1994 as Project 94173. Previous related projects have been funded by the Trustee Council. Bird Study Number 9 (Oakley and Kuletz 1994), begun in 1989 immediately after the oil spill, compared various population and reproductive parameters of pigeon guillemots before (Oakley and Kuletz 1979, Kuletz 1981, 1983, Oakley 1981) and after the spill. Also, Project 93034, an extensive survey of pigeon guillemot colonies throughout Prince William Sound, was conducted during the summer of 1993 (Sanger and Cody 1994).

INTRODUCTION

The pigeon guillemot (*Cepphus columba*) is a pursuit–diving seabird that forages mostly in nearshore waters about 10–30 m deep (Storer 1952, Ewins 1993). Adults feed primarily on benthic fish and invertebrates, but also on schooling fish. Chicks are fed mostly fish. Guillemots nest in small scattered colonies or in solitary pairs in natural cavities along rocky shorelines. Unlike most other members of the family Alcidae, the pigeon guillemot typically lays a clutch of two eggs. The chicks are semiprecocial, usually spending about 35 to 45 days in the nest. During the daylight hours, they are fed by both parents, which return to the nest with one fish at a time in their bills.

The population of pigeon guillemots in Prince William Sound (PWS) has decreased from about 15,000 in the 1970's (Dwyer et al. ND) to less than about 5,000 in the 1990's (Agler et al. 1994, Sanger and Cody 1994). There is some evidence suggesting that this population was in decline before the *T/V Exxon Valdez* oil spill in March of 1989 (Oakley and Kuletz 1994). Over 600 guillemot carcasses were recovered after the spill, but this might represent only 10–30% of the actual number killed (Piatt et al. 1990). Based on censuses taken around the Naked Island complex (Naked, Peak, Storey, Smith, and Little Smith Islands), prespill counts (ca. 2,000 guillemots) were roughly twice as high as postspill counts (ca. 1,000 guillemots; Oakley and Kuletz 1994). Also, on Naked I., the relative decline in the numbers of guillemots was greater along oiled shorelines than along unoiled shorelines (Oakley and Kuletz 1994).

King and Sanger (1979) considered the pigeon guillemot to be one of the birds that is most vulnerable to oil spills because of its nearshore foraging habits. Several studies have reported sublethal toxic effects of oil on marine birds (Peakall et al. 1980, Peakall et al. 1982, 1983 as cited in Oakley and Kuletz 1994). Marked declines in populations of the pigeon guillemot or its congener, the black guillemot (*C. grylle*) have been attributed to oil pollution (Ainley and Lewis 1974, Asbirk 1978, Ewins and Tasker 1985).

At Naked I., adult guillemots delivered fewer schooling fish, particularly sand lance (*Ammodytes hexapterus*), to their chicks after the spill than before the spill (Oakley and Kuletz 1994). Numerous studies have shown that changes in the availability of prey species can result in widespread reproductive failure of seabirds (Vermeer et al. 1979, Anderson et al. 1982, Springer et al. 1986, Safina et al. 1988, Uttley et al. 1989, Furness and Barrett 1991; but see Burger and Piatt 1990).

Predation on eggs and chicks, not important previously on Naked I. (Oakley 1981, Kuletz 1983), has been a major factor contributing to the lower reproductive success of guillemots after the spill (Oakley and Kuletz 1994). Studies at otherguillemot colonies have related lowered productivity or emigration to the presence of mammalian predators (Asbirk 1978, Petersen 1979, Cairns 1985, Ewins 1985, 1989).

Thus, because 1) pigeon guillemots constitute an injured resource, 2) their population has been declining for some time, 3) there has been a marked change in their diet, 4) predation at the nest is more prevalent than in the past, and 5) there exist valuable prespill data for this species in PWS, they have been selected for intensive study. We studied the breeding and feeding ecology of pigeon guillemots nesting on two islands in the western part of PWS and found important differences between the two populations relative to the foraging habits of adults, diet of chicks, and the levels of predation occurring during the chick stage.

OBJECTIVES

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

2.Determine if adult survival and recruitment are affecting the population of guillemots by banding adults and chicks.

METHODS

Study Area

Our field season extended from 1 June through 23 August 1995. Our two principal study sites were located on Naked I. and Jackpot I. in PWS (Fig. 1). Naked I. (ca. 3,862 ha) has a maximum elevation of 400 m and is part of a group of three main islands. The bays of Naked I., and the passages between it and the two neighboring islands, Peak and Storey, form an expanse of water that is less than 100 m deep. Jackpot I. (ca. 1.6 ha) has a maximum elevation of about 15 m and is located near the mouth of Jackpot Bay and the southern entrance to Dangerous Passage. The shoreline of each of these islands is characterized by low cliffs and cobble or boulder beaches; high, steep, exposed cliffs occur along portions of the eastern shores of the Naked Island group. Each is forested to its summit; the principal species of tree are Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and mountain hemlock (*T. mertensiana*). All of these islands are part of the Chugach National Forest.

Naked I., about 30 km southwest of the site where the *T/V Exxon Valdez* ran aground on Bligh Reef, was one of the first areas to be oiled (see Fig. 3, Kuletz 1994:35). Between 27 March and 2 April, 1989, portions of the eastern, northern, and northwestern shorelines were oiled. The prevailing winds moved most of the oil to the south, away from the island, but between 7 and 9 April, southerly winds brought the oil into contact with the southern and western shorelines of Naked I. again. Jackpot Island was not oiled.

Selection of Study Sites

We chose Naked I. in 1994 as one of our principal study sites and as a base of operations. This island has been used as a base camp for several previous guillemot studies (Eldridge and Kuletz 1980, Oakley 1981, Kuletz 1983, Oakley and Kuletz 1994). The two main criteria for determining the potential of a new guillemot colony as a study site were the number of breeding guillemots in that colony and the accessibility of the nest sites. Jackpot I. was the only other island that met our criteria.

Censusing: Population and Colony Attendance

Pigeon guillemot populations at Naked, Peak, Storey, Smith, and Little Smith Islands (the Naked Island complex) were censused by circumnavigating each island in a small boat at a distance of between 50 m and 100 m from the shore when the weather was good and the tides were near high. These censuses were conducted on 3 June during the same time of day (0400–1000 Alaska Daylight Time) and at the same time of year that previous censuses of the this area were made. Guillemots at Jackpot I. were also censused in early June. Also, throughout the breeding season, but mostly during the chick–rearing period, counts of the maximum number of guillemots present at a particular colony were made at 15–minute intervals whenever that colony was being monitored from a boat or a blind.

Nest Sites and Monitoring

At Naked I., we monitored those nests used in 1994 plus several new ones as well. Most were at colonies along the western shoreline. Personnel on Jackpot I. used the 1994 sample plus numerous new ones. Because of their inaccessibility or our inability to determine their contents, some of these nests were monitored only during feeding observations and were not used as part of our productivity sample. Nest sites were classified according to the type of habitat in which they occurred: tree root systems, rock crevices, or talus piles.

We checked nests frequently around hatching to determine hatch dates and then at three–day intervals until near fledging, at which time they were again checked more frequently.

Banding and Morphometrics

Some adults were caught by hand at the nest or with a mist net as they attempted to deliver food to their chicks. Adults were banded on the left foot with a USFWS metal band (bottom) and a color plastic cohort band (top), and on the right foot with a unique combination of two color plastic bands. Chicks were banded on the right foot with a USFWS metal band (bottom) and a color plastic cohort band (top) and on the left foot with a unique combination of two color plastic bands. The 1995 cohort plastic band was orange.

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

Nesting Chronology

Only nests that were discovered during the egg stage were used to construct the nesting chronology of guillemots at Naked and Jackpot Islands. Laying dates were sometimes back–calculated from hatching dates assuming an incubation period of 32 days for the first egg and 30 days for the second egg.

Productivity

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

Productivity (chicks fledged/eggs laid) was defined as hatching success (eggs hatched/eggs laid) times fledging success (chicks fledged/eggs hatched). Thirty days is approximately the minimum time spent in the nest by guillemot chicks; the actual time is often much longer. For purposes of estimating fledging, however, any chick surviving in the nest for 30 days was assumed to have fledged. Other measures of productivity used were mean clutch size, number of chicks hatched per nest, and number of chicks fledged per nest.

Predation

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

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

Chick Growth and Fledging Weights

We calculated the growth rates of chicks as the change in weight (g/d) during the linear phase of their growth, which is the period eight to 18 days after hatching (Koelink 1972). Two methods were used to calculate growth rate. In the first (i.e., difference method), the difference between the first and last weights for a given chick during this period was divided by the numbers of days between the two measurements. In the second (i.e., slope method), a linear regression was done on all weights obtained from a given chick within this period to determine the slope (growth rate). Fledging weight was assumed to be the last recorded weight of a chick that was measured within 24 hours of fledging at Naked I. and within 72 hours of fledging at Jackpot I.

Chick Provisioning and Diet

Either from blinds or from boats we observed adult guillemots bringing food items to their chicks throughout the chick–rearing period. Feeding watches ranged from 0.5 h to 18 h; shifts lasted up to 4.5 h. Usually only one observer was in the blind at a time. Binoculars and spotting scopes were used to identify prey items in the bills of guillemots to the lowest possible taxon or "type" of prey. When time and visibility permitted, we also estimated the length of the prey item as a multiple of the guillemot's bill to the nearest half bill length. We recorded the time of each delivery and the number of the nest to which the prey was delivered, as well as how long the adult first remained on the water with the fish before delivering it. We also obtained information about chick diet by retrieving fish found in the nests or by intercepting fish at or near the nest entrance with a mist net.

To test whether deliveries were distributed more or less evenly throughout the daylight hours, the day was divided into three approximately equal periods: early (0600–1100), mid–day (1100–1700), and late (1700–2200). Although a few deliveries occurred very early and very late, when it was too dark to make reliable observations, the period used for analysis was truncated at both ends in accordance with the times listed above. Using a Chi–square goodness–of–fit test, the actual number of deliveries observed during each of the three periods was compared to the expected number of deliveries in those periods if they had been distributed evenly throughout the day.

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

Sampling of Fish

We occasionally sampled waters (< ca. 15 m) around Naked I. with fish traps set on the bottom or occasionally above it to obtain specimens of fish for analysis of energy content or to aid us in identifying those in the bills of guillemots. Beach seine sets were made at several locations around Naked I. Seines were made at or around high tide at beaches having a substrate that would prevent snagging the net. We measured wet weight and standard length of all fish caught in the traps and from samples taken from the beach seine catches.

Data Analysis

Comparisons between Naked and Jackpot Islands or between years were made with two–tailed t–tests, 2 x 2 contingency tables analyzed with a G–test and corrected for continuity, Chi–square tests, and ratio estimation with Z statistics. The level of significance was set at ? = 0.05. All means are reported as the mean plus or minus one standard deviation.

RESULTS

Censusing

In 1995, 887 pigeon guillemots were counted around the shorelines of the Naked Island complex during the census on 3 June (Table 1). About 80 guillemots were counted around Jackpot I. in early June. Maximum counts of pigeon guillemots usually occurred in the early morning hours, shortly after first light. The birds were first detected in rafts a considerable distance from shore, then gradually moved closer to the colony. The maximum number of guillemots counted at two of the Naked I. colonies was as follows: Nomad (30 on 26 July) and Tuft (38 on 14 July).

Nesting Chronology

Nesting chronology at Naked and Jackpot Islands was similar in 1994. Nesting chronology at

Naked I. in 1995 was similar to that of 1994. Dates for Naked I. in 1995 are as follows: median laying (1 June, range 20 May to 24 June); median hatching (1 July, range 21 June to 26 July); and median fledging (10 August, range 23 July to 25 August). The mean number of days that chicks spent in the nest was 39.4 ? 3.3 d (n = 21, range = 34 – 45 d) at Naked I. and 38.0 ? 1.9 d (n = 11, range = 35 – 40 d); the difference was not significant (t = 1.264, df = 30, *P* > 0.20).

Productivity

The mean clutch size was 1.77 ? 0.43 (n = 39) on Naked I. and 1.79 ? 0.41 (n = 38) on Jackpot I; the difference was not significant (G = 0.003, df = 1, *P* > 0.95). Of a total of 69 eggs (39 clutches; 30 with 2 eggs, 9 with 1 egg) on Naked I., 55 hatched, 2 were incubated but failed to hatch, 7 were abandoned, and 5 were probably taken by predators. Of a total of 68 eggs (38 clutches; 30 with 2 eggs, 8 with 1 egg) on Jackpot I., 45 hatched, 17 were abandoned, 4 failed to hatch, and 2 were probably taken by predators. Of a total of 55 chicks monitored on Naked I., 30 fledged, 7 were found dead in or near the nest, 1 was killed by a magpie, 9 were probably taken by predators, and the fate of 8 others is unknown. Of a total of 45 chicks monitored on Jackpot I., 25 chicks fledged, 7 were found dead in the nest, 2 were probably taken by predators, and the fate of 11 others is unknown.

Hatching success was 0.80 (n = 69) at Naked I. and 0.66 (n = 68) at Jackpot I.; it was not significantly different between islands (Z = 1.38, *P* = 0.0838), nor between years at each island (Naked I., Z = 1.15, *P* = 0.1251; Jackpot I., Z = 1.27, *P* = 0.1020). Fledging success was 0.54 (n = 55) at Naked I. and 0.56 (n = 45) at Jackpot I.; it was not significantly different between islands (Z = 0.09, *P* = 0.4641). Fledging success was significantly different between years at Jackpot I. (Z = 1.89, *P* = 0.0294), but not at Naked I. (Z = 0.26, *P* = 0.3974).

Twenty–one of 39 nests (54%) at Naked I. produced at least one fledgling compared to 20 of 38 nests (53%) at Jackpot I. The difference between the proportion of successful nests was not significant (G = 0.015, df = 1, *P* > 0.90) between the two islands.

Clutch size, hatching success, and fledging success are compared for nine years at Naked I. and two years at Jackpot I. in Figures 2 – 4. Weighted averages for all years at Naked I. are given inside the box in each figure. Weighted averages from numerous studies in British Columbia, Washington, and Oregon (see Ewins 1993 and references therein) are also given for clutch size and fledging success. It is important to note that the definition of fledging used in these other studies may not be the same as ours (i.e., chicks surviving to 30 days).

Predation

In 1995, there was less direct evidence of predation on Naked I., but the disappearance of chicks too young to fledge strongly suggested that predation was responsible. The same was true for Jackpot I., although the nature of the nests (mostly cavernous tree root systems) made it more difficult to determine with certainty that the chicks were not present.

A magpie was observed flying out of a nest containing the still–warm carcass of a young guillemot chick on Naked I. Magpies and crows were routinely seen following fish–carrying guillemots up to, and occasionally into, the guillemot nests on Naked I. At Jackpot I., a crow forced a guillemot chick out of its nest, over a ledge, and into the water; the chick was not seen again. A crow was seen entering a nest on Jackpot I. containing two chicks, then remained inside for approximately five minutes; one chick was missing the next day. Largely intact, empty eggs with oval–shaped holes (ca. 25 mm long) or egg shell fragments were found outside the entrances of nests on both islands. Piles of feathers were found on Jackpot I. associated with apparent river otter scat. On Naked I. two chicks disappeared from a nest that was just above a river otter latrine site. The same nest was definitely depredated in 1994 (blood feathers and a chewed–off leg from a guillemot were found just outside that nest). The nearly constant alarm calling by guillemots when crows, magpies, or river otters were nearby strongly suggests that guillemots perceived these animals as threats. All three of these potential predators were seen often at both islands.

Chick Growth and Fledging Weights

Using the difference method, the mean growth rate of chicks was 19.5 ? 4.4 g/d (n = 13, range = 11.8 – 26.7 g.d) at Naked I. and 17.4 ? 2.7 g/d (n = 16, range = 12.44 – 22.6 g/d) at Jackpot I.; this difference was not significant (t = 1.550, df = 27, P > 0.10; see Table A1 for a comparison of growth rates from previous years based on this method). Using the slope method, the mean growth rate of chicks during the linear phase of their growth was 19.5 ? 5.0 g/d (n = 13, range = 10.3 – 26.8 g/d) at Naked I. and 16.7 ? 2.8 g/d (n = 15, range = 11.9 – 22.2 g/d) at Jackpot I.; this difference was not significant (t = 1.867, df = 26, *P* > 0.05).

The mean peak weight of chicks was 480 ? 65 g (n = 22, range = 350 – 612 g) at Naked I. and 473 ? 45 (n = 10, range = 392 – 521 g) at Jackpot I.; this difference was not significant (t = 0.321, df = 30, *P* > 0.50). The mean fledging weight of chicks was 455 ? 74 g (n = 22, range = 311 – 561 g) at Naked I. and 468 ? 43 g (n = 10, range = 392 – 521 g) at Jackpot I.; this difference was not significant (t = 0.485, df = 30, *P* > 0.50; see Table A2 for a comparison of fledging weights from previous years).

Chick Provisioning and Diet

Collectively, guillemots delivered fish to their chicks throughout the daylight hours at Naked and Jackpot Islands (Fig. 5). Neither distribution was significantly different from a theoretical even distribution of deliveries made throughout the day (Naked I., ?^{2} = 0.435, df = 2, *P* > 0.75; Jackpot I., ?^{2} = 0.685, df = 2, *P* > 0.50). Feeding rates varied considerably among nests. At any particular nest, there were periods of several hours in which no deliveries were made. The tidal cycle had no significant effect on the rate of deliveries. The time after sunrise or time before sunset also had little or no effect on the rate of deliveries. Delivery rates to guillemot nests at Naked and Jackpot Islands for 1994 and 1995 are shown in Figure 6.

The diet of pigeon guillemot chicks at the two islands was considerably different (Fig. 7). Schooling fish accounted for about 22% of the chick diet at Naked I. and about 41% at Jackpot I. The fact that three capelin and no herring were among the 26 fish recovered from or intercepted at guillemot nests suggests that the herring/smelt category may have been dominated by capelin at Naked I. At Jackpot I., seven herring and no capelin were among the 22 fish similarly obtained; herring almost certainly dominated the herring/smelt category at this island. The other fish in these two samples are listed in Table 2. At each island there were also marked differences between years. At Naked I., the proportion of sand lance delivered was the same in both years, but that of herring/smelt and gunnels increased, while that of gadids decreased considerably. At Jackpot I., the proportion of sand lance, gunnels, and pricklebacks increased, while that of herring/smelt and gadids decreased.

Foraging

Pigeon guillemots at Naked I. sometimes foraged directly in front of their colony in water less than 15 m deep, but usually foraged in nearby bays or on the broad, shallow–water (< 25 m deep) shelf surrounding Naked I. Guillemots were rarely seen foraging in the immediate vicinity of Jackpot I., but instead flew toward shallower areas near the mouths of Jackpot Bay or Icy Bay or the southern entrance to Dangerous Passage (each ca. 2–4 km distant), presumably foraging there. Guillemots carrying fish were observed returning to the colony at Jackpot I. from the general direction of these areas.

Fish Types Caught in Traps and Seines

Shrimp (mostly *Pandalus danae* and *Eualus gaimardii*) were the most frequently taken animal in the fish traps at Naked I., but were not counted because they were never seen being delivered to guillemot nests in 1994 or 1995. Of 131 fish caught in the traps in 1995, the relative proportions of each type were as follows: 38 arctic shannies (*Stichaeus punctatus*), 30 pricklebacks (*Lumpenus fabricii*), 20 crescent gunnels (*Pholis laeta*), 25 sculpins (three species), 8 walleye pollock (*Theragra chalcogramma*), 4 Pacific cod (*Gadus macrocephalus*), four greenlings (three species), and two northern ronquils (*Ronquilus jordani*). Of 36 fish caught in traps around Jackpot I. in 1995, the relative proportions of each type were as follows: 12 arctic shannies, 8 northern ronquils, 5 crescent gunnels, 2 Pacific cod, 2 pricklebacks (*Lumpenus* spp.), 2 cockscombs (*Anoplarchus* spp.), and one sculpin.

Few benthic fish were caught with the beach seines. Either herring or sand lance or sometimes both made up the bulk of the beach seine sets at most locations (Table 3; see Figure A1 for locations of beach seine sets).

DISCUSSION

Censusing

Early season counts of pigeon guillemots in the Naked Island complex suggest that their population has decreased considerably from 1978 and 1979. The low counts for Naked I. and the Naked Island complex in 1995 may not reflect the true numbers of guillemots in the area; replicate counts may have resulted in higher numbers. Vermeer et al. (1993a) reported that the optimal time to determine the population of nesting guillemots was at high tide in the morning. Observed colony attendance patterns of guillemots at Naked I. in 1994 indicate that the time of day is extremely important when planning guillemot censuses (Hayes 1995). Replicate counts at the appropriate time of day and tidal cycle would increase our confidence in the actual number guillemots at Naked I.

Productivity

The ideal and most straightforward method of calculating productivity is from a sample of known nests that are followed from before egg-laying through fledging. We did have known nests on both islands that had been found in 1994, but because of when we arrived at the study sites (1 June, when some eggs had already been laid), we had to include nests monitored from incubation through fledging as well. It is important to note that the nests used for measuring productivity do not constitute a "sample" in the true sense of the word. On Naked I., they represent all of the nests that we were able to find and then reach, not a random sample of nests on the island. We can only assume that they are fairly representative of the island as a whole. On Jackpot I., because we believe that we have found most of the nests on the island, they constitute the actual population.

Although the difference was not significant, hatching success was lower at both islands in 1995 than in 1994, especially at Jackpot I. This is likely the result of increased disturbance at the colony; researchers were present on this small island almost every day during the incubation and early hatching period lookinginto nests to determine hatch dates or searching for new nests. Several investigators at other guillemot colonies have observed reduced productivity apparently associated with human disturbance (Bergman 1971, Cairns 1980, Vermeer et al. 1993b). Still, the values reported here for productivity of the pigeon guillemots at Naked and Jackpot Islands are well within the range of values reported for this species in other areas of its range (see Ewins 1993 for a review).

Predation

Oakley and Kuletz (1994) noted that the primary difference in productivity of pigeon guillemots on

Naked I. that they observed following the oil spill was lowered nesting success, which was the result of nest predation during the chick stage. Increased predation pressure relative to that in the past appears to be a continuing problem on Naked I. Its detrimental effects on guillemot productivity should not be underestimated.

Although we have proof only of avian predation, we strongly suspect that mammalian predators are responsible for some of the disappearances of eggs or young guillemot chicks. River otters were seen frequently in the vicinity of our study colonies in both years and are the most likely mammalian predator, but mink may also be involved. On Naked I. in 1994, we found carcasses of guillemot chicks with the heads chewed off, suggesting that some kind of mustelid is likely responsible for the predation. Ewins (1985) reported that on the island of Mousa in Shetland, otters (*Lutra lutra*) killed both chicks and incubating adults, and that decapitated carcasses were a sure sign of these predators. Ewins also noted that there were few nests inaccessible to them. Likewise, many of the nests on Naked I., including some of those in rock crevices, and all of the nests on Jackpot I. are probably accessible to otters. Few, if any, nest sites would be inaccessible to the smaller and more agile mink. Crows and magpies are the likeliest avian predators on eggs and chicks. Other studies indicate that crows are a major source of egg predation and sometimes take young chicks as well (Emms and Verbeek 1989, Ewins 1989).

Whatever predators are responsible for taking eggs and chicks on Naked I., the increased predation pressure there might have caused breeding guillemots to move elsewhere. It is possible that guillemots in PWS are emigrating from some colonies on the mainland and large islands like Naked I. to smaller ones like Jackpot I., where ground predators have not become permanently established. Emigration of black guillemots from colonies in Sweden and Iceland have been attributed to predation by mink (Asbirk 1978, Petersen 1979). The principal factor controlling local distributions in Scotland appears to be introduced mammals (M.L. Tasker, personal communication).

River otters and mink typically forage in the intertidal zone.. A study that compared the diet of river otters in two areas of PWS before and after the spill showed that there were significant declines in species richness and diversity(mostly bony fish and mollusks) in otter diets on the oiled area compared to the unoiled area (Bowyer et al. 1994). Another study, also conducted in PWS, clearly indicated that oil contamination was affecting the health of river otters up to two years after the spill (Duffy et al. 1993, 1994). Contamination of the normal intertidal food supply of river otters and mink might have ultimately caused some of these predators to switch to other types of prey, including guillemot chicks.

Adults, and especially fledglings, are probably sometimes taken by large raptors. Bald eagles are known predators of adult guillemots in British Columbia (Vermeer et al. 1989 as cited in Ewins et al. 1993). Beaks of guillemots were found beneath an eagle's nest on Naked I. during a previous study (K. Kuletz, personal communication). We often witnessed a change in the guillemots' behavior when an eagle flew into the area. The guillemots' reactions to the presence of bald eagles (e.g., flushing, moving farther offshore, alarm calling, and diving) suggest that they perceive this potential predator as a real threat.

Chick Growth and Fledging Weights

In 1995, our estimates of growth rates during the linear phase of growth (Naked I., 19.5 g/d; Jackpot I., 17.4 g/d) were similar to those of Oakley and Kuletz (1994) at Naked I. (range = 16.6 – 23.8 g/d), as were our estimates of fledging weights. Growth rates were also similar to those reported by Koelink (1972) for Mandarte Island (15.9 g/d) and Ainley and Boekelheide (1990) for the Farallon Islands (16.5 g/d).

Both methods of estimating chick growth indicated that those on Naked I. grew faster than those on Jackpot I. in 1995. However, in 1994 our data suggested that chicks on Jackpot I. grew faster and fledged at greater weights than those on Naked I. It is important that caution be used when making comparisons based on these data. The sample sizes were small in both years, especially for growth rate in 1994. Also, our estimates of fledging weight in 1995 were far superior to those of 1994 (there was a significant difference between islands in 1994 but not in 1995).

Chick Provisioning

Members of the genus *Cepphus* typically lay two eggs. Most other alcids lay only a single egg, but the near–shore foraging habits of guillemots probably account for their ability to raise two chicks. Mehlum et al. (1993) maintain that long–distance foraging by black guillemots, which typically raise two–chick broods and have a high wing loading relative to most other seabirds, is too energetically demanding and might exceed their maximum sustainable working level. Koelink (1972) argues this same point for chick–rearing pigeon guillemots. In his study, although artificial broods of three were successfully raised to fledging, there was a proportional decrease in the amount of food delivered per chick throughout the nestling period. In black guillemots also, artificial triplets have been successfullyraised but with differing results regarding fledging weights. In Denmark, the mean fledging weight of triplets was higher than that of chicks from normal broods (Asbirk 1979 as cited in Harris and Birkhead 1985). In Iceland, triplets fledged at lower mean weights than chicks from normal broods (Petersen 1981 as cited in Harris and Birkhead 1985).

Our measured rates of food deliveries to individual nests (range = 0.31 – 1.38/nest/hr at one–chick nests; range = 0.38 – 1.56/nest/h at two–chick nests) are comparable to those of other studies of *Cepphus* guillemots (Thoresen and Booth 1958, Bergman 1971, Asbirk 1979 as cited in Harris and Birkhead 1985, Cairns 1981, 1987, Kuletz 1983). Without a knowledge of the weight of each prey item delivered, a comparison of provisioning rates (i.e., g/h/chick) is impossible. Furthermore, fish vary considerably in their composition of lipids, proteins, and carbohydrates. Fish higher in lipids have a higher energy content, which can be particularly relevant to the reproductive success of the seabirds feeding upon them. Also, the lipid content even within a single species of fish can vary widely with season, sex, reproductive status, and age class (D. Roby, personal communication). It is almost impossible to accurately estimate the weight of prey items delivered to chicks noninvasively. Measuring the actual energy content of the prey cannot be done by noninvasive means; prey must be intercepted and analyzed in the laboratory. Obviously, this cannot be done repeatedly at the same nest without affecting the food intake of the chicks involved.

Foraging

The maximum diving depth of black guillemots is about 50 m (Piatt and Nettleship 1985). Assuming that the pigeon guillemot has similar diving capabilities, it is restricted to waters no deeper than this when feeding on benthic prey items. The pigeon guillemots breeding on Naked I. generally forage around the island, usually within about 600 m of the shore and in water shallower than 25 m (Kuletz 1983). There is a broad, shallow–water shelf surrounding Naked I. and the neighboring islands (see Fig. 14 in Hayes 1995), which allows guillemots to forage nearby. On Jackpot I., there is very little shallow water immediately around the island (see Fig. 15 in Hayes 1995), and thus guillemots breeding there fly greater distances to obtain food for their chicks. These birds apparently find it necessary to fly several kilometers to Jackpot Bay or Icy Bay or toward Dangerous Passage to find food for their chicks instead of trying to forage around Jackpot I.

Chick Diet

In 1994 and 1995, the most obvious difference in the diet of chicks at Naked and Jackpot Islands was in the proportion of schooling fish, especially herring (Fig. 7). Interestingly, herring or smelt were not noted in the diet of chicks on Naked I. in 1979 or 1980, then accounted for about 16% and 23% of the diet in 1981 and 1989, respectively, and only about two percent in 1990 and 1994 (Fig. 8,Oakley and Kuletz 1994, Hayes 1995). In the years 1979–1981 Pacific sand lance were the single largest component (42%) of the diet, while in the four years 1989–1990 and 1994–1995, sand lance accounted for a much smaller fraction (12%) of the diet.

The proportion of schooling fish in the diet of chicks might be related to the ephemeral nature of schools of this type of fish and their presence within the foraging range of guillemots. Their capture might occur only coincidentally when behavioral factors (e.g., spawning) or oceanographic factors (e.g., currents, upwelling) bring these prey into shallower nearshore waters. However, the relative increase in the proportion of gadids, presumably caught by the guillemots on or near the bottom, could indicate a pronounced shift in the ecosystem. The fact that gadids did not show up in fish traps in appreciable numbers (Kuletz 1983, Oakley and Kuletz 1994) until 1994 lends support to this hypothesis.

Because of the relatively large proportion of fish that could not be identified, especially at Naked I., the values reported above represent minimum percentage contributions of those types of fish to the total delivered. Those fish listed as unidentified were done so usually because of one of three reasons: 1) the fish was too far away; 2) it was too dark; 3) the observer did not see it for long enough; and 4) the observer got a good look at the fish but it was of a type not recognized. Because the last category was encountered infrequently, there was no distinction made between any of the above four categories when data was being recorded. There is probably a slight bias in the unidentified category in that it probably contains proportionally fewer gunnels (and perhaps pricklebacks); these fish were the easiest to identify, especially under less than optimal conditions.

Fish Types Caught in Traps and Seines

The proportion of pricklebacks caught in the fish traps is perhaps not representative of their distribution; they were rarely caught until we started "fishing" for them by setting the traps in a particular spot among some beds of eelgrass, where these fish seemed particularly abundant. Trap sites were not selected randomly, the traps were not set or checked systematically, and baits may have differed in their relative attractiveness to the different types of fish. Although arctic shannies were the most common fish caught in the traps, they were infrequently seen being delivered to guillemot chicks and were not among the samples obtained at the nests.

Beach seine sets were made at high tide and at beaches having substrates not likely to snag the net as it was pulled in. The operation was not always smooth because of snagging or other problems and some schools may have escaped before we closed the net. Few benthic fish were caught in the nets, either because they could escape under the net, or because the beaches we selected were not the appropriate habitat. Therefore, results of beach seines should not be considered quantitative.

CONCLUSIONS

There have been marked changes in the diet of guillemot chicks on Naked I. Sand lance were the single most important species in the diet of pigeon guillemot chicks on Naked I. in the late 1970's, but accounted for only about ten percent of the chick diet in 1994 and 1995. Likewise, gadids are now more prevalent in the diet than they were. The overall population of pigeon guillemots at Naked I. has decreased from about 2,200 in 1979 to about 1,300 today. The percent of breeding birds among these also appears to have decreased. However, Jackpot I. currently supports a dense, thriving colony of guillemots; over 40% of the chick diet is schooling fish, mostly herring. The decline in many guillemot populations in PWS and their failure to recover may be related to the apparent decline in the abundance of sand lance. The marked shift in the diet of guillemots from predominantly schooling to benthic fish may be linked to some key change in the ecosystem that is affecting other marine birds and mammals in PWS.

Pigeon guillemots appear to be opportunistic foragers and seem to prefer schooling fish when available. When these fish are abundant, foraging at dense schools close to shore is probably more efficient than searching for solitary demersal fish over large areas of the bottom. Because their foraging range is limited by their nearshore habits, the presence of schooling fish, especially sand lance or herring, may be essential for maintaining productive colonies of guillemots in Alaska.

Predation on eggs and chicks is still an important factor that is affecting the reproductive success of pigeon guillemots on both islands, but especially on Naked I. Its effects, and those of observer disturbance, should be considered when making comparisons of productivity between these two islands.

Future work on pigeon guillemots in PWS should focus on 1) determining what animals are responsible for the increased levels of predation at the nest site on Naked I., 2) marking chicks and breeding adults for estimating recruitment and adult survival, 3) censusing designated colonies on a regular basis using standardized methods, 4) diet composition and energy content of prey items as they relate to growth and productivity, and 5) proportion of schooling fish in the chick diet relative to the size of colonies.

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Table 1. Counts of pigeon guillemots during June censuses at Naked, Peak, Storey, Smith, and Little Smith Islands, Prince William Sound, Alaska, before and after the *T/V Exxon Valdez* oil spill. Censuses conducted between 3 and 6 June unless otherwise noted. Dashes indicate no surveys were conducted.

Year	Naked Island	Storey Island	Peak Island	Smith Island	Little Smith Island	Total
1978	1115	392	94	175	72	1965
1979	1226	495	150	301	58	2230
1980	891	--	--	--	--	--
1989[a]	615	193	73	--	--	--
1990	729	293	102	124	31	1279
1991	755	293	102	76	35	1261
1992	586	230	87	100	23	1025
1993[b]	385	242	94	75	32	828
1994	739	298	81	121	23	1262
1995[c]	550	165	38	111	23	887

[a] Census conducted on 13-14 June.

[b] From Sanger and Cody 1994 (censuses in May or June 1993)

[c] In 1994 Naked Island census was done on 30 May, Storey and Peak Islands on 31 May, and Smith and Little Smith Islands on June 1.

Note: Data from all years except 1993 and 1994 from Table 1 (Oakley and Kuletz 1994).

Table 2. Types of fish and numbers (in parentheses) recovered from or intercepted at guillemot nests on Naked and Jackpot Islands in 1995.

Naked Island (n = 26)	Jackpot Island (n = 22)
Sand lance (2)	Pacific herring (7)
Capelin (3)	Crescent gunnel (2)
Crescent Gunnel (7)	Ribbed sculpin (1)
Daubed shanny (1)	Crested sculpin (2)
Snake prickleback (1)	Walleye pollock (6)
Black prickleback (1)	Pacific tomcod (1)
High cockscomb (1)	Northern ronquil (3)
Ribbed sculpin (1)	
Roughspined sculpin (1)	
Armorhead sculpin (1)	
Red Irish lord (1)	
Walleye pollock (1)	
Pacific cod (2)	
Northern ronquil (1)	
Dover sole (1)	
Lingcod (1)	

BEACH SEINE CATCH NAKED ISLAND -- 1995 [seine95]

DATE	GAD	SALMON	GRN	SAN	GUN	SCU	FLA	HERRING	UNK	TOTAL (EST.)	SETS	LOCATION	
07/16/95	30	0	2	200	0	0	0	7	5	244	3	~H2	1
07/23/95	7	0	1	0	0	0	0	0	0	8	2	R-TH	2
07/23/95	0	0	10	1110	0	3	0	181	0	1304	2	MACPHER.	3
07/28/95	5	5	3	2	0	1	0		0	16	2	N CABIN BAY	4
08/16/95	2			50	0	0	0	200	0	252	1	E BOB DAY BAY	5
08/16/95	0	0		4	0	1	1	0	0	6	2	W BOB DAY BAY	6
08/16/95	1	2		14	0	4	0	0	0	21	2	MACPHER.	7
08/20/95	0	0	1	150	1	2	0	500	0	654	2	FUEL-CABIN BAY	8

Table 3

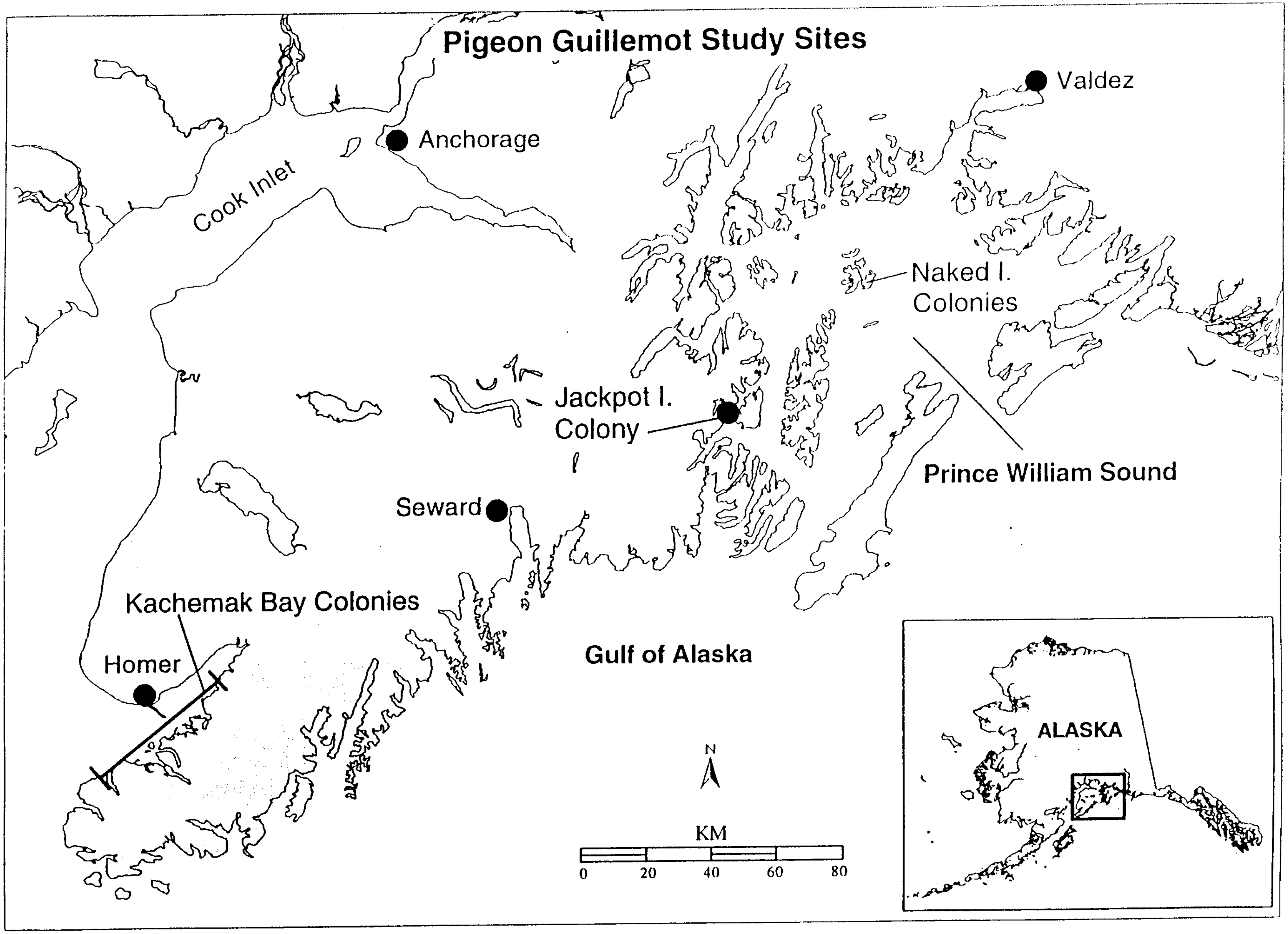

Pigeon Guillemot Study Sites
Valdez
Anchorage
Cook Inlet
Naked I. Colonies
Jackpot I. Colony
Prince William Sound
Seward
Kachemak Bay Colonies
Homer
Gulf of Alaska
ALASKA
N
KM
0
20
40
60
80

Figure 1

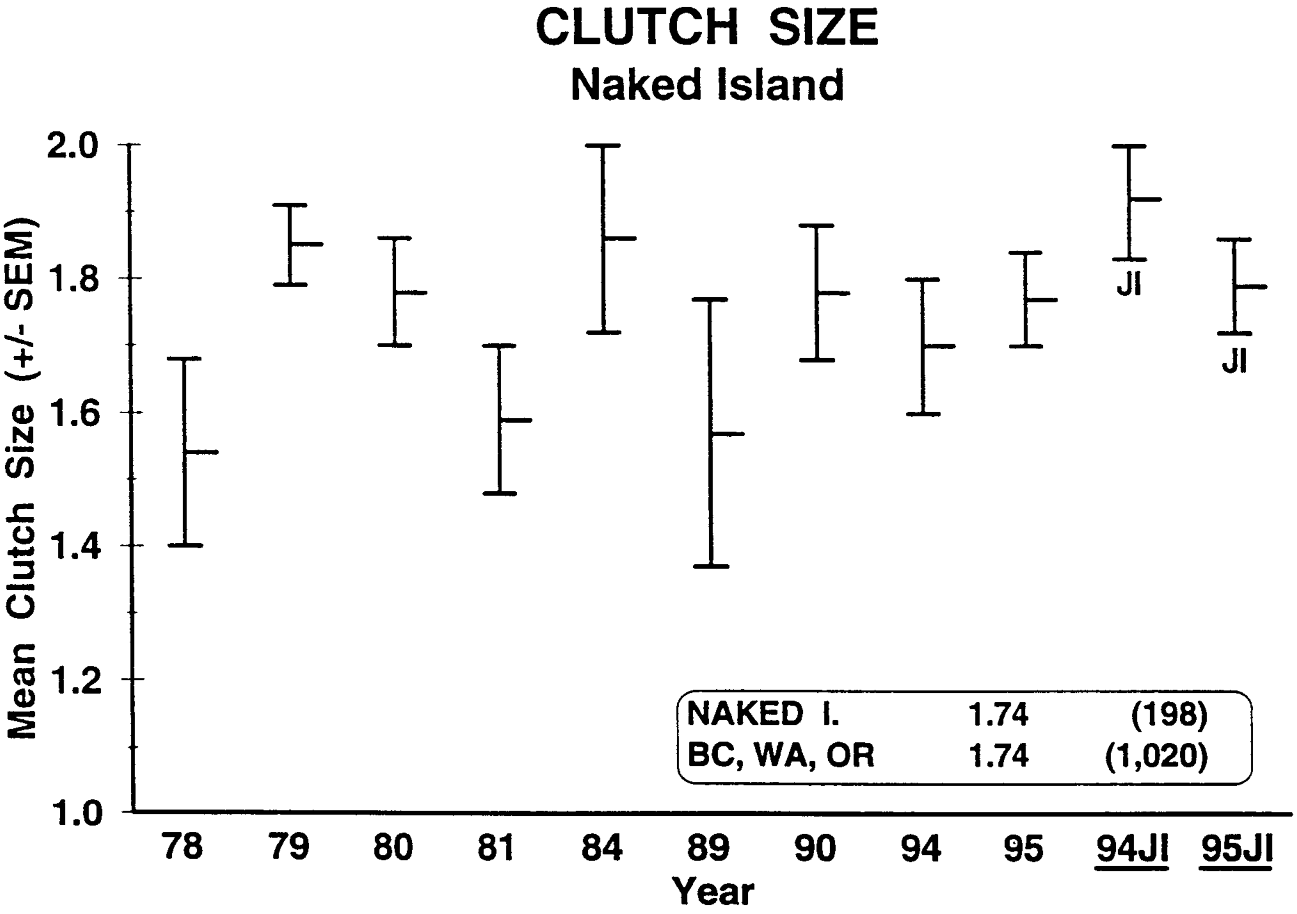

CLUTCH SIZE
Naked Island
Mean Clutch Size (+/- SEM)
2.0
1.8
1.6
1.4
1.2
1.0
78
79
80
81
84
89
90
94
95
94JI
95JI
Year
JI
JI
NAKED I. 1.74 (198)
BC, WA, OR 1.74 (1,020)

Figure 2

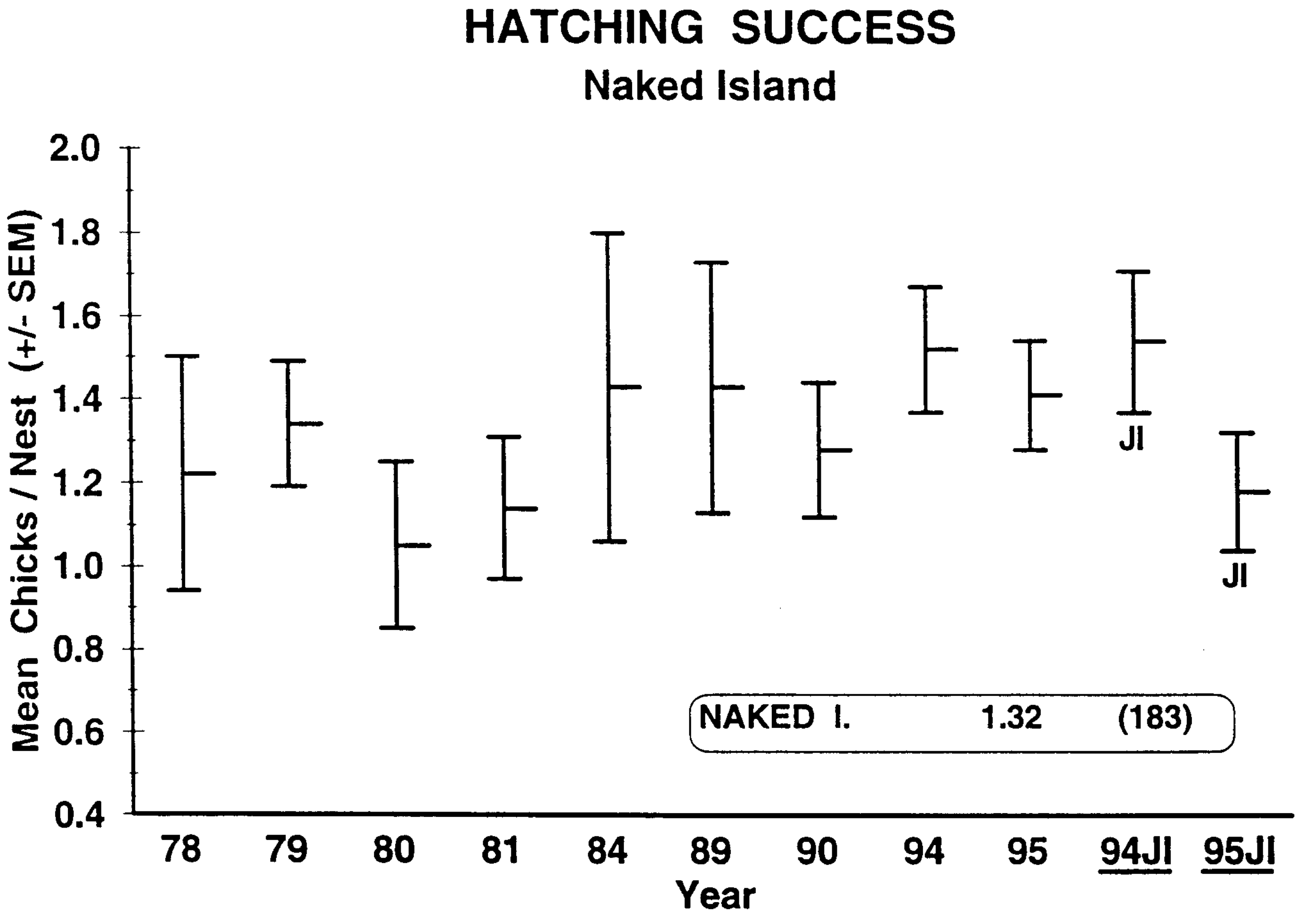

HATCHING SUCCESS
Naked Island
Mean Chicks / Nest (+/- SEM)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
JI
JI
NAKED I. 1.32 (183)
78
79
80
81
84
89
90
94
95
94JI
95JI
Year

Figure 3

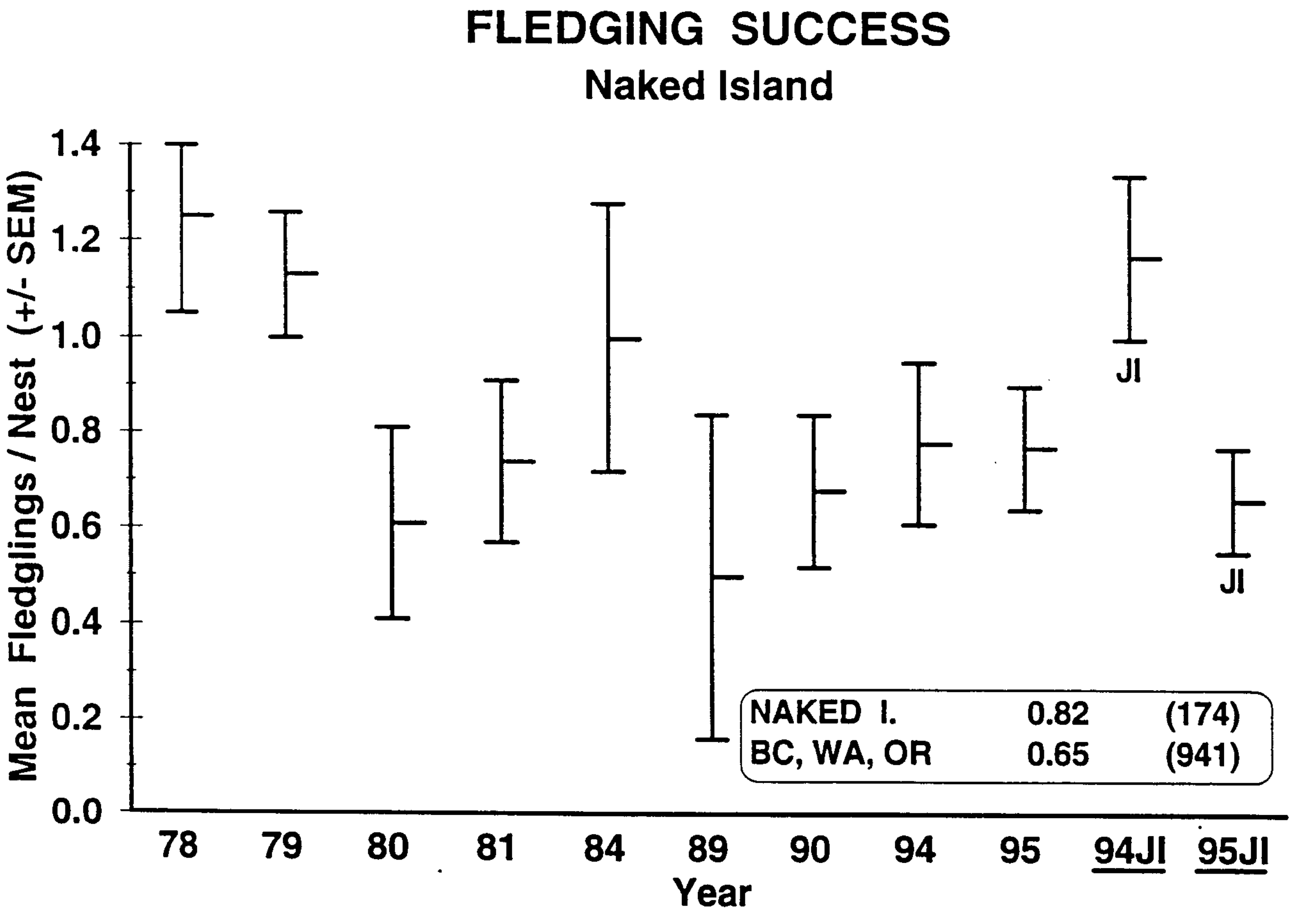
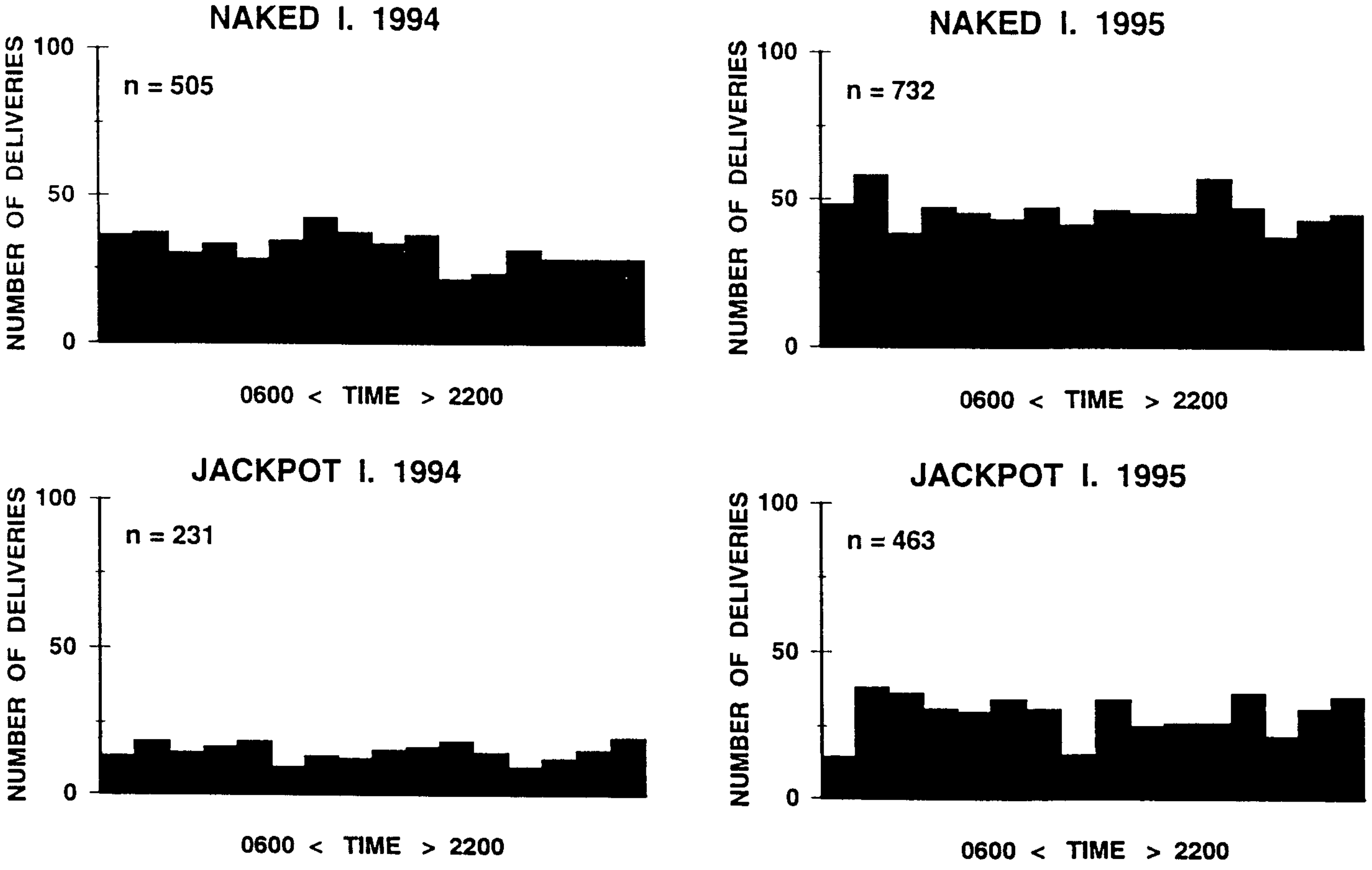

FLEDGING SUCCESS
Naked Island
Mean Fledglings / Nest (+/- SEM)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
JI
JI
NAKED I. 0.82 (174)
BC, WA, OR 0.65 (941)
78
79
80
81
84
89
90
94
95
94JI
95JI
Year

Figure 4



TEMPORAL DISTRIBUTION OF DELIVERIES

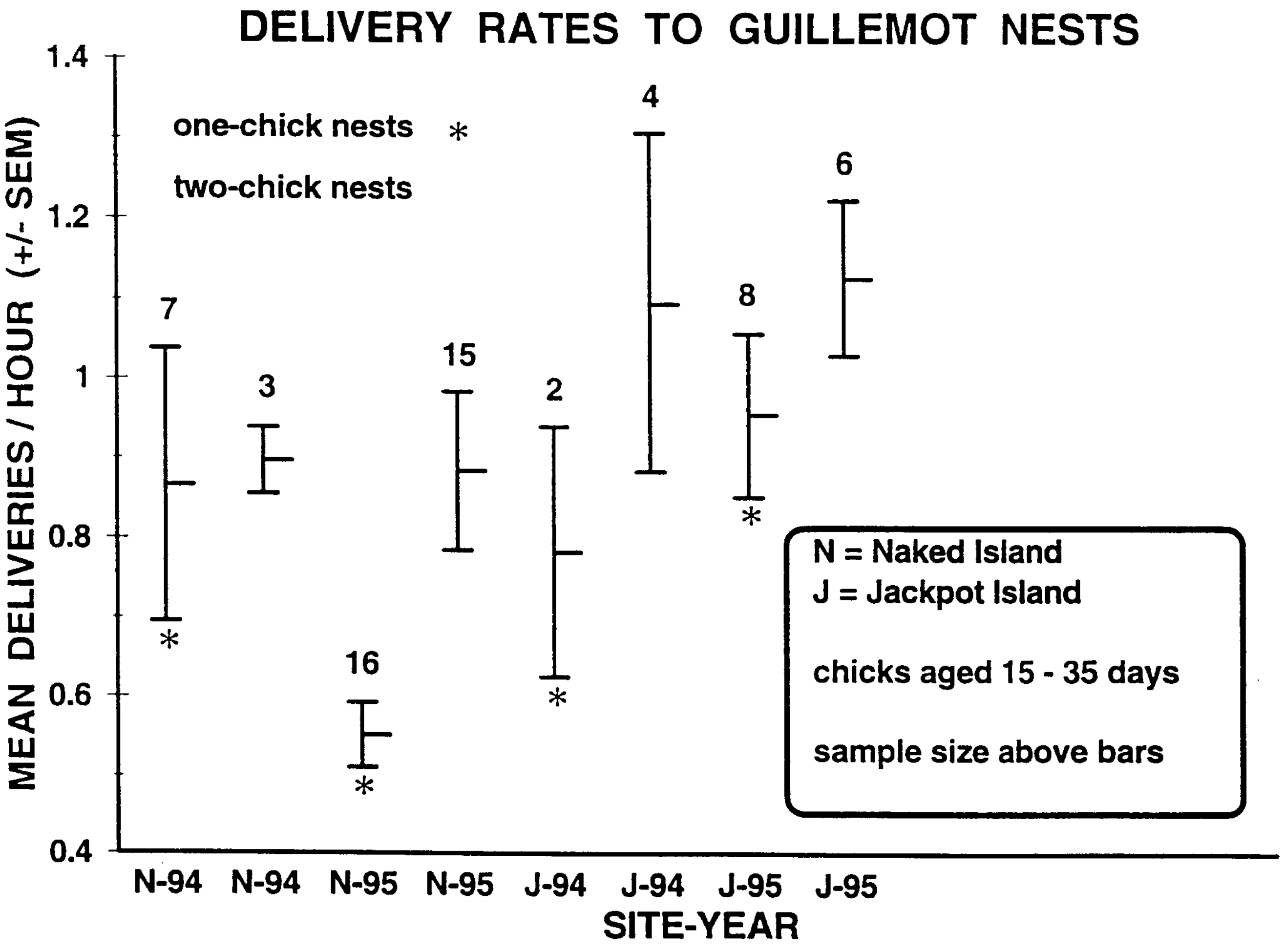
NAKED I. 1994

NAKED I. 1995

JACKPOT I. 1994

JACKPOT I. 1995

Figure 5



DELIVERY RATES TO GUILLEMOT NESTS
MEAN DELIVERIES / HOUR (+/- SEM)
1.4
1.2
1
0.8
0.6
0.4
one-chick nests *
two-chick nests
7
3
16
15
2
4
8
6
*
N = Naked Island
J = Jackpot Island
chicks aged 15 - 35 days
sample size above bars
N-94
N-94
N-95
N-95
J-94
J-94
J-95
J-95
SITE-YEAR

Figure 6

PIGEON GUILLEMOT CHICK DIET

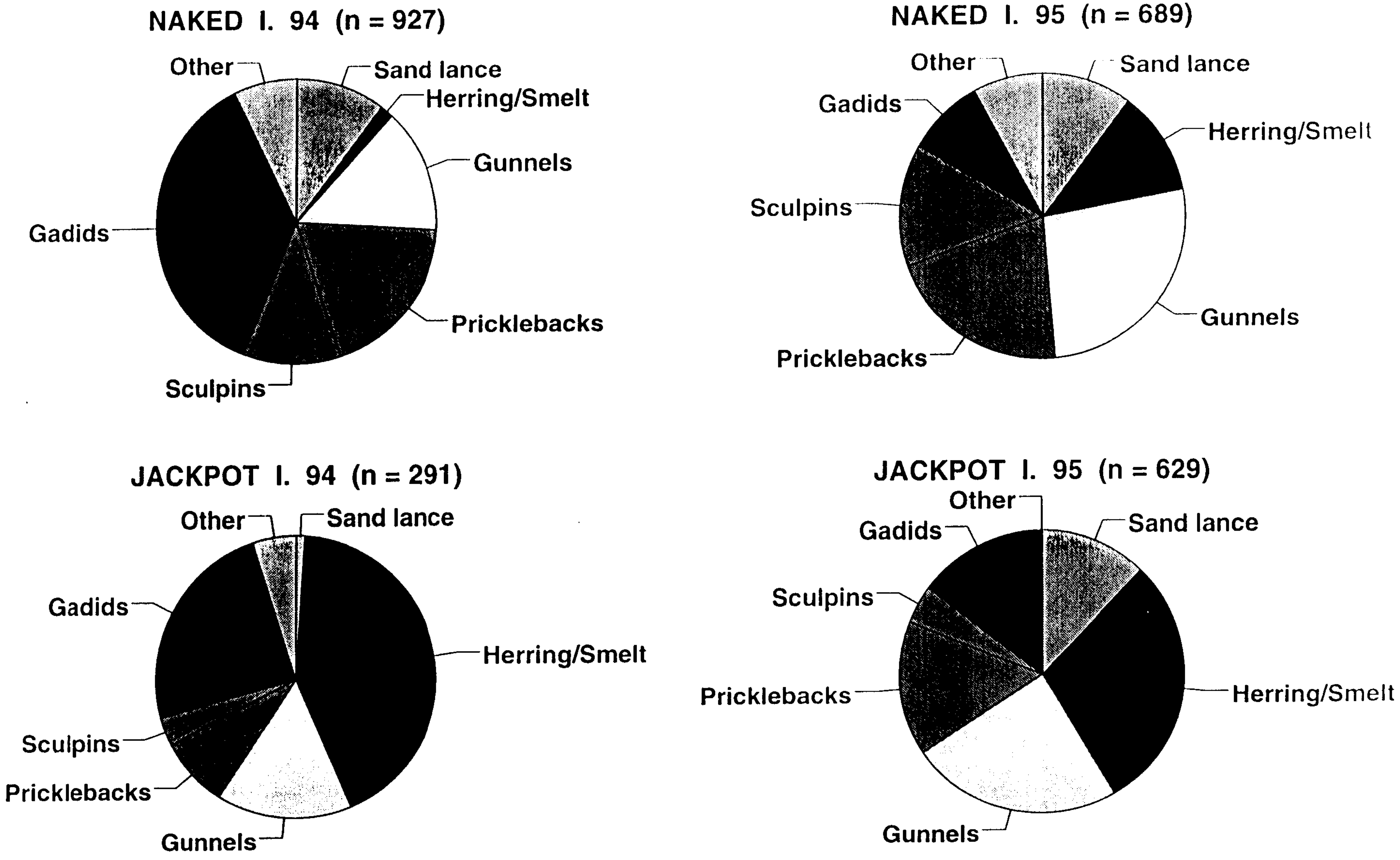


Figure 7

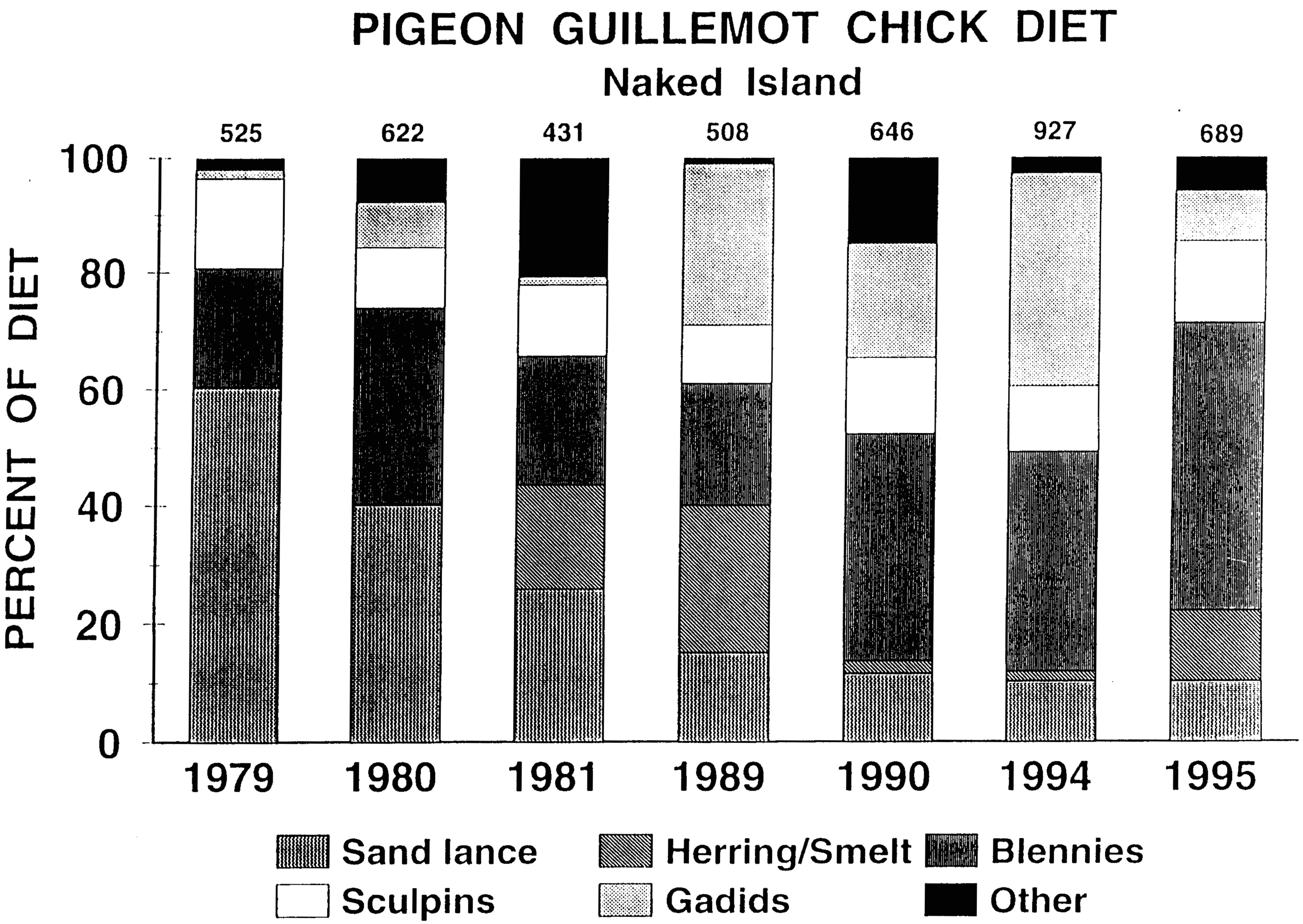

PIGEON GUILLEMOT CHICK DIET
Naked Island
525
622
431
508
646
927
689
PERCENT OF DIET
100
80
60
40
20
0
1979
1980
1981
1989
1990
1994
1995
Sand lance
Herring/Smelt
Blennies
Sculpins
Gadids
Other

Figure 8

Table A1. Growth rates of pigeon guillemot chicks raised at Naked Island and Jackpot Island, Prince William Sound, Alaska, before (< 1989) and after the *T/V Exxon Valdez* oil spill.

Year	Number of Chicks	Mean Growth Rate (g/d)[a]	Standard Error	Minimum Growth Rate(g/d)	Maximum Growth Rate(g/d)
Naked I					
1978	15	19.6	1.4	7.4	31.7
1979	16	23.8	1.2	17.1	32.0
1980	[b]1	19.0	--	--	--
1981	11	19.2	1.8	11.4	34.3
1989	5	18.1	2.5	11.5	23.4
1990	12	16.6	1.2	10.1	23.6
1994	10	15.7	2.1	5.0	29.0
1995	13	19.5	1.2	11.8	26.7
Jackpot I					
1994	6	20.3	1.4	15.0	23.5
1995	16	17.4	.7	12.4	22.6

[a] Mean number of grams gained per day during the linear growth phase, which is the period between 8 and 18 days after hatching (Koelink 1972).

[b] Few chicks were measured in 1980 because of loss of nests from netting and tagging of adults for foraging studies (Kuletz 1983).

Note: Data from before 1994 from Table 14 (Oakley and Kuletz 1994).

Table A2. Fledging weights[a] of pigeon guillemot chicks raised at Naked Island and Jackpot Island, Prince William Sound, Alaska, before (< 1989) and after the *T/V Exxon Valdez* oil spill.

Year	Number of Chicks	Mean Fledging Weight (g)	Standard Error	Minimum Weight(g)	Maximum Weight(g)
Naked I					
1978	29	467	9	291	542
1979	17	506	12	427	590
1980	[b]2	517	52	466	569
1981	13	428	29	202	546
1989	10	507	16	420	570
1990	13	438	16	310	510
1994	17	453	13	357	525
1995[c]	22	455	16	311	561
Jackpot I					
1994	17	508	9	440	585
1995[d]	10	468	14	392	521

[a] The last weight obtained from a chick that was measured within one week of fledging.

[b] Few chicks were measured in 1980 because of loss of nests from netting and tagging of adults for foraging studies (Kuletz 1983).

[c] The last weight obtained from a chick that was measured within 24 hours of fledging.

[d] The last weight from a chick that was measured within 72 hours of fledging.

Note: Data from before 1994 from Table 13 (Oakley and Kuletz 1994).

1

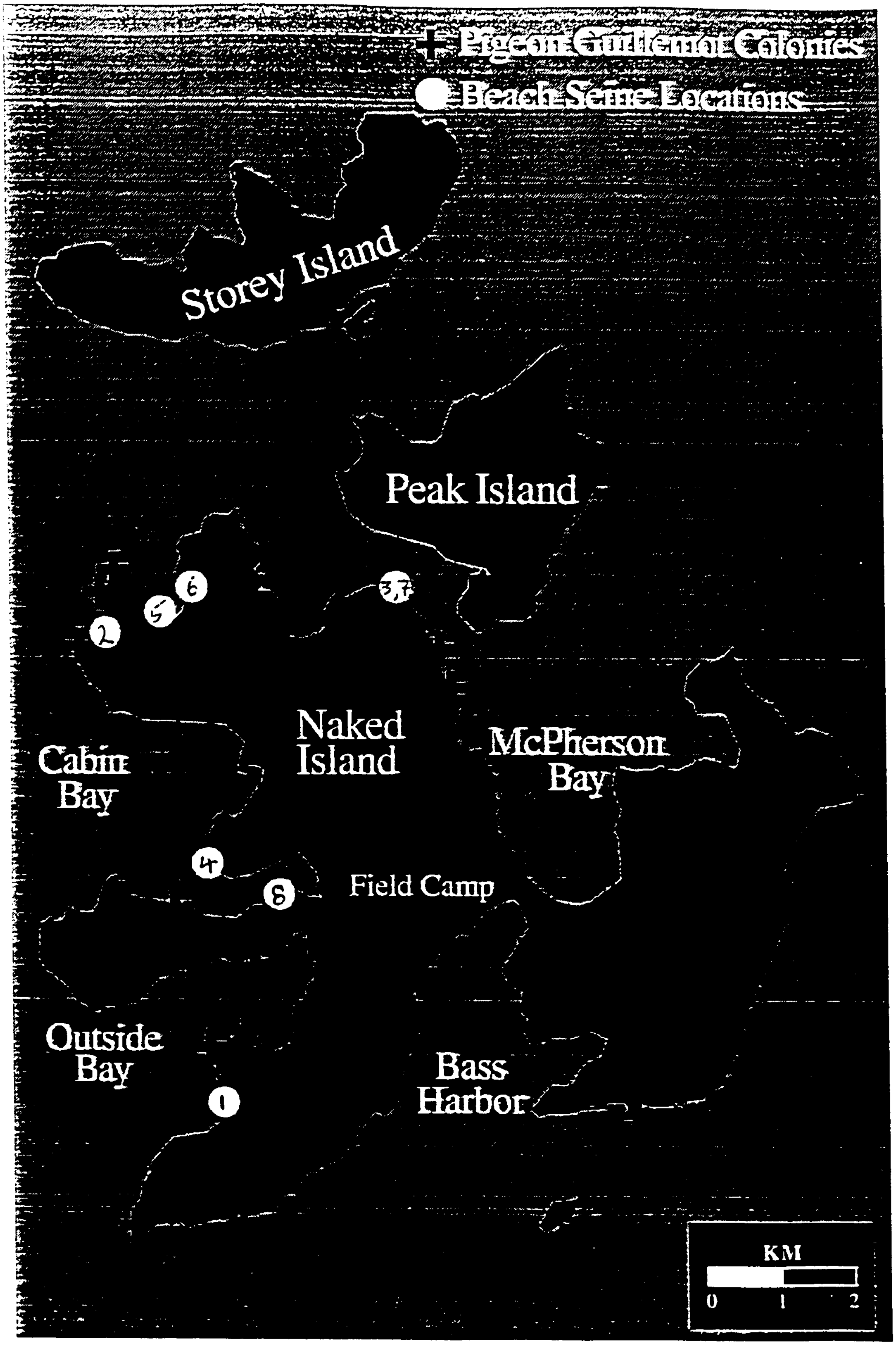


Figure [redacted] A1

APPENDIX G

APEX: 95163 G

Exxon Valdez Oil Spill
Restoration Project Annual Report

Diet Composition, Reproductive Energetics, and Productivity of Seabirds Damaged by the *Exxon Valdez* Oil Spill

Restoration Project 95163 G (formerly 95118-BAA)

Annual Report

Start-up Date: April 1995

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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SUMMARY

This restoration research project is a component of the APEX Project (Alaska Predator Ecosystem Experiment), which is investigating whether low food abundance contributes to the decline of seabird and marine mammal populations in the Exxon Valdez Oil Spill (EVOS) area. The basic premise of this research component is that a shift in diet quality may have constrained recovery of piscivorous seabirds injured by the spill: pigeon guillemots (*Cepphus columba*), common murres (*Uria aalge*), and marbled murrelets (*Brachyramphus marmoratus*). The major hypothesis to be tested is that differences in the nutritional quality of forage fishes are a primary determinant of energy provisioning rates to seabird nestlings, which influence not only the growth and survival of young, but also other factors that regulate seabird populations (e.g., post-fledging survival and recruitment rates).

Pigeon guillemots, black-legged kittiwakes (*Rissa tridactyla*), and tufted puffins (*Fratercula cirrhata*) were the piscivorous species studied during the 1995 breeding season. In cooperation with other APEX projects, we collected samples of nestling meals and measured nestling growth rates, provisioning rates, and nesting success in relation to diet at (1) two guillemot breeding sites in Prince William Sound (PWS) (Naked Island, an oiled site, and Jackpot Island, an un-oiled site), and one in Kachemak Bay (a reference site); (2) three kittiwake colonies in PWS (Eleanor and Seal islands, both oiled sites, and Shoup Bay, an un-oiled site), and one on the Barren Islands (a reference site); and (3) one puffin colony in PWS (Seal Island, an oiled site), and one on the Barren Islands (a reference site). In addition, forage fishes collected using a variety of methods were analyzed in the lab to determine quality as seabird prey.

The primary factor determining the energy density of forage fishes was lipid content (% of dry mass). This varied from as much as 48% in some juvenile Pacific herring (*Clupea harengus*) to as low as 3% in some juvenile walleye pollock (*Theragra chalcogramma*). Average energy density (kJ/g wet mass) of age 1+ herring was 2.5 times greater than that of age 1+ pollock. Among the schooling forage fishes, sand lance (*Ammodytes hexapterus*) was second only to herring in lipid content and energy density, and capelin (*Mallotus villosus*) was third. Juvenile gadids (pollock, Pacific cod [*Gadus macrocephalus*], Pacific tomcod [*Microgadus proximus*]) were generally low in lipids and had the lowest energy densities of the sampled forage fishes. Nearshore demersal fishes (e.g., gunnels, pricklebacks, eelblennies, shannies), important prey of pigeon guillemots, were intermediate between herring and gadids in lipid content and energy density. The lipid content and energy density of herring, sand lance, and capelin, though generally high, were variable depending on age, sex, and reproductive status (pre- or post-spawning).

The diet of pigeon guillemots differed among the 3 study sites and was dominated by gadids and blennies at Naked Island, herring and blennies at Jackpot Island, and sand lance at Kachemak Bay. In 1995, growth performance of guillemot nestlings was highest at Kachemak Bay, lowest at Naked Island, and intermediate at Jackpot Island. In 1994, when herring were a large proportion of guillemot diets at Jackpot Island, growth performance of Jackpot Island nestlings was greater than at the other two sites. These trends are in agreement with measured energy densities for the dominant forage fish at the respective breeding sites. We hypothesize that recovery of pigeon guillemots at Naked Island (oiled site) is limited by low availability of high-quality, schooling forage fishes (specifically sand lance or herring), which are apparently crucial for maintaining high densities of breeding guillemots. Results from the first season of APEX field work support the hypothesis that breeding populations of pigeon guillemot in the EVOS area are constrained by the availability of high quality forage fishes.

The diet of black-legged kittiwakes also differed among the four study sites and was dominated by herring at Shoup Bay, Eleanor Island, Seal Island (PWS colonies), and capelin and sand lance at the Barren Islands. These three forage fish species had the highest lipid content and energy density of those schooling species sampled. Nestling regurgitations collected at all three PWS study sites had high average energy densities, but average energy density of nestling regurgitations from Shoup Bay was higher than that from Eleanor Island (sample sizes from Seal Island were small and did not differ significantly from either Shoup Bay or Eleanor Island), reflecting a higher quality diet at Shoup Bay. Shoup Bay kittiwakes also transported larger meals back to the colony to feed their nestlings, but they delivered meals less frequently than at Eleanor Island. These results support the independent observation that foraging trips by Shoup Bay kittiwakes lasted longer and extended further from the colony than did those of Eleanor Island kittiwakes (APEX Component 95163 E). Because of higher diet quality and larger chick meals, Shoup Bay kittiwakes provisioned energy to their nests at higher rates than Eleanor Island kittiwakes. Nestling growth rates were similar at the three PWS study sites, but the incidence of brood reduction was greater at Eleanor and Seal islands compared to Shoup Bay (APEX Component 95163 E). Productivity and nestling survival were fair-good at the four study colonies, a marked improvement over the early 1990s. Productivity of black-legged kittiwakes in the EVOS area appears limited by the availability of sand lance, herring, and capelin. Thus, results from the first season of APEX field work support the hypothesis that productivity of black-legged kittiwakes in the EVOS area is constrained by the availability of high quality forage fishes.

The diet of tufted puffin nestlings at Seal Island consisted mostly of juvenile prowfish, age 0+ herring, juvenile pink salmon, and 0+ pollock, in decreasing order of percent biomass of the diet. These forage fishes are found primarily in deeper water and are minor components of guillemot and kittiwake diets. Energy densities of prey averaged relatively low (2.6 kJ/g wet mass), and 0+ herring and pollock are also quite small. Consequently, large numbers of these prey must be supplied to meet nestling energy demands. Despite low quality diets, tufted puffin adults breeding on Seal Island were able to provision nestlings at a sufficient rate to support above average growth rates (APEX Component 95163 D). Tufted puffins nesting at Seal Island appear to be somewhat anomalous compared with other piscivorous seabirds nesting in Prince William Sound. Sand lance, capelin, or herring do not predominate in the diet, yet productivity and nestling growth rates are high. Seal Island is, however, a small puffin colony (c. 100 breeding pairs), and there is some evidence that puffin diets at other colonies in Prince William Sound (e.g., Naked Island, Agnes Island) are different. Also, the diet of puffin nestlings at Seal Island agrees well with availability, as indicated by forage fish surveys in that portion of the Sound.

In summary, results from the first season of field work support APEX Hypothesis 9, that productivity of pigeon guillemots and black-legged kittiwakes in the EVOS area is determined in part by differences in nutritional quality of forage fishes. By implication, the productivity of two other seabird species that were injured by the spill, common murre and marbled murrelet, may also be constrained by availability of high quality forage fishes.

INTRODUCTION

Reproductive success in seabirds is largely dependent on foraging constraints experienced by breeding adults. Previous studies on the reproductive energetics of seabirds have indicated that productivity is energy-limited, particularly during brood-rearing (Roby 1991a). Also, the young of most seabird species accumulate substantial fat stores prior to fledging, an energy reserve that can be crucial for post-fledging survival in those species without post-fledging parental care (Perrins et al. 1973; but see Schreiber 1994). Data on foraging habitats, prey availability, and diet composition are critical for understanding the effects of changes in the distribution and abundance of forage fish resources on the productivity and dynamics of seabird populations.

The composition of forage fish is particularly relevant to reproductive success because it is the primary determinant of the energy density of meals delivered to nestlings. Parent seabirds that transport chick meals in their stomachs (e.g., kittiwakes) or in a specialized pouch (e.g., auklets) normally transport meals that are close to the maximum load. Seabirds that transport chick meals as single prey items held in the bill (e.g., guillemots, murres, murrelets) experience additional constraints on meal size if optimal-sized prey are not readily available. Consequently, seabird parents that provision their young with fish high in lipids are able to support faster growing chicks that fledge earlier and with larger fat reserves. This is because the energy density of lipid is approximately twice that of protein and carbohydrate. Also, forage fish are generally very low in carbohydrate, and metabolism of protein as an energy source requires the energetically expensive process of excreting the resultant nitrogenous waste. While breeding adults can afford to consume prey that are low quality (i.e., low-lipid) but abundant, reproductive success may depend on provisioning young with high quality (i.e., high-lipid) food items. If prey of adequate quality to support normal nestling growth and development are not available, nestlings either starve in the nest or prolong the nestling period and fledge with low fat reserves.

Forage fish vary considerably in lipid content, lipid:protein ratio, energy density, and nutritional quality. In some seabird prey, such as lanternfishes (Myctophidae) and eulachon (*Thaleichthys pacificus*), lipids may constitute over 50% of dry mass (A. R. Place, unpubl. data; J. Piatt, unpubl. data; S. Payne, unpubl. data); while in other prey, such as juvenile walleye pollock (*Theragra chalcogramma*) and Pacific cod (*Gadus macrocephalus*), lipids are frequently less than 5% of dry mass (J. Wejak, unpubl. data; J. Piatt, unpubl. data). This means that a given fresh mass of lanternfish or eulachon may have 3-4 times the energy content of the same mass of juvenile pollock or Pacific cod. By increasing the proportion of high-lipid fish in chick diets, parents can increase the energy density of chick meals in order to compensate for the low frequency of chick feeding (Ricklefs 1984, Ricklefs et al. 1985).

Three seabird species that were damaged by the *Exxon Valdez* oil spill (EVOS) are failing to recover at an acceptable rate: pigeon guillemot (*Cepphus columba*), common murre (*Uria aalge*), and marbled murrelet (*Brachyramphus marmoratus*). Damage from the spill to a fourth species of seabird, black-legged kittiwake (*Rissa tridactyla*), is equivocal, but recent reproductive failures of kittiwakes within the spill area may be due to longer term ecosystem perturbation related to the spill (D. B. Irons, pers. comm.). The status of pigeon guillemots and marbled murrelets in PWS and Lower Cook Inlet (LCI) has been of concern for nearly a decade due to declines in numbers of adults observed on survey routes (Laing and Klosiewski 1993, D. Zwiefelhofer, pers. comm.). All of these damaged or potentially damaged seabirds are piscivorous and rely to a greater or lesser extent on pelagic schooling fishes during the breeding season.

One prevalent hypothesis for the failure of these seabirds to recover is that changes in the abundance and species composition of forage fish resources within the spill area has resulted in reduced availability and quality of food for breeding seabirds. Concurrent population declines in some marine mammals, particularly harbor seals and Stellar sea lions, have also been blamed on food limitation. Seabirds, unlike marine mammals, offer the possibility of directly measuring diet composition and feeding rates, and their relation to productivity. Thus the piscivorous seabirds breeding in PWS and LCI present an opportunity to assess the relationship between the relative availability of various forage fishes and the productivity of apex predators. Whether these changes in forage fish availability are related to or have been exacerbated by EVOS is unknown.

This study is relevant to EVOS Restoration Work because it is designed to develop a better understanding of how shifts in the diet of seabirds breeding in EVOS area affect reproductive success. By monitoring the composition and provisioning rates of seabird nestling diets, prey preferences can be assessed. Measuring provisioning rates is crucial because even very poor quality prey may constitute an acceptable diet if it can be supplied at a high rate without increased parental investment. Understanding the diet composition, foraging niche, and energetic constraints on seabirds breeding within the spill area will be crucial for designing management initiatives to enhance productivity in species that are failing to recover from EVOS. If forage fish that are high in lipids are an essential resource for successful reproduction, then efforts can be focused on assessing stocks of preferred forage fish and the factors that impinge on the availability of these resources within foraging distance of breeding colonies in the EVOS area. As long as the significance of diet composition is not understood, it will be difficult to interpret shifts in the utilization of forage fishes and develop a management plan for effective recovery of damaged species.

Guillemots are the most neritic members of the marine bird family Alcidae (i.e., murres, puffins, and auks), and like the other members of the family, capture prey during pursuit-dives. Pigeon guillemots are a well-suited species for monitoring forage fish availability for several reasons: (1) they are a common and widespread seabird species breeding in the EVOS area (Sowls et al. 1978); (2) they primarily forage within 5 km of the nest site (Drent 1965); (3) they raise their young almost entirely on fish; (4) they prey on a wide variety of fishes, including schooling forage fishes (e.g., sand lance, herring, pollock) and subtidal/nearshore demersal fishes (e.g., blennies, sculpins; Drent 1965, Kuletz 1983); and (5) the one- or two-chick broods are fed in the nest until the young reach adult body size. Guillemots carry whole fish in their bills to the nest-site crevice to feed their young. Thus individual prey items can be identified, weighed, measured, and collected for composition analyses. In addition, there is strong evidence of a major shift in diet composition of guillemot pairs breeding at Naked Island. Sand lance were the predominant prey fed to young in the late 1970s (Kuletz 1983), but currently sand lance is a minor component of the diet (D. L. Hayes, unpubl. data). In contrast, guillemots breeding in Kachemak Bay continue to provision their young predominately with sand lance, and sand lance is particularly prevalent in the diet at breeding sites that support high densities of nesting guillemots (A. Prichard, unpubl. data).

Black-legged kittiwakes also breed abundantly in the spill area and rely largely on forage fish during reproduction. Unlike guillemots, kittiwakes are efficient fliers, forage at considerable distances from the nest, and capture prey at or near the surface. Although kittiwakes are highly colonial, cliff-nesting seabirds, they construct nests and can be readily studied at the breeding colony without causing substantial egg loss and chick mortality. Like guillemots, kittiwakes can raise one- or two-chick broods, and chicks remain in the nest until nearly adult size. Kittiwake breeding colonies at Shoup Bay, Eleanor Island, and Seal Island in PWS are easily accessible so that chicks can be weighed regularly without resorting to technical climbing. Kittiwake colonies at Gull Island, Chisik Island, and the Barren Islands in LCI are not as accessible as the PWS colonies, but acquiring sufficient data on reproductive performance for comparison with PWS colonies is feasible.

This study is a component of the Alaska Predator Ecosystem Experiment (APEX) Project (EVOS Projects 95163A-L), whose goal is to test the general hypothesis that a shift in the marine trophic structure of the EVOS area has prevented recovery of injured resources. APEX addresses 10 more specific hypotheses, and two of those specific hypotheses are the focus of this study:

1. Changes in seabird reproductive productivity reflect differences in forage fish abundance as measured in adult seabird foraging trips, chick-meal size, and chick-provisioning rates (APEX Hypothesis 8).

2. Seabird reproductive productivity is determined in part by differences in forage fish nutritional quality (APEX Hypothesis 9).

These two hypotheses address the two primary determinants of energy provisioning rates to nestling seabirds, which in turn have a direct bearing on fitness through variation in reproductive output. Another variable, parental investment, is assumed to remain constant among breeding sites and years. This assumption may need to be tested in the future by measuring parental energy expenditure rates during chick-rearing.

OBJECTIVES

The overall objective of this research is to determine the energy content and nutritional value of various forage fishes used by seabirds breeding in the EVOS area, and to relate differences in prey quality and availability to nestling growth performance and productivity of breeding adults. The research in 1995 emphasized pigeon guillemots, black-legged kittiwakes, and tufted puffins and the primary study sites were in Prince William Sound: Naked Island (guillemots), Jackpot Island (guillemots), Eleanor Island (kittiwakes), Shoup Bay (kittiwakes), and Seal Island (puffins). Additional data on tufted puffins and black-legged kittiwakes nesting on the Barren Islands were available for comparison (APEX Components J and L). Also, comparative data for guillemots nesting in Kachemak Bay were available from a separate research project funded by the Coastal Marine Institute at the University of Alaska Fairbanks (Lawrence Duffy, PI).

Objective 1. To determine the proximate composition of various forage fish species consumed by seabirds in the EVOS area as a function of size, sex, age class, and reproductive status, including:

- a) lipid content
- b) water content

    c) ash-free lean dry matter (protein) content
    d) energy density (kJ/g wet mass)

Objective 2. To determine dietary parameters of pigeon guillemot, black-legged kittiwake, and tufted puffin chicks in the EVOS area, including:
    a) provisioning rate (meal size X delivery rate)
    b) taxonomic composition of diets
    c) biochemical composition of diets
    d) energy density of diets

Objective 3. To determine the relationship between diet and the growth, development, and survival of seabird nestlings. Variables measured will include:
    a) growth rates of total body mass
    b) rates and patterns of wing and flight feather growth
    c) fledgling body mass
    d) fledging age

Objective 4. To determine the contribution of specific forage fish resources to the overall productivity of seabird breeding pairs and populations, including:
    a) relative contribution of each forage fish species to overall energy intake of nestlings
    b) gross foraging efficiency of parents
    c) conversion efficiency of food to biomass in chicks
    d) net production efficiency of the parent/offspring unit
    e) estimates of population-level requirements for forage fish resources during brood-rearing

STUDY AREAS

Collection of data from the field occurred in Prince William Sound (Naked, Jackpot, Eleanor, and Seal islands, and Shoup Bay) and Lower Cook Inlet (south shore of Kachemak Bay and the Barren Islands) during the 1995 breeding season. These sites were identical to those seabird breeding sites that were used by other components of APEX.

Field work on pigeon guillemots was conducted at breeding colonies on Naked Island (oiled area), Jackpot Island (non-oiled area, both in PWS), and in Kachemak Bay (reference site). Approximately 500 guillemots nest along the shores of Naked Island (Sanger and Cody 1993), supporting a large proportion of the total breeding population of guillemots in PWS. The field camp in Cabin Bay served as the base camp for field studies of guillemots nesting on the western and northern shorelines of Naked Island (see annual report for APEX Component 95163F by D. Lindsey Hayes). Naked Island has been the site of long term studies of guillemot reproductive ecology since 1979 by the U.S. Fish and Wildlife Service (Kuletz 1983).

Jackpot Island is a small island in southwestern PWS that supports the highest known breeding density of guillemots in the Sound (G. Sanger, D. L. Hayes, pers. comm.). Jackpot Island was the site of intensive studies of guillemot nesting success during the 1994 field season and is located in a non-oiled portion of PWS. Kachemak Bay served as a third study site for guillemots. The breeding population of guillemots on the south shore of Kachemak Bay between Mallard Bay and Seldovia has been the site of intensive studies by Alex Prichard, a UAF graduate student, of guillemot breeding biology and productivity during the 1994 and 1995 breeding seasons. Results in 1994 suggested that the guillemot prey base in Kachemak Bay is largely sand lance, and is perhaps similar to the prey base at Naked Island 15-20 years ago. Consequently, the Kachemak Bay guillemot study site provides an excellent reference site for guillemot studies in PWS.

Field work on black-legged kittiwakes in PWS was conducted at three breeding colonies: (1) Shoup Bay in Port Valdez (non-oiled area), the largest kittiwake colony in PWS consisting of c. 1600 breeding pairs, (2) Eleanor Island in central PWS near Knight Island (oiled area), and (3) Seal Island, also in the oiled area of central PWS. Both of the latter are smaller colonies of about 200 breeding pairs. The Shoup Bay colony is the site of continuing long-term studies of kittiwake nesting ecology in PWS by the U.S. Fish and Wildlife Service, and Eleanor Island has been selected as a site for intensive study for comparison purposes (see annual report for APEX Component 95163 E by David B. Irons and Robert M. Suryan). In Lower Cook Inlet, kittiwake breeding colonies at the Barren Islands (high productivity), Gull Island (moderate productivity), and Chisik Island (low productivity) were monitored for diet and reproductive success (see annual report for APEX Component 95163 M by John Piatt) .

About 550 tufted puffins were thought to breed on Big Smith Island, and another 160 on Little Smith Island (Sowls et al. 1978). However, preliminary surveys of tufted puffins nesting on these two islands revealed far fewer breeding pairs than earlier reports indicated. Consequently, the puffin field crew was moved to Seal Island where preliminary surveys suggested about 100 nesting pairs were using relatively accessible nest sites (see annual report for APEX Component 95163 D by J. Piatt). Additional data on puffin diets and nest success were obtained at the Barren Islands (see annual report for APEX Component 95163 J by David Roseneau).

METHODS

Field Data Collection

The research approach utilized a combination of sample/data collection in the field (in conjunction with other APEX components in PWS and LCI) and laboratory analyses of forage fish samples. A minimum of 40 active and accessible nests of each species were located and marked prior to hatching at each of the study colonies, and these nests were closely-monitored until the young fledged or the nesting attempt failed. Samples of forage fishes were collected concurrently with data on seabird reproduction during the 1995 breeding season.

Fresh samples of forage fishes used by guillemots were collected for determination of species composition and proximate composition of the diet. Guillemot diet samples were collected primarily by capturing adults in scraps of mist net as they entered the nest crevice with a chick meal held in their bill. A few guillemot chick meals were collected opportunistically when dropped meals were discovered in nest crevices. Supplemental samples of fishes fed to guillemot chicks were collected using beach seines and minnow traps deployed in guillemot foraging areas and by netting specimens at low tide during spring tide series.

Adult kittiwakes transport chick meals in the stomach and esophagus, so chick diet samples consist of semi-digested food. Most kittiwake diet samples were collected when chicks regurgitated during routine weighing and measuring. Additional diet samples were collected by capturing adult kittiwakes as they returned to feed their young and encouraging them to regurgitate the contents of their esophagus. Fresh specimens of forage fishes used by kittiwakes were provided by mid-water trawl (APEX Component 95163 A).

Puffins frequently transport several fish at a time held in the bill when delivering meals to chicks. We used the puffin screening technique to acquire fresh samples of tufted puffin bill loads at the Seal Island colony. Screens were placed in a sample of active puffin nest burrows for a maximum of 3-hour periods, usually early in the morning when most chick meals are delivered. Care was taken to avoid screening burrows of chicks that were used to measure nestling growth rates.

Guillemot chick meals, kittiwake regurgitations, puffin bill loads, and fresh fish samples were weighed (± 0.1 g) in the field on battery-powered, top-loading balances, placed in whirl-pacs, and immediately frozen in small, propane-powered freezers that were maintained at each of the study sites. Samples of fresh forage fish, guillemot chick meals, and puffin bill loads were shipped frozen to Dr. Alan Springer's laboratory at the Institute of Marine Science, UAF, where the fourth author (KRT) sorted, identified, sexed, aged, measured, and determined reproductive status of specimens in preparation for proximate analysis. Kittiwake regurgitations were shipped frozen to the University of California Santa Cruz, where the semidigested material was sorted and identified to species to the extent possible by Greg Golet.

Proximate analysis of all samples was conducted by the second author (JLR) in the lab of the first author (DDR) at the Institute of Arctic Biology, UAF. Forage fish specimens and chick meals were reweighed on an analytical balance (± 0.1 mg), dried to constant mass in a convection oven at 60°C to determine water content. Lipid content of dried samples was determined by solvent extraction using a Soxtec HT-12 soxhlet apparatus and hexane/IPA 7:2 (v:v) as the solvent system. In cases where the dry mass of fish specimens was less than 2 g, specimens were combined to so as to achieve a sample mass for extraction of 2-3.5 g. Lean dry samples were then transferred from extraction thimbles to glass scintillation vials and ashed in a muffle furnace at 550°C in order to calculate ash-free lean dry mass (protein) by subtraction. Energy density (kJ/g wet mass) and energy content of forage fishes and chick meals were calculated from their composition (water, lipid, ash-free lean dry matter, and ash), using published energy equivalents of these fractions (Roby 1991).

Chick provisioning rates for pigeon guillemots, black-legged kittiwakes, and tufted puffins at each of the study sites were determined by monitoring active nests to determine meal delivery rates (meals/day) throughout the 24 h period (dawn to dusk watches). Average meal mass was determined for guillemots using the sample of individual prey items collected at nest sites. Average meal mass for black-legged kittiwakes was estimated using the periodic weighing technique. Nestlings were weighed in a sample of nests at 2-hour intervals during concurrent watches to determine meal delivery rates. The mass increment between weighings of chicks that were fed was corrected for mass loss between weighings and feedings by adding the average of mass loss in the previous 2-hour period and mass loss in the subsequent 2-hour period to the observed mass increment. This corrected mass increment was used as an estimate of meal size. Average meal size of tufted puffins was measured using the burrow screening technique. Bill loads dropped in front of the screen were washed clean, weighed, and either frozen for later proximate analysis or fed to the nestling. The product of average meal size (g) and average meal delivery rate (meals/day) was used as an estimate of average quantity of food delivered to a nest daily by a pair of adults (g/(nest day)). The taxonomic and proximate composition of the diet was used to calculate average energy density of chick diets for each species at each site. Finally, the product of average energy density of chick diets (kJ/g wet mass) and average quantity of food delivered (g/day) was calculated as an estimate of energy provisioning rates (kJ/day) for each species at each site.

Active guillemot and kittiwake nests were checked daily or every other day during the hatching period in order to determine hatching date. In the case of two-chick broods, siblings were marked soon after hatching so that individual growth rates could be monitored throughout the nestling period. Nestlings growth rates were determined by weighing and measuring chicks (known-age, in most cases) on a regular basis (every three days, if possible) throughout the nestling period. Nestling survival rates were calculated from the results of periodic nest checks, using the Mayfield method. During the fledging period, we attempted to weigh nestlings every other day in order to more precisely determine fledging mass and age. Data on nestling body mass, wing chord, and primary feather length were separated by colony for each species, Breeding adult guillemots and kittiwakes that were captured at the nest were weighed, measured, and banded for future identification.

RESULTS and DISCUSSION

Objective 1: Proximate Composition of Forage Fishes

Specimens of the following forage fish taxa (sample sizes dictated by the availability of frozen specimens) were subjected to proximate analysis:

- juvenile walleye pollock (*Theragra chalcogramma*)
- juvenile Pacific cod (*Gadus macrocephalus*)
- juvenile Pacific tomcod (*Microgadus proximus*)
- Pacific sand lance (*Ammodytes hexapterus*)
- capelin (*Mallotus villosus*)
- Pacific herring (*Clupea harengus pallassii*)
- slender eelblenny (*Lumpenus fabricii*)
- padded sculpin (*Artedius fenestralis*)
- four horned sculpin (*Myoxocephalus quadricornis*)
- arctic shanny (*Stichaeus punctatus*)
- crescent gunnel (*Pholis laeta*)

The first six species represent dominant species of schooling fishes that are known to figure prominantly in diets of piscivorous seabirds in the EVOS area, while the last five species are representative of nearshore demersal fishes that commonly occur in the diet of pigeon guillemots.

Several patterns in the proximate composition of these forage fishes were revealed by inter-specific comparison (Fig. 1, Table 1). First, herring and sand lance had the highest lipid content (% dry mass) and, therefore, the highest energy density (kJ/g wet mass) of the species analyzed. Second, gadid species (pollock, cod, tomcod) consistently had the lowest lipid content and, consequently, the lowest energy density of the species analyzed. Capelin fell in the middle, but only spawned-out adult males were available for analysis, so it is likely that the proximate composition of pre-spawn adult capelin will be more similar to herring and sand lance than to gadids. Analysis of three capelin collected as guillemot chick meals (Table 3) support this supposition. There is a clear dichotomy in quality among the schooling forage fishes: gadids are generally low quality and other species are relatively high quality. No such dichotomy in quality was revealed among the nearshore demersal species (Fig. 1, Table 2), which tended to have higher lipid content and energy density than gadids, but lower than herring or sand lance.

Within-species comparisons of proximate composition revealed some age- and sex-related differences. The lipid content of herring increased dramatically from age class 0+ to older fish (Fig. 2). Lipid content, however, was highly variable (5-

48% of dry mass) even within an age class (Fig. 3), suggesting large variation in condition of herring from PWS. Some of this variation could be attributed to differences between sites in the average lipid content of herring (Fig. 2). The pattern of increasing lipid content with age was also evident in sand lance (Fig. 4), but was less pronounced than in herring. Also, variability in lipid content within an age class was less in sand lance compared to herring. Surprisingly, the lipid content of 1+ sand lance was somewhat greater than in 2+ sand lance. Female 2+ sand lance had higher lipid content and higher energy density than male 2+ sand lance. Juvenile pollock exhibited a different pattern of lipid content as a function of age: 0+ pollock had slightly higher lipid content than 1+ or 2+ pollock (but lower than 0+ herring or sand lance; Table 1).

The observed inter- and intra-specific differences in lipid content of forage fishes reflect differences in life history as they influence reliance on stored energy reserves for survival or reproduction. For example, sand lance spawn in the fall (Dick and Warner 1982), and adults, especially females, presumably deposit lipid reserves during summer for later investment in gametes. Juvenile pollock, however, feed year-round and selection has favored allocation of assimilated energy to rapid somatic growth over storage of lipid during the juvenile period.

The energy densities for those forage and nearshore demersal fishes that were collected and analyzed in 1995 differed by a factor of up to 2.5. A parent seabird breeding in PWS could potentially increase its rate of energy provisioning to its brood by a factor of as much as 2.5 by selecting prey based on quality, given similar availability. Such an increase in energy provisioning rate could dramatically enhance fitness.

Objective 2: Dietary Parameters of Nestling Seabirds

Pigeon Guillemots

Taxonomic composition of nestling diets were more similar between Naked and Jackpot islands in 1995 than they were in 1994 (Fig. 5). Jackpot Island diets continued to include a higher proportion of schooling forage fishes (especially Pacific herring), while Naked Island diets included a higher proportion of nearshore demersal fishes (pricklebacks, sculpins, gunnels).

Twenty-nine pigeon guillemots chick meals (individual fish) were collected at Naked Island and 27 at Jackpot Island. Table 3 shows the species of fish collected as chick meals at the two sites, their proximate composition, and their energy content. These samples of chick meals were generally representative of nestling diets at the respective study sites, as indicated by the species composition of fish observed being delivered to nests (Fig. 5). No chick meals were collected at Kachemak Bay.

Average mass of chick meals collected at Naked Island (14.7 g, sd = 7.9, n = 29) was less than that of chick meals collected at Jackpot Island (20.0 g, sd = 8.4, n = 27). Feeding frequency (chick meals delivered/(nest day)) was higher at Jackpot Island (16.5 meals/(nest day), n = 14) than at Naked Island (11.4 meals/(nest day), n = 31) or Kachemak Bay (10.8 meals/(nest day), n = 37; Fig. 6), even after means were adjusted for proportions of nests that contained 2-chick vs. 1-chick broods. Consequently, the estimated mass of food delivered to guillemot nests at Jackpot Island (330 g/day) was nearly twice that of guillemot nests at Naked Island (168 g/day).

The average energy density of chick meals collected at the two colonies was similar in 1995 (Table 3), despite the higher incidence of herring in the diet at Jackpot Island. The high lipid content of the capelin and sand lance chick meals collected at Naked Island and the low lipid content of the pollock and tomcod chick meals collected at Jackpot Island produced this result.

Black-legged Kittiwakes

Nestling meal sizes at Shoup Bay and Eleanor Island were estimated using both the average mass of chick regurgitations and the average mass increment from 2-hour periodic weighing of nestlings. Average mass of chick regurgitations from Shoup Bay (21.6 g, sd = 9.9, n = 86) was greater than that from Eleanor Island (12.4 g, sd = 9.3, n = 30; t = 4.60, P < 0.001). Average chick meal size based on periodic weighing was also greater at Shoup Bay (29.0 g, sd = 17.3, n = 37) than at Eleanor Island (21.3 g, sd = 12.3, n = 21; t = 1.78, P = 0.08).

The smaller chick meals delivered at Eleanor Island were more than compensated for by a higher frequency of chick meal deliveries. Nests on Eleanor Island received an average of 4.9 chick meal deliveries/day, while Shoup Bay nests received only 3.3 chick meals/day on average. Consequently, Eleanor Island nests received an estimated 105 g of food daily, compared with about 95 g of food daily at Shoup Bay nests. This despite a much higher prevalence of 2-chick broods at Shoup Bay compared to Eleanor Island.

Diet quality appears to be a key factor for Shoup Bay kittiwakes. Although the taxonomic composition of chick regurgitations from Shoup Bay and Eleanor Island were similar (herring, followed by sand lance, were the two dominant prey items at both sites), the average energy density of regurgitations from Shoup Bay (4.8 kJ/g wet mass, sd = 0.99, n = 85) was higher than regurgitations from Eleanor Island (4.2 kJ/g wet mass, sd = 0.85, n = 30; Table 4). Together with larger size, the higher energy density of Shoup Bay regurgitations resulted in a total energy content nearly twice that of Eleanor Island regurgitations (Table 4). Lipid content, and thus energy density, of chick regurgitations was high at both colonies (Table 4), reflecting the preponderance of high quality forage fishes (herring, sand lance) in the diet.

Tufted Puffins

Fourty-two puffin bill loads ranging from 1 to 11 fish were collected at Seal Island, and the average mass of these bill loads was 13.7 g (sd = 15.4, range = 0.7 - 73.9 g). The large range of bill load sizes probably reflects the inclusion of partial bill loads in the sample. Adult puffins transporting bill loads for nestlings do not always drop the entire load when they encounter a screen blocking the entrance to the nest burrow (J. Piatt, pers comm.). The largest "bill loads" may actually have consisted of two separate bill loads deposited at the screen by each parent. Consequently, there is some error associated with measuring chick meal size by using the puffin screening technique. Feeding frequency was reported as 4.9 meals/day (sd = 1.5, n = 21). These data suggest that on average puffin chicks raised on Seal Island in 1995 were fed about 67 g of food daily.

The diet of tufted puffin nestlings on Seal Island consisted primarily of juvenile prowfish (32% of biomass), juvenile herring (27%), juvenile pink salmon (20%), and juvenile pollock (12%). With the exception of herring, these species have small lipid reserves and low energy densities (Table 5). Out of 50 herring collected as part of bill loads, all but 3 were age class 0+ and consequently very small (0.6 - 5.5 g) and had low lipid contents (Table 5). High quality forage fish (1-2+ herring, 1-2+ sand lance) seem to be the exception in diets of tufted puffins nesting in Prince William Sound, at least based on the diets of Seal Island puffins. Larger sand lance and capelin constitute a greater proportion of the diet at the Barren Islands (Table 5; APEX Component 95163 J). The average energy density of puffin prey taxa at Seal Island is low (2.6 kJ/g wet mass), much lower than the average energy density of guillemot prey or kittiwake regurgitations.

Objective 3: Diet and Nestling Growth and Survival

Pigeon Guillemots

Data on body mass of nestling guillemots were plotted as a function of wing length for each of the study sites (Naked and Jackpot islands, Kachemak Bay). By taking the square root of body mass and the square root of the log of wing length, this relationship was linearized and homogeneity of variance was achieved. The slope of the resultant least squares regression line can serve as an index to growth performance of nestlings over the entire pre-fledging period. Figure 7 compares the slopes of these regression lines for the 3 guillemot study sites in 1994 and 1995. In 1994, the growth performance index for Jackpot Island was significantly greater than that for Naked Island or Kachemak Bay. In 1995, Jackpot Island and Kachemak Bay growth performance indices were higher than the Naked Island index.

Guillemot nestlings on Jackpot Island were fed larger meals more frequently compared with Naked Island guillemot nestlings in 1995. Although chick meal size was not measured at Kachemak Bay, most of the diet of guillemot chicks in Kachemak Bay consists of 1-2+ sand lance, a high quality diet for guillemot chicks.

While it is too early to conclude that inter-colony differences in growth performance indices are diet-related, the pattern is certainly suggestive.

Black-legged Kittiwakes

No significant differences were detected in growth rates of kittiwake chicks from Shoup Bay, Eleanor Island, or Seal Island colonies in 1995 (analyses based on comparing slopes of the linear phase of growth; APEX Component E). This is not surprising given the similarity in diets among the three sites. The average growth rate of kittiwake nestlings on the Barren Islands was significantly greater than at the PWS colonies, perhaps reflecting the preponderance of capelin and 1-2+ sand lance in the diet.

The lower incidence of brood reduction at Shoup Bay compared with Eleanor or Seal islands may reflect the somewhat higher quality of nestling diets at Shoup Bay.

Tufted Puffins

Growth rates of puffin nestlings during the linear phase (17.7 g/day) and survival to fledging age (>81%) were high in 1995 on Seal Island (APEX Component 95163 D). Despite low provisioning rates and low diet quality, Seal Island puffins experienced good reproductive success compared to many larger colonies in the Aleutians and off the Alaska Peninsula (J. Piatt, pers. comm.).

Tufted puffins nesting at Seal Island appear to be somewhat anomalous compared with other piscivorous seabirds nesting in Prince William Sound. Sand lance, capelin, or 1+ herring do not predominate in the diet, yet productivity and nestling growth rates are good compared with other puffin colonies in the Northern Gulf of Alaska. Seal Island is, however, a small puffin colony (about 100 breeding pairs), and there is some evidence that puffin diets at other colonies in Prince William Sound (e.g., Naked Island, Agnes Island) may differ. Also, the diet of puffin nestlings at Seal Island agrees well with availability, as indicated by forage fish surveys in that portion of the Sound.

Objective 4: Contribution of Forage Fish Resources to Seabird Productivity

Energy provisioning rates (kJ/(nest day)) can be estimated from measurements of feeding frequency (meals/(nest day)), meal size (g wet mass), and energy density of meals (kJ/g wet mass). Measurements of these three parameters are available for guillemots breeding at Naked and Jackpot islands in PWS, kittiwakes breeding at Shoup Bay and Eleanor Island in PWS, and tufted puffins breeding at Seal Island in PWS. Measurements of these parameters and the resultant estimates of energy provisioning rates are presented in Table 6.

Several striking patterns emerge from Table 6. First, energy provisioning rates were apparently much higher (4-7X) for guillemots than for tufted puffins, even taking into account the larger average brood size of guillemots. This despite an apparently successful breeding season for puffins at Seal Island. It is possible that the estimate of energy provisioning rate for Seal Island puffins is too low, and the most plausible explanation for a low estimate is that the measurement of average bill load size is biased. The very small size of some bill loads collected at Seal Island in 1995 suggests that they represent only a fraction of the entire bill load. Even if average bill load size was underestimated by as much as a factor of 2-3, it is apparent that puffins provision their young at a considerably lower rate than guillemots. Puffins forage primarily in the pelagic zone, raise only 1-chick broods, and nestlings grow more slowly and fledge at an older age compared with guillemots. The estimates of energy provisioning rates presented here suggest that post-natal development in tufted puffins is energetically much more efficient than in guillemots. Given the more pelagic foraging habits of tufted puffins, it is puzzling that they appear to exercise little selection for prey quality; diet composition seems to be dictated primarily by availability. This may reflect nest site limitation as the primary constraint on the puffin breeding population at Seal Island. If this population is nest site-limited, then food may be readily available in proximity of the colony and selection for high quality prey may be less crucial for reproductive success.

Second, guillemots breeding at Jackpot Island are provisioning their young at a much higher rate than those breeding at Naked Island, due to larger meal sizes and higher feeding frequencies at Jackpot Island. These differences are apparently a consequence of the preponderance of schooling forage fishes in the diet of Jackpot Island guillemots. The difference in energy provisioning rates is associated with higher growth performance, higher nestling survival, and higher nesting density of guillemots at Jackpot Island compared with Naked Island. These differences were apparently even more pronounced in 1994.

Third, energy provisioning rates by kittiwakes were intermediate between those for guillemots and puffins. Diet quality was higher in kittiwakes than in either puffins or guillemots, and the high energy density of chick meals helped compensate for low feeding frequencies. Energy provisioning rates were somewhat higher at Shoup Bay, despite lower feeding frequencies than at Eleanor Island. Shoup Bay kittiwakes were able to provide their broods with larger and higher quality chick meals that more than compensated for lower feeding frequencies. The high energy density of kittiwake chick diets suggests that breeding adults are selecting prey based at least partly on quality.

CONCLUSIONS

Objective 1

1. Juvenile herring and sand lance had the highest average energy densities
2. Gadids (pollock, cod, tomcod) had the lowest average energy densities
3. Age 0+ fish had lower energy densities than older conspecifics for herring and

sand lance, the reverse was true for gadids
4. Adult female sand lance had higher energy densities than males

Objective 2

1. Provisioning rates of energy to guillemot nestlings were higher at Jackpot Island and Kachemak Bay than at Naked Island
2. Provisioning rates of energy to kittiwake nestlings were higher at Shoup Bay than at Eleanor Island
3. Diet quality and provisioning rates of energy to puffin nestlings at Seal Island were lower than for either guillemot nestlings or kittiwake nestlings

Objective 3

1. Guillemot growth performance and nestling survival was apparently correlated with estimated energy provisioning rates
2. Kittiwake growth was similar at PWS study sites, and diet and energy provisioning rates were similar as well
3. Puffin nestlings at Seal Island were fed a low quality diet, but quantity was sufficient to support good growth rates

Objective 4

1. Guillemots may require access to high quality forage fish (herring, sand lance) to maintain high nesting densities in the EVOS area
2. Productivity of kittiwakes in the EVOS area appears to depend on availability of high quality forage fishes (sand lance, capelin, herring)
3. In Prince William Sound, juvenile herring and adult sand lance are the primary energy sources for piscivorous seabirds
4. Outside the Sound, sand lance and capelin are the primary energy sources for piscivorous seabirds in the EVOS area

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Table 1. Proximate composition of schooling forage fishes from the EVOS area, 1995 (std. dev. in parentheses).

Species, age	N	Sex	Location	Date	Fresh Mass (g)	% Water	% Lipid (dry mass)	% AFLDM (dry mass)	Energy Content (kJ/fish)	Energy Density (kJ/g wet mass)
Herring, 0+	49	?	S. Graveyard	7/16'	3.19 (0.56)	77.6 (0.10)	9.7 (0.9)	81.0 (0.8)	12.5 (2.85)	4.0 (2.85)
Herring, 1+	25	?	Naked I.	7/16'	13.2 (3.97)	77.9 (2.60)	22.3 (9.0)	64.1 (8.0)	62.2 (24.9)	4.4 (0.97)
Herring, 1+	30	M	Pt. Gravina	8/11'	18.5 (5.10)	67.7 (3.35)	29.1 (6.9)	62.8 (5.9)	129.8 (53.3)	7.1 (1.40)
Herring, 2+	4	?	Jackpot	7/25'	36.9 (13.3)	74.2 (3.00)	31.5 (8.2)	58.7 (7.0)	225.0 (110.0)	5.8 (1.11)
Sandlance, 0+	27	?	Naked I.	7/16'	1.86 (0.53)	78.4 (0.68)	12.1 (1.5)	78.8 (0.7)	6.6 (2.30)	4.2 (0.30)
Sandlance, 0+	9	?	Naked I.	8/16'	1.59 (0.51)	77.1 (1.33)	14.9 (2.8)	76.5 (2.2)	7.2 (2.60)	4.4 (0.30)
Sandlance, 0+	36	?	Block I.	8/10-12'	2.04 (0.40)	76.0 (1.43)	17.9 (3.0)	78.4 (8.6)	10.2 (2.64)	4.9 (0.28)
Sandlance, 1+	10	?	Block I.	7/13'	9.36 (0.78)	71.4 (1.10)	27.7 (2.8)	65.1 (2.5)	59.3 (6.90)	6.3 (0.40)
Sandlance, 1+	10	?	Block I.	8/10'	9.32 (0.67)	72.2 (1.50)	25.7 (4.3)	67.0 (3.3)	56.0 (6.12)	6.0 (0.58)
Sandlance, 2+	6	F	Block I.	7/13-8/10'	16.1 (3.94)	73.8 (1.50)	21.7 (3.5)	71.0 (3.2)	83.4 (21.1)	5.3 (0.30)
Sandlance, 2+	5	M	Block I.	7/13-8/10'	13.6 (2.08)	75.6 (1.00)	17.5 (1.7)	73.9 (1.9)	64.3 (7.47)	4.8 (0.21)
Capelin, adult	10	M	Naked I.	8/3'	21.9 (1.53)	79.2 (1.50)	13.0 (6.8)	77.4 (5.2)	82.6 (14.4)	3.8 (0.66)
Pollock, 0+	87	?	Naked/Seal I	8/1-8/10'	1.16 (0.40)	79.3 (1.5)	7.7 (0.8)	80.5 (0.8)	4.1 (1.48)	3.5 (0.26)
Pollock, 2+	14	?	E.Graveyard	8/5'	33.1 (7.2)	78.2 (1.1)	5.9 (2.4)	80.7 (1.8)	120.0 (31.3)	3.6 (0.29)
Tomcod, 0+	13	?	Naked I.	7/16-28'	2.11 (0.66)	81.7 (6.6)	5.8 (0.6)	78.9 (2.1)	6.2 (2.0)	2.8 (0.1)
Pac. Cod, 0+	38	?	Naked I.	7/16-8/16'	3.1 (1.7)	83.2 (1.2)	6.0 (1.1)	80.2 (0.9)	8.9 (5.1)	2.8 (0.1)
Pac. Cod, 1+	5	?	Kachemak B.	7/15'	13.2 (2.8)	77.0 (1.7)	4.4 (0.5)	79.2 (0.8)	44.9 (13.2)	3.4 (0.4)

Table 2. Proximate composition of nearshore demersal fishes of Prince William Sound, 1995 (std. dev. in parentheses)

Species	N	Fresh Mass (g)	% Water	% Lipid (dry mass)	% AFLDM (dry mass)	Energy Content (kJ/fish)	Energy Density (kJ/g wet mass)
Crescent Gunnel	10	**11.6** (2.2)	**74.2** (1.5)	**13.2** (4.5)	**74.8** (2.4)	**52.4** (9.4)	**4.8** (0.6)
Slender Eelblenny	14	**8.2** (2.9)	**76.8** (1.0)	**15.6** (2.6)	**73.3** (2.5)	**36.0** (14.6)	**4.4** (0.3)
Arctic Shanny	19	**6.4** (3.0)	**75.7** (1.2)	**14.4** (3.4)	**73.5** (1.3)	**28.5** (13.8)	**4.5** (0.5)
Padded Sculpin	21	**8.3** (4.2)	**78.7** (1.6)	**9.8** (3.8)	**73.2** (2.6)	**30.1** (19.7)	**3.6** (0.5)
Four-horned Sculpin*	7	**1.5** (0.6)	**81.5** (2.3)	**8.6**	74.8	4.5	**3.0**

* individual fish pooled for proximate analysis

Table 4. Proximate composition and energy content of black-legged kittiwake chick regurgitations from three colonies in Prince William Sound (std. dev. in parentheses).

Location	N	% water (field)	% lipid (dry mass)	% AFLDM (dry mass)	Energy Density (kJ/g dry mass)	Energy Density (kJ/g wet mass)	Energy Content (kJ)
Shoup Bay	**86**	**75.7** (3.3)	**17.3** (7.0)	**72.6** (6.4)	**19.7** (1.7)	**4.84** (0.99)	**104.1** (53.1)
Seal Island	**14**	**76.5** (2.4)	**14.9** (5.5)	**74.3** (5.7)	**19.1** (1.3)	**4.50** (0.73)	**64.8** (32.3)
Eleanor Island	**30**	**77.7** (2.6)	**13.6** (7.6)	**75.7** (7.0)	**18.8** (1.8)	**4.23** (0.85)	**53.8** (47.4)

Table 5. Proximate composition and energy content of fish fed to nestling tufted puffins in the EVOS area, 1995 (std. dev. in parentheses).

Species/Age	N:	% water (field)	% lipid (dry mass)	% AFLDM (dry mass)	Energy Density (kJ/g wet mass)	Energy Content (kJ)
SEAL ISLAND						
Prowfish, 1+	10	86.9 (1.0)	11.0 (2.8)	75.4 (2.3)	2.25 (0.23)	42.4 (25.8)
Pink Salmon, 1+	5	82.3 (1.1)	5.3 (0.7)	82.5 (0.9)	2.92 (0.83)	59.5 (19.1)
Capelin (spwn.male)	1	81.3	9.8	76.6	3.31	71.7
Herring, 1+	1	72.7	36.4	55.8	6.49	211.2
Herring, 0+	35	84.1 (2.7)	6.5 (0.8)	78.6 (0.8)	2.62 (0.30)	4.8 (2.1)
Pollock 0+	45	85.5 (2.3)	5.8 (1.0)	78.5 (0.7)	2.23 (0.22)	2.8 (0.9)
Sand lance, 0+	3	79.7 (3.9)	15.5	71.9	3.82	3.9 (1.1)
ALL SPECIES					2.64 (0.85)	13.0 (27.9)
NAKED ISLAND						
Sand lance, 0-1+	18	74.4 (2.6)	17.1 (1.1)	72.0 (1.3)	5.30 (0.95)	14.1 (3.6)
AGNES ISLAND						
Pollock, 1+	1	81.9	5.5	76.6	2.81	50.5
Prowfish, 1+	1	88.0	9.8	75.0	1.99	19.3
Prowfish, 2+	1	87.5	9.2	74.4	2.02	47.4
ALL SPECIES					2.29 (0.45)	39.1 (17.2)
BARREN ISLANDS						
Pink Salmon, 1+	4	77.1 (0.9)	4.9 (0.8)	84.1 (1.1)	3.80 (0.18)	79.4 (39.8)
Prowfish, 1+	1	83.0	11.2	74.5	2.94	33.6
Sand lance, 2+	3	67.6 (2.0)	35.0 (1.9)	57.0 (2.1)	7.56 (0.59)	97.3 (12.0)
Capelin, 1+	6	77.0 (2.7)	6.0 (2.3)	78.2 (0.6)	3.58 (0.01)	10.9 (2.5)
ALL SPECIES					4.78 (1.95)	51.0 (43.6)

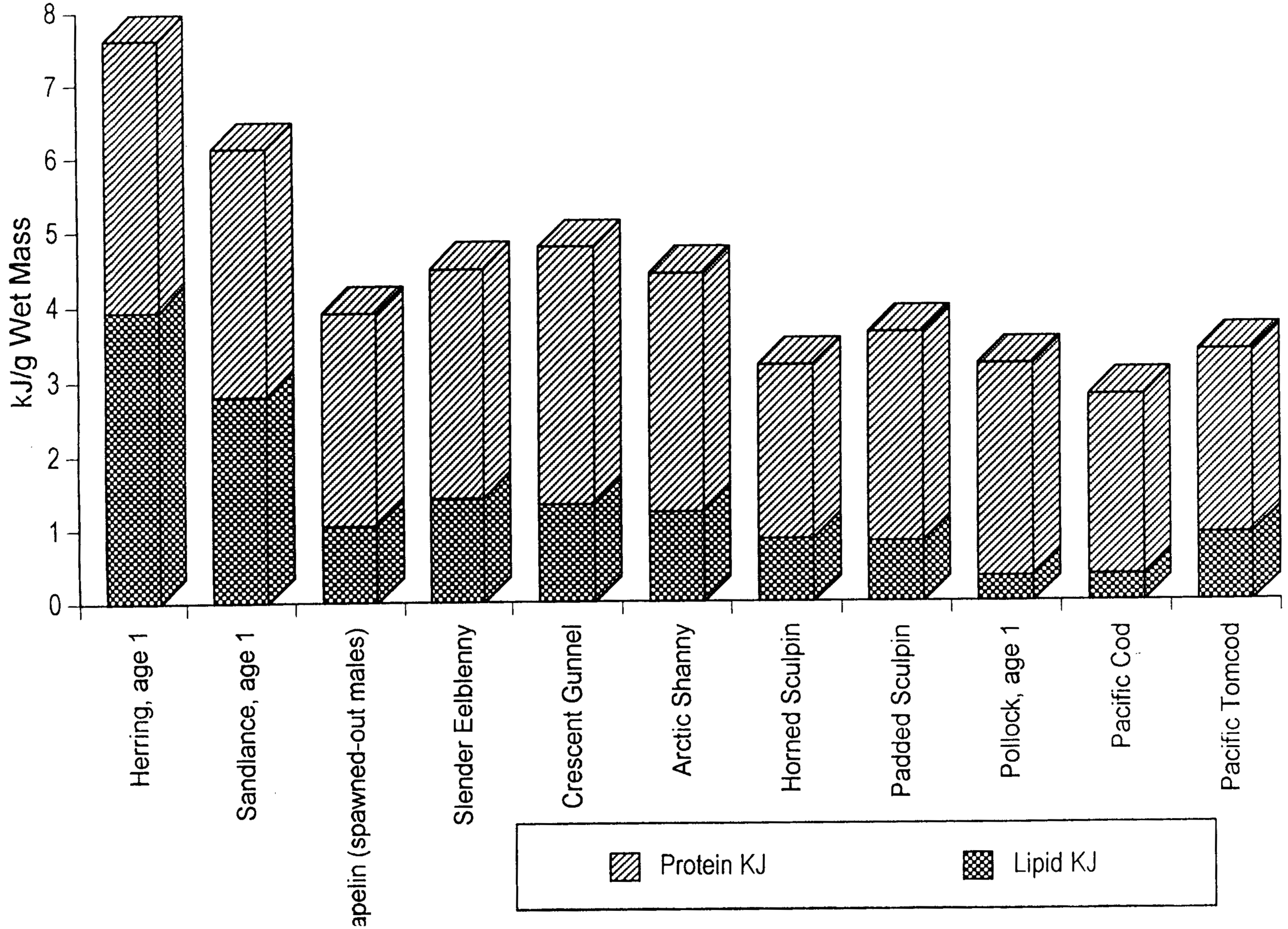
Table 6. Calculations for energy provisioning rates to nests for three species of piscivorous seabirds in the EVOS area, 1995 (std. dev., sample size in parentheses)

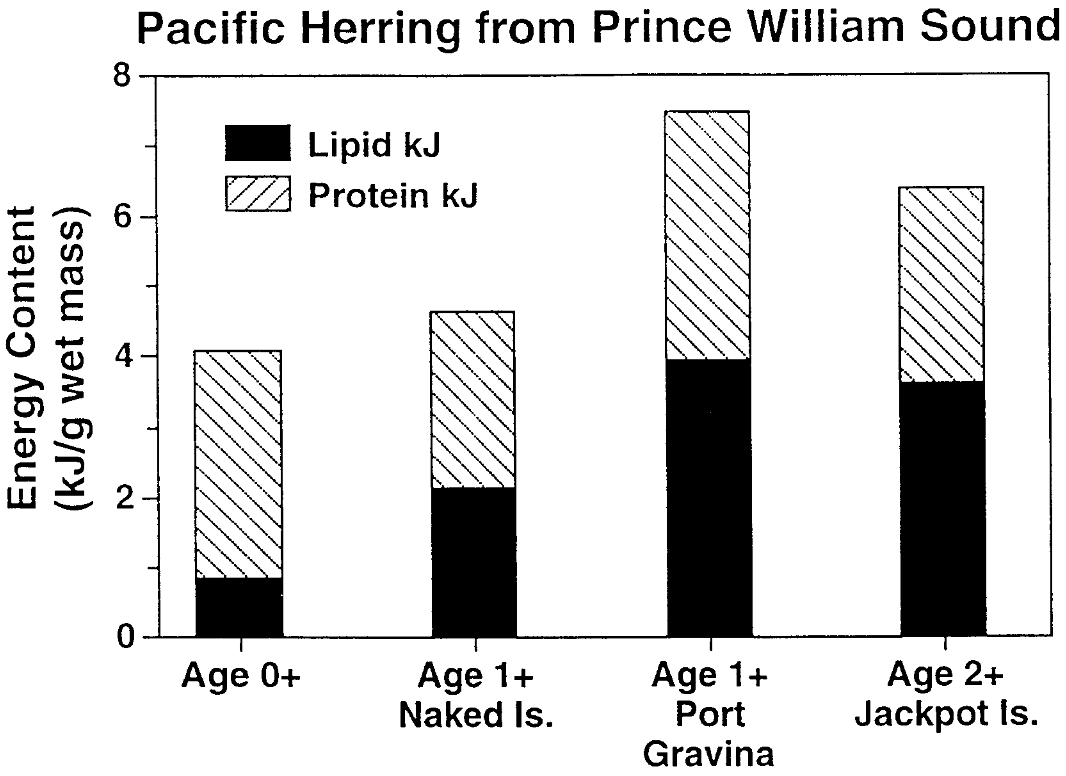
Species/Location	Feeding Frequency (meals/(nest day))	Meal Size (g wet mass)	Energy Density (kJ/g wet mass)	Energy Provisioning Rate (kJ/(nest day))
PIGEON GUILLEMOT				
Jackpot I.	**16.6** (4.2, 14)	**20.0** (8.4, 27)	**3.73** (1.53, 27)	**1,238**
Naked I.	**11.4** (4.4, 31)	**14.7** (7.9, 29)	**4.00** (0.74, 28)	**670**
BLACK-LEGGED KITTIWAKE				
Shoup Bay	**3.3** (0.7, 10)	**29.0** (17.3, 37)	**4.84** (0.99, 85)	**463**
Eleanor I.	**4.9** (1.7, 9)	**21.3** (12.3, 21)	**4.23** (0.85, 30)	**441**
TUFTED PUFFIN				
Seal I.	**4.9** (1.5, 21)	**13.7*** (15.4, 42)	**2.64** (0.85, 42)	**177**

* may be biased low; see text

Fig. 1.

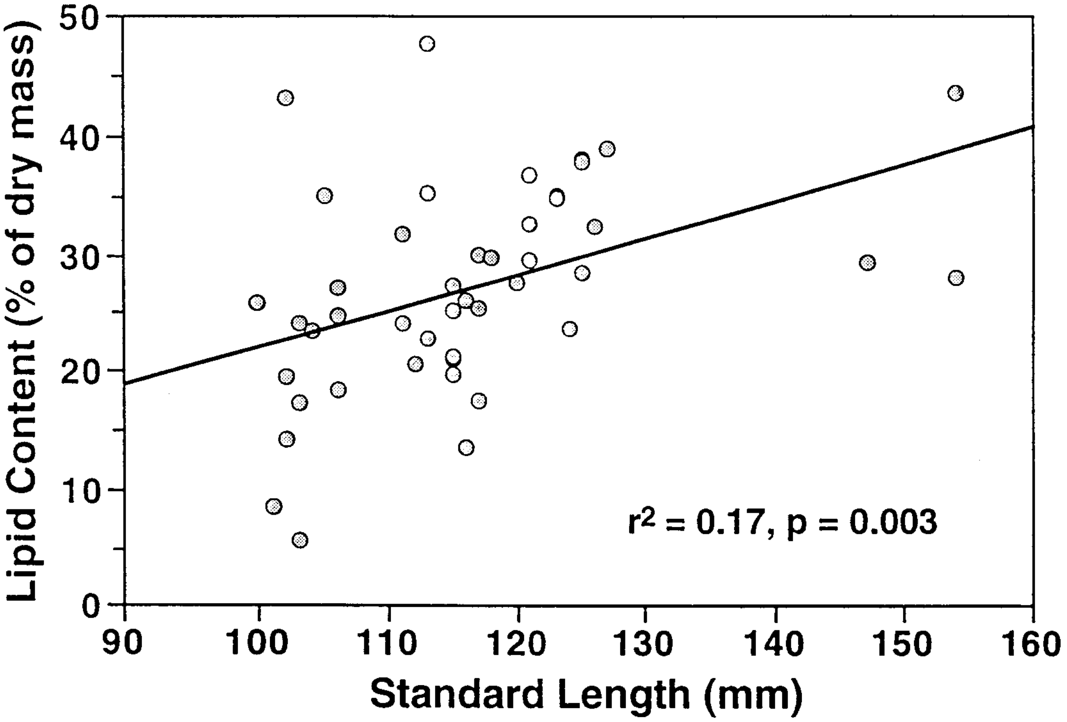
Energy density (protein KJ, lipid KJ) of forage fishes in Prince William Sound, Alaska





Pacific Herring from Prince William Sound
Energy Content (kJ/g wet mass)
0
2
4
6
8
Lipid kJ
Protein kJ
Age 0+
Age 1+ Naked Is.
Age 1+ Port Gravina
Age 2+ Jackpot Is.

Fig. 3



Lipid Content (% of dry mass)
0
10
20
30
40
50
90
100
110
120
130
140
150
160
Standard Length (mm)
$r^2 = 0.17$, $p = 0.003$

Fig. 4

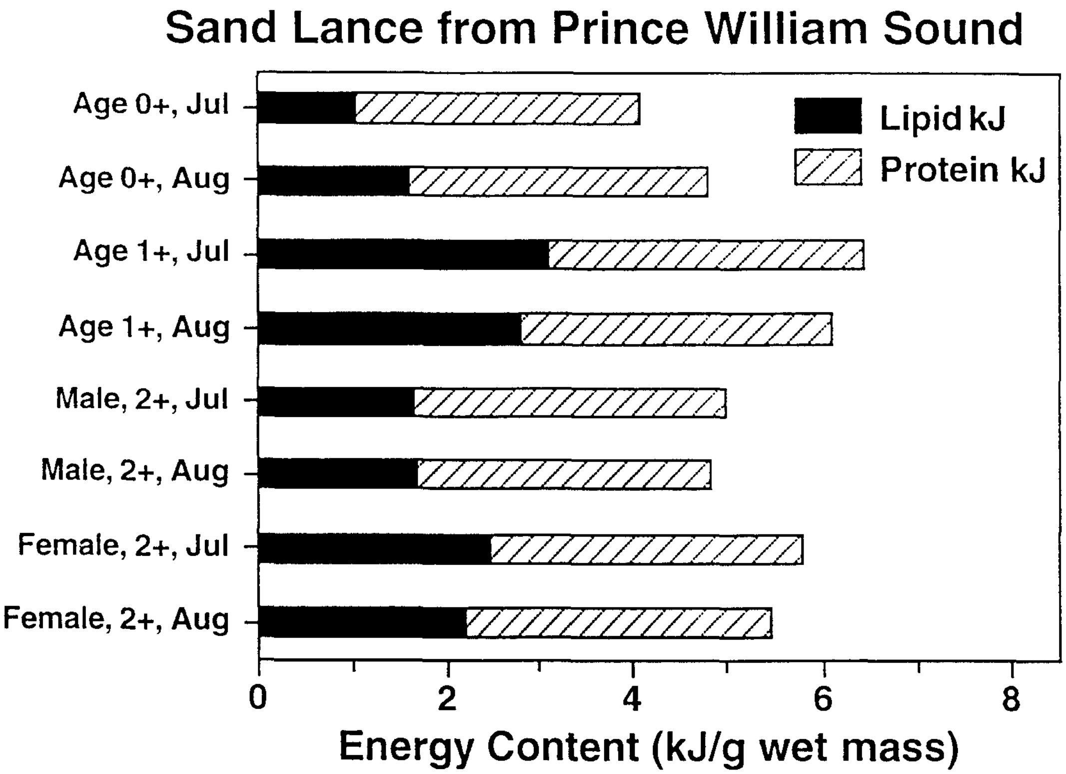

Sand Lance from Prince William Sound
Age 0+, Jul
Age 0+, Aug
Age 1+, Jul
Age 1+, Aug
Male, 2+, Jul
Male, 2+, Aug
Female, 2+, Jul
Female, 2+, Aug
Lipid kJ
Protein kJ
0
2
4
6
8
Energy Content (kJ/g wet mass)

Fig. 5

Pigeon Guillemot Diets in Kachemak Bay and Prince William Sound (Jackpot Island and Naked Island), Alaska

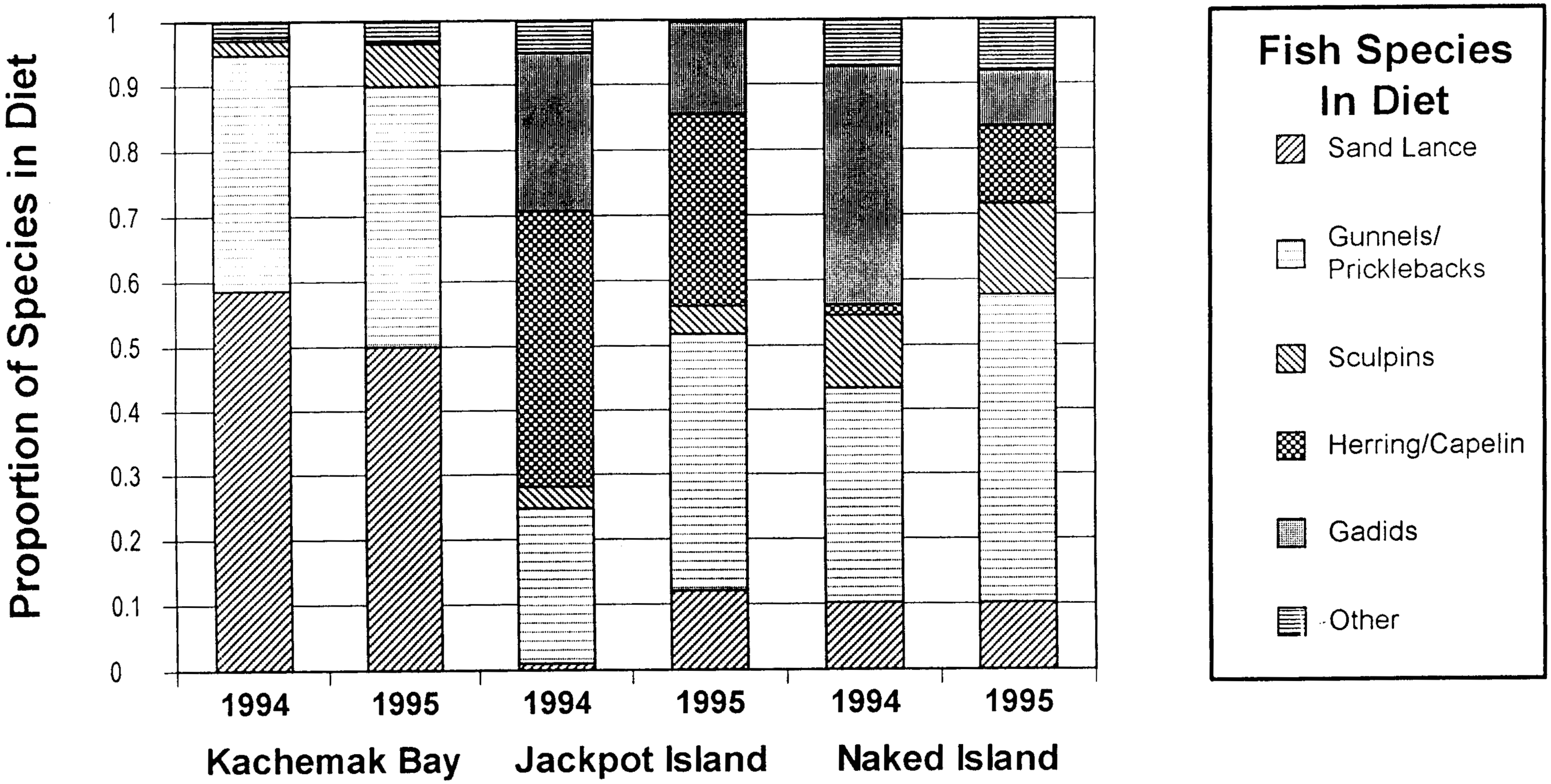


Fig. 6

Prey Delivery Rates to Guillemot Nests in Kachemak Bay and Prince William Sound (Jackpot Island, Naked Island), Alaska

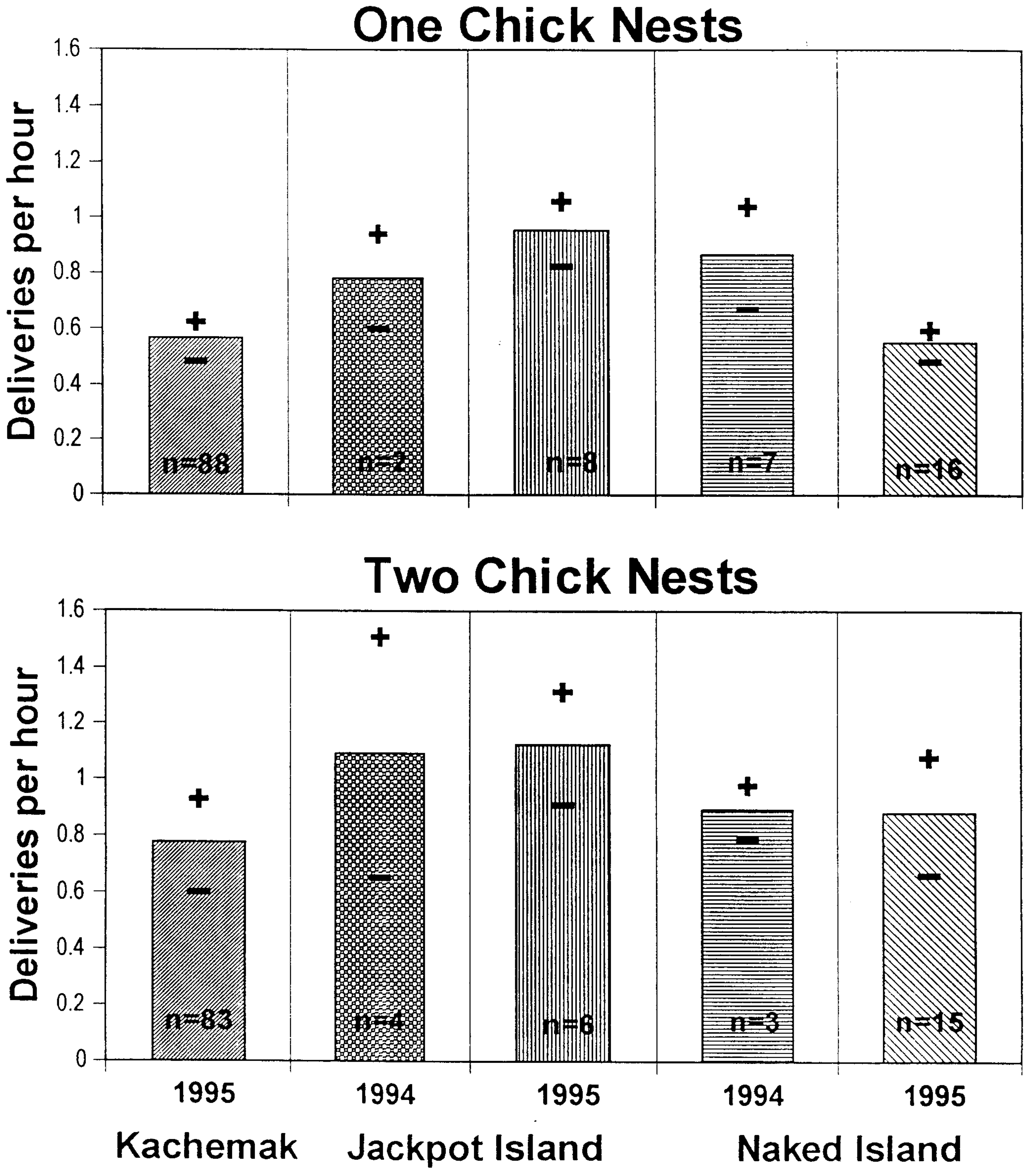


Fig 7

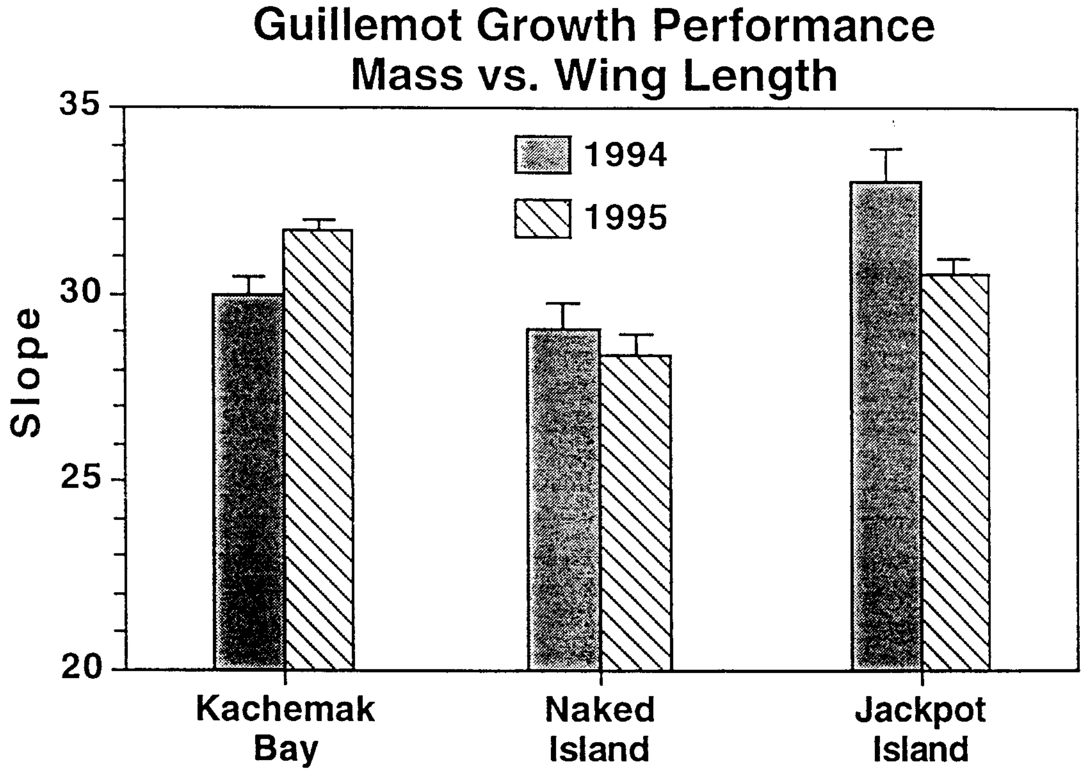
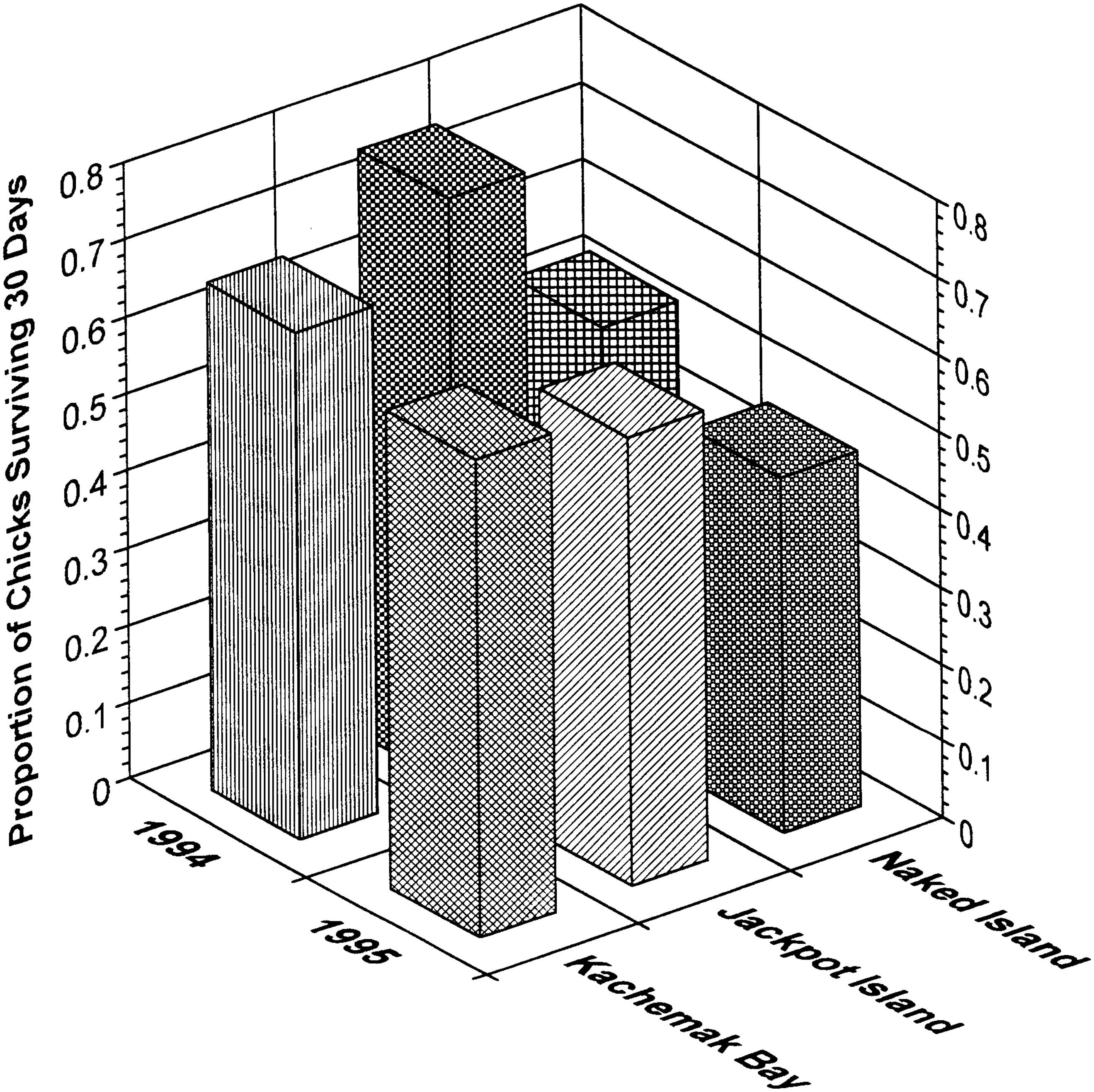

Guillemot Growth Performance
Mass vs. Wing Length

Fig. 8

Nestling Survival

Kachemak Bay and Prince William Sound (Jackpot Island, Naked Island), Alaska



Chick survival for first 30 days of nestling period (Mayfield Method)

APPENDIX H

APEX: 95163 H

This project was not active during the period under review.

APPENDIX I

APEX: 95163 I

The main report constitutes the report for this subproject.

APPENDIX J

APEX: 95163 J

Exxon Valdez Oil Spill
APEX Project Annual Report

Barren Islands Seabird Studies, 1995

APEX Project 95163J
Annual Report

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May 1996

Barren Islands Seabird Studies, 1995

APEX Project 95163J
Annual Report

Study History: This project has no study history. It is a new project that was implemented in 1995 as part of the *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Experiment (APEX).

Abstract: As part of the 1995 APEX seabird - forage fish project, we conducted a pilot study to collect data on common murres *(Uria aalge)*, black-legged kittiwakes *(Rissa tridactyla)*, and tufted puffins *(Fratercula cirrhata)* at the East Amatuli Island - Light Rock colony in the Barren Islands. The work was included in the APEX program because some information on these species were already available from the colony, and its offshore location provided opportunities to compare data from oceanic environments with information being collected in Prince William Sound and in other areas of lower Cook Inlet - Kachemak Bay. Also, capelin (*Mallotus villosus*), an important forage fish species scarce in the northern Gulf of Alaska since the late 1970's, were abundant near the Barren Islands in 1993-1994. The presence of large stocks of these fish and other forage fishes (e.g., sand lance, *Ammodytes hexapterus*; young walleye pollock, *Theragra chalcogramma*) in surrounding waters provided an opportunity to study seabird - forage fish relationships and natural ecological processes that might help explain why populations of some seabird species have not increased in the T/V Exxon Valdez oil spill area. During the study, data were collected on nesting chronology, productivity, growth and feeding rates of chicks, time budgets of adults, and types and amounts of prey fed to chicks. Although some data are still being analyzed, preliminary results indicate that sufficient types and amounts of information can be collected at this northern Gulf of Alaska colony to help test three APEX project hypotheses: (a) composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fishes near the nesting colonies; (b) changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks; and (c) seabird productivity is determined by differences in forage fish nutritional quality.

Key Words: Barren Islands, black-legged kittiwake, common murre, East Amatuli Island, East Amatuli Light Rock, *Exxon Valdez*, forage fish, *Fratercula cirrhata*, oil spill, Prince William Sound, *Rissa tridactyla*, tufted puffin, *Uria aalge*, *Uria lomvia*.

Citation: Roseneau, D.G., A.B. Kettle, and G.V. Byrd. 1996. Barren Islands seabird studies, 1995. Unpubl. annual rept. by the Alaska Maritime National Wildlife Refuge, Homer, Alaska for the *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska (APEX Project 99163J). 34 pp.

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INTRODUCTION

As part of the 1995 *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Experiment (APEX), we conducted a pilot study to collect data on black-legged kittiwakes *(Rissa tridactyla)*, common murres *(Uria aalge)*, and tufted puffins *(Fratercula cirrhata)* at the East Amatuli Island - Light Rock colony in the Barren Islands. The Barren Islands study was included in the APEX seabird - forage fish project because some information on these species was already available from the colony (e.g., Bailey 1975a,b and 1976; Manuwal 1978, 1980; Manuwal and Boersma 1978; Nysewander and Dipple 1990, 1991; Dippel and Nysewander 1992; Nysewander *et al.* 1993; Dragoo *et al.* 1994; Boersma *et al.* 1995; Erikson 1995; Roseneau *et al.* 1995, 1996), and its offshore location provided opportunities to compare data from oceanic environments with information from APEX studies in Prince William Sound and Minerals Management Service (MMS) research in lower Cook Inlet - Kachemak Bay. Also, capelin *(Mallotus villosus)*, an important forage fish species scarce in the northern Gulf of Alaska since the late 1970's (Piatt and Anderson 1995; P. Anderson, unpubl. data), were abundant near the Barren Islands in 1993-1994 (Roseneau *et al.* 1995, 1996). Large stocks of these fish and the presence of other forage fishes, including sand lance *(Ammodytes hexapterus)* and young cods (e.g., 0-1+ age-class walleye pollock, *Theragra chalcogramma*, and Pacific cod, *Gadus macrocephalus)* in surrounding waters provided an opportunity to study seabird - forage fish relationships and natural ecological processes that might help explain why populations of some seabird species have not increased in the T/V *Exxon Valdez* oil spill area.

Data collected during the study will be used to help test three APEX hypotheses:

Hypothesis 7: Composition and amounts of prey in seabird diets reflect changes in relative abundance and distribution of forage fish near nesting colonies.

Hypothesis 8: Changes in seabird productivity reflect differences in forage fish abundance as measured by amounts of time adult birds spend foraging for food, amounts of food fed to chicks, and provisioning rates of chicks.

Hypothesis 9: Seabird productivity is determined by differences in forage fish nutritional quality.

Because some types of information needed to test these hypotheses had not been obtained from the Barren Islands before, we evaluated the feasibility of collecting these data at the East Amatuli Island - Light Rock colony (e.g., for murres and kittiwakes, data on feeding frequencies and types of prey fed to chicks, time-activity budgets of adults; for kittiwakes, chick growth rates and amounts of food fed to chicks).

During the work, we collected data on kittiwake, murre, and puffin productivity and nesting chronology; types and amounts of prey fed to kittiwake, murre, and puffin chicks; growth rates of kittiwake and puffin chicks; feeding frequencies of kittiwake and murre chicks; and time-activity budgets of kittiwake and murre adults. Based on our pilot study results, we have concluded that sufficient amounts and types of information can be obtained at the Barren Islands to help test the APEX hypotheses.

Preliminary results from our pilot study are summarized below. Most of these results have already been shared with other APEX investigators to allow them to begin making comparisons between colonies (e.g., D. Irons, Project 95163E, and J. Piatt, Project 96163M; prey samples were also provided to D. Roby, Project 95163G, for energy content and density analyses). In several cases, we have compared our results with data from the 1993-1994 EVOS-sponsored Barren Islands common murre restoration monitoring projects (Projects 93049 and 94039; see Roseneau *et al.* 1995, 1996). After the 1996 field season has been completed, we will reanalyze these data sets and test them for trends (e.g., four years of murre, kittiwake, and puffin productivity data will be available for these types of analyses). We will also expand the comparisons to include relevant information from historical Barren Islands studies (e.g., kittiwake productivity data in Manuwal 1980) and other data sets that can be tested for between-years differences (e.g., two years of kittiwake and murre feeding frequency and time budget data will be available for testing after the 1996 field season).

OBJECTIVES

Our overall 1995 objective was to determine the feasibility of collecting the types of data at the Barren Islands that are needed for a multispecies, multicolony, multiyear analysis of seabird productivity and energetics in Prince William Sound and lower Cook Inlet. Specific objectives were to:

1. Determine the productivity of common murres (fledglings per egg laid), black-legged kittiwakes (fledglings per nest), and tufted puffins (percent of occupied burrows containing chicks).
2. Determine the nesting chronology of common murres, black-legged kittiwakes, and tufted puffins (median hatch date).
3. Determine the growth rates of black-legged kittiwake and tufted puffin chicks (grams per day).
4. Determine the types of prey fed to common murre (percent by number), black-legged kittiwake (percent by number and weight), and tufted puffin (percent by number and weight) chicks.
5. Determine the feeding frequencies of common murre and black-legged kittiwake chicks (feedings-per-hour and per-nest, respectively).
6. Determine amounts of food fed to black-legged kittiwake chicks (grams per regurgitation) and tufted puffin chicks (grams per screened sample).
7. Determine adult activity budgets for common murres and black-legged kittiwakes (foraging trip duration, minutes per hour both adults were present at nests, minutes per hour both adults were absent from nests).

METHODS

The Barren Islands are located at about 58° 55' N, 152° 10' W, between the Kodiak archipelago and the Kenai Peninsula (Fig 1). The study was conducted at the East Amatuli Island - Light Rock colony, and personnel stayed at the Amatuli Cove camp (Fig 2). Four people occupied the camp during 15 June - 9 September. They commuted to murre and kittiwake study sites in outboard-powered, 4.8-m-long, ridged-hulled inflatable boats and hiked to puffin study areas near Valley Rise.

Productivity

Murres: Murre productivity data were collected at the 10 East Amatuli Island - Light Rock plots used for this purpose in 1993-1994 (MPP 1-10; see Roseneau *et al.* 1995, 1996) and one additional plot (MPP 11) set up during this study (Fig. 2). The plots, containing about 25-50 nest sites (sites with eggs) each (total = 342), were checked with 7 x 42 binoculars and 15-60 power spotting scopes from land-based observation posts as often as weather allowed (range = 1-6 days). Viewing distances varied from about 30 to 100 m, and observers were assigned specific plots for the duration of the field season. Nest sites were mapped using photographs and sketches, and data were recorded for each site using previously established codes. Plot checks consisted of searching for eggs and chicks and adults in incubation and brooding postures, and counting adults. Each plot was checked 25 times during 24 June - 3 September, from just before eggs were laid until after sea-going of chicks peaked. Data were analyzed by treating plots as sample units and calculating productivity as fledglings per egg (see Roseneau *et al.* 1995, 1996). Productivity data were also used to compute hatching and fledging success (see Roseneau *et al.* 1995, 1996). Differences among 1993-1995 results were tested with ANOVA.

Kittiwakes: Kittiwake productivity data were collected from 12 East Amatuli Island plots; five established in 1993 (KPP 1-4; D.G. Roseneau and A.B. Kettle, unpubl. data) and seven set up during this study (KPP 5-12; Fig. 2). The plots, located on the same headlands as the murre productivity plots, contained 25-50 nests each (total = 431; 391 with eggs). Methods for collecting and analyzing data were similar to those used for murres; methods were also compatible with Project 95163E PWS protocols. Nest checks consisted of searching for eggs and chicks, and counting adults (incubation and brooding postures were not used for kittiwakes). Each plot was checked 26 times during 22 June - 30 August, from just after egg-laying began until after fledging peaked. During data analysis, plots were treated as sample units and productivity was calculated as fledglings per egg. Data were also analyzed using nests as sample units to obtain a fledglings per nest value for direct comparison with Project 95163E PWS information. Laying, hatching, and fledging success were also computed from the productivity data. Differences among 1993-1995 results were tested with ANOVA.

Puffins: Puffin productivity data were obtained from five study plots (TPP 1-5) set up by UW personnel in 1990 to collect information on chick growth rates (see growth rates below), and four transects (TPT 1-4) totaling 270 m^2 established by FWS crews in 1986 to monitor numbers and occupancy rates of burrows (Nishimoto 1990; Fig 2). Burrows on the three UW plots were searched for signs of occupancy (trampled and cleared vegetation, guano from adults and chicks, fresh digging) and chicks during 29 July - 4 August, when most nestlings were about one week old. A 35-cm-long flexible scoop was used to help determine presence/absence of chicks. After the initial visit, all burrows containing nestlings were checked every five days until 6 September (most chicks had fledged by this date). Burrows on the FWS transects were checked once on 1 September, just prior to fledging, to count occupied burrows and nestlings. Using the transect information (numbers of occupied burrows and nestlings), productivity was calculated as the percentage of occupied burrows containing chicks. *[Data from the five study plots are still being analyzed; when complete, the same procedures will be used to calculate productivity for this data set. The study plot data will provide information on fledging success.]*

Nesting Chronology

Murres: Median hatch date was chosen as the primary measurement of murre nesting chronology; this variable was derived from the productivity plot data (see Roseneau *et al.* 1995, 1996). Median dates were calculated for each plot, and these values were averaged to describe timing of nesting events. Because laying and hatching of eggs and fledging of chicks were rarely observed on the productivity plots, the date that nest sites changed status (i.e., from eggs to chicks) was estimated to be the midpoint between the closest pre- and post-event observation dates. Two methods were used to maintain precision during data analysis. Nest sites with data gaps of more than seven days between pre- and post-event laying and hatching observation dates were excluded from the data set. Also, at sites where the range of possible laying dates was smaller than the range of possible hatching dates, hatching dates were calculated by adding 32 days to laying dates (see Byrd 1986, 1989; Roseneau *et al.* 1995, 1996). Differences among the 1993-1995 results were tested with ANOVA.

Kittiwakes: Median hatch date, derived from productivity plot data, was used to measure kittiwake nesting chronology. The date was computed by the same methods described for murres, except that 27 days (instead of 32) were added to laying dates at sites where the range of possible laying dates was smaller than the range of possible hatching dates (see Byrd 1986, 1989). The difference between 1994 and 1995 results was checked with a two-tailed *t*-test (no eggs or chicks were present on the plots in 1993).

Puffins: Median hatch date was used to measure puffin nesting chronology. This information was derived from chick growth rate data rather than laying or hatching information, because the burrows were not visited until the chicks were about one week old (visiting them prior to this time can result in abandonment of eggs or chicks). The date was obtained by estimating the ages of 43 chicks from first wing measurements and a growth equation reported by Amaral (1977), and then calculating the median of the nestlings' estimated hatch dates.

Chick Growth Rates

Murres: Data on murre chick growth rates were not obtained during the study, because disturbing the birds to weigh and measure chicks could have caused high levels of chick mortality.

Kittiwakes: Kittiwake growth rate information was collected from 41 chicks that were weighed (to nearest g) and measured (e.g., wing chord, culmen, tarsus, and back of head to tip of bill to nearest 0.1 mm) 3-4 times, beginning shortly after they had attained weights of about 200 g (weights were not obtained prior to this time because time was needed to find accessible nests and set up ropes to reach study sites). Methods for calculating growth rates followed Project 95163E PWS protocol. Weights higher than 325 g were excluded from the data set (growth rates are linear until they reach this point), and the difference in weight between each chick's first and last measurements were divided by the number of days between these measurements (15 chicks were weighed at least twice before reaching 325 g). The resulting nestling values were then used to calculate mean growth rates for 'A' chicks (chicks in single-chick nests plus first chicks to hatch in 2-chick nests; n = 9), 'B' chicks (the second to hatch chicks in 2-chick nests; n = 6), and chicks in single-chick nests (n = 6). *[Exploratory work conducted during 1995 will allow sample sizes to be increased in 1996.]*

Puffins: Forty-three puffin chicks on three of the five UW growth rate plots (see productivity above) were weighed (to nearest g) and measured (culmen, wing chord, and tarsus to nearest 0.1 mm) every five days, from the time they were about one week old until they fledged (most nestlings were weighed seven times prior to fledging). Twenty-one additional nestlings were weighed and measured three times on the two other growth rate plots during the chick-rearing period to check for effects of disturbance on growth. Weight was chosen as the primary measurement of growth. Data were analyzed by fitting a simple liner model to the 150-450 g section of each chick's growth curve (the portion that is nearly linear), and then calculating the average daily weight gain by using the slope of the line and numbers of days between first and last measurements. The final grams per day rate was the mean of 34 chick values. *[Data from the 21 "control" nestlings are still being analyzed; when complete, the average growth rate of these chicks will be compared with the average value obtained from the 34 "experimental" nestlings.]*

Chick Food Types

Murres: Prey delivered to murre chicks were identified during feeding frequency and adult activity budget observations (see feeding frequency below). Food items brought to chicks on ledges adjacent to the feeding frequency plots were also recorded, as time allowed, to supplement plot observations. Prey were identified with 7 x 42 binoculars and field guides. In total, 460 prey items, all fish, were observed during 16 August - 3 September, when chicks were about one - three weeks old. Three hundred fifty-six (78%) of the fish were identifiable to species or family groups (e.g. gadidae) on the basis of color and body and fin shapes (e.g., caudal, anal, adipose fins). Data were analyzed by calculating percentages by number of identifiable items for five categories of prey (capelin, *Mallotus villosus*; sand lance, *Ammodytes hexapterus*; prowfish, *Zaprora silenus*; and cods, Gadidae).

Kittiwakes: Samples of prey brought to kittiwake chicks were obtained by visiting nests and gently inducing nestlings to regurgitate food. A total of 69 samples was obtained on eight different dates during 17 July - 5 August, when chicks were about 9-28 days old. Samples were fixed in 10% buffered formaldehyde for 24 hrs before being stored in 50% ethanol (weights were obtained after samples were decanted in the lab). Prey items were analyzed by A.M. Springer, Institute of Marine Sciences, University of Alaska-Fairbanks. Fish were identified, counted, and aged from otoliths, and otoliths were also used to help calculate wet weights. Wet weights (to nearest g) were estimated by using standard regression equations relating otolith lengths to fish lengths and fish lengths to wet weights of fish (e.g., see Springer *et al.* 1984, 1986). For unidentified cods (probably Pacific cod, *Gadus macrocephalus*), average weights of similar-size Pacific cod collected during the puffin burrow screening work (this study, see below) were used to estimate wet weight. Invertebrates were identified and counted from whole specimens and hard parts (e.g., jaws, rostra). Wet weights were estimated by weighing whole specimens, or in some cases by using average weights from specimens collected during the work (for small euphausiids and squid; this study, see below). Data were analyzed by calculating percentages by number and weight of identifiable items (n = 629) for five categories of prey (capelin; sand lance; walleye pollock, *Theragra chalcogramma*; cods, Gadidae; and invertebrates).

Puffins: Samples of prey brought to puffin chicks were collected by temporarily blocking burrows with small squares of hardware cloth (screens). One hundred thirty-nine samples containing 346 identifiable items were obtained during six days of screening at East Amatuli Island and four at West Amatuli Island during 31 July - 8 September. Samples were weighed (to nearest g) and prey items were measured (length, to nearest mm) before being frozen (28 August and 2 September) or fixed in 10% buffered formaldehyde for 24 hrs and stored in 50% ethanol. Most specimens were identified in the field using field guides and taxonomic keys; however, some items (e.g., larval fishes) were sent to UAF and NOAA personnel for identification. Frozen prey items were thawed and weighed (to nearest g) in the lab. These data and the measurements made in the field were used to estimate wet weights of preserved specimens. Data were analyzed by calculating percentages by number and weight of identifiable prey items for eight categories of prey (capelin; sand lance; walleye pollock; prowfish; Pacific cod; larval daubed shannies, *Lumpenus maculatus*; squids, Cephalopoda; and euphausiids, *Thysanoessa* spp.).

Chick Feeding Frequencies

Murres: Murre chick feeding frequency data were obtained from two plots set up in different types of nesting habitat near the productivity plot observation posts (see productivity above). One plot (The Cliff) consisted of a narrow ledge on a steep cliff-face about 15 m below an observation post; this plot contained 12 nest sites with chicks. The second plot (Rubble), containing 16 nest sites with chicks, was located in a flat rock-strewn area about 35 m from another observation post. Food deliveries were recorded on the plots during two 13-hr-long dawn-to-dusk watches on 24 and 26 August, and during shorter blocks of time (2.5-7.5 hrs) on 16, 17, 18, 21, 22, and 23 August. Data analyses consisted of calculating the average number of feedings per hour for the 0630-2000 hr dawn-to-dusk watches, two 0630-1030 hr blocks of time (24 and 26 August), and three 0800-1200 hr blocks of time (22, 24, and 26 August) using hours and chicks as sample units. Hours were treated as sample units to check temporal variation and help identify the most active part of the day, and chicks were used as sample units to measure variation among nests and provide an average feeding rate for comparison with data from other lower Cook Inlet studies (e.g., 1995 data collected by J. Piatt at Gull and Chisik islands). Differences in feeding rates between the two dawn-to-dusk watches and between the two 0630-1030 blocks of time were checked with two-tailed t-tests, and differences among the four 0800-1200 blocks of time were tested by ANOVA. *[Data from the Rubble plot and shorter blocks of time on other days are still being analyzed to help refine protocols for collecting this type of information (data can be analyzed in several ways—e.g., for blocks of time encompassing the most active times of the day, or for blocks of time that best represent an average rate for the entire day). Methods for collecting and analyzing these data will be finalized in cooperation with J. Piatt, Project 96163M, before the 1996 field season begins.]*

Kittiwakes: Kittiwake chick feeding frequency data were obtained from 11 nests in one of the kittiwake productivity plots (see productivity above). The nests contained 18 chicks. Most of the information was collected by watching the nests with 7 x 42 binoculars from about 20 m away and recording times of begging and feeding events. Some data were also obtained by recording these activities on video tape (using an 8-mm Sony HandyCam) and reviewing tapes in camp (no differences were found between data collected simultaneously by the video and direct observation methods). Observations began when the nestlings were about 20 days old (chicks ages were known because of the productivity work). Because chicks may be fed several times after foraging adults return to nests, and because birds sometimes leave their nests for short periods of time without foraging at sea, only first feedings after trips lasting 30 minutes or more were counted as feeding events. Two 13-hr-long dawn-to-dusk watches were conducted on 26 and 27 July to help identify the most active 4-hr part of the day, and data were collected on two additional dates (5 and 6 August) during that period (0800-1200 hrs). Data analysis consisted of dividing the data into 1- and 2-chick nests, and calculating the average number of feedings per hour for the dawn-to-dusk watches and for the four 0800-1200 hr blocks of time using hours and nests as sample units. Hours were treated as sample units to check temporal variation, and nests were used as sample units to measure variation among nests and provide an average feeding rate for comparison with data from other lower Cook Inlet colonies and studies in Prince William Sound (e.g., 1995 data collected by J. Piatt at Gull and Chisik islands, and D. Irons at Shoup Bay and Eleanor Island, respectively). Differences in feeding rates between the two dawn-to-dusk watches were checked with two-tailed t-tests, and differences among the four 0800-1200 blocks of time were tested by ANOVA. *[These data and some additional information collected during shorter times on three other dates are still being analyzed to help refine protocols for this parameter. Methods for collecting and analyzing these data will be finalized in cooperation with D. Irons, Project 96163E; D. Roby, Project 96163G; and J. Piatt, Project 96163M, before the 1996 field season begins.]*

Puffins: Data on feeding frequencies of puffin chicks were not obtained during 1995; however, a potential study site was located near the East Amatuli Island observation posts. Plans are being made to set up a blind and assess the feasibility of collecting these data. *[If these data can be obtained during August 1996, they will be compared among years and discussed in context with murre and kittiwake results.]*

Amounts of Food fed to Chicks

Murres: Data on amounts of food fed to murre chicks were not collected during the study, because disturbing the birds to collect and weigh fish could have caused high levels of chick mortality.

Kittiwakes: Information on amounts of food fed to kittiwake chicks was obtained from regurgitated samples (see chick food types above). Because the amount of food fed to nestlings increased until they were about 20 day old, the average weight of 44 samples collected from chicks that were that age or older was used as the seasonal index for this variable.

Puffins: Information on amounts of food fed to puffin chicks was obtained from burrow screening samples (see chick food types above). Because it was obvious that some screened samples were only partial bill-loads (e.g., only tails of fish were present; adults were seen flying off with some prey items still in their bills), the average weight of 110 samples was used as the seasonal index for this variable.

Activity Budgets of Adults

Murres: Murre activity budget information was obtained during chick feeding frequency observations (see chick feeding frequencies above). Adult arrival and departure times, and times when members of pairs exchanged duties (i.e., incubating eggs or brooding chicks) were recorded at each nest site. Average trip time was obtained by treating trips as sample units and calculating the mean duration of all trips made by birds during the two dawn-to-dusk watches (i.e., during the combined 26 hrs of observations). Nest sites were used as sample units to calculate the average numbers of minutes per hour that no adults and two adults were present at the nests during the same 26 hr period of time. Differences in attendance between the two days were tested with two-tailed *t*-tests.

Kittiwakes: Kittiwake activity budget information was obtained during chick feeding frequency observations (see chick feeding frequencies above). Adult arrival and departure times, and times when members of pairs exchanged duties (i.e., incubating eggs or brooding chicks) were recorded at each nest. Data were analyzed by treating nests as sample units and calculating the average number of minutes per hour that no adults and two adults were present at 1- and 2-chick nests during the two dawn-to-dusk watches (i.e., during the combined 26 hrs of observations). Differences in attendance between the two days were tested with two-tailed *t*-tests. *[Data are still being analyzed to obtain an average trip duration value using the same procedures described for murres—see above.]*

Puffins: Information on puffin activity budgets was not obtained in 1995. *[However, this information will be collected in 1996, if feasibility tests to obtain puffin feeding frequency data are successful.]*

Population Counts

Population counts of birds were not included in the 1995 APEX Barren Islands study plan. However, some counts were made when time was available.

Murres: Murres were counted five times on the 8 East Amatuli Island - Light Rock multicount plots censused in 1993-1994 (plots BMP 1-8; see Roseneau *et al.* 1995, 1996), and they were also counted on the productivity plots every time the plots were checked (25 times; these counts were also made in 1993-1994). Methods for collecting and analyzing these data were the same as those used during the 1993-1994 Barren Islands restoration monitoring studies (see Roseneau *et al.* 1995, 1996).

Kittiwakes: Kittiwakes were counted at the productivity plots every time the plots were checked (26 times). These counts were made and analyzed by the same procedures used during 1993-1994 (D.G. Roseneau and A.B. Kettle, unpubl. data).

Puffins: During the puffin work, about 200 burrows on the five UW growth rate plots and 63 burrows on the FWS transects were checked for occupancy. This information is being analyzed to provide an index of occupied burrows per m^2 that can be used to help monitor changes in population size during coming years.

RESULTS

Productivity

Murres: Common murre productivity was high in 1995 (0.77 fledglings per egg, SD = 0.09; Table 1, Fig. 3a) and similar to the 1994 results (0.73 fledglings per egg; Roseneau *et al.* 1995); values from both of these years were significantly higher than in 1993 (0.55 fledglings per egg, $P = 0.001$ and 0.007, respectively; Roseneau *et al.* 1996). Fledging success was also high (0.91 chicks per egg, SD = 0.006; see Byrd *et al.* 1993) and nearly identical to the 1994 level (0.93), and results from both years were higher than the 1993 value (0.79; $P = 0.004$ and 0.011, respectively). Hatching success exhibited a different pattern: while the 1995 and 1994 figures (0.85 chicks per egg, SD = 0.07, and 0.79, respectively; also high values, see Byrd *et al.* 1993) were similar each other, only the 1995 value was significantly higher than the 1993 figure (0.70; $P = 0.017$).

Kittiwakes: Productivity of kittiwakes was high in 1995 (0.81 fledglings per nest, SD = 0.20; Table 1, Fig. 3b—also see Hatch *et al.* 1993) and similar to the 1994 level (0.64 fledglings per nest; D.G. Roseneau and A.B. Kettle, unpubl. data). These results were in sharp contrast to 1993, when nesting pairs failed early in the nesting season and reproductive success was zero (no eggs or chicks were present on the five East Amatuli Island plots; however, a few fledglings were observed at the colony at the end of the breeding season—Roseneau *et al.* 1995). Hatching success (0.73 chicks per egg, SD = 0.11) was higher than it was in 1994 (0.50, SD = 0.21; $P = 0.012$), but fledging success (0.61, SD = 0.15) was lower than the 1994 value (0.87, SD = 0.05; $P = 0.005$).

Puffins: Based on the information obtained from transects TPT 1-4, productivity of puffins (0.52 chicks per occupied burrow; Table 1 and 2, Fig. 4) fell between the 1993 and 1994 values (60% and 47%, respectively). *[Data from the growth rate study plots are being analyzed to obtain productivity values for 1993-1995; the plots sample a much larger area then the transects.]*

Nesting Chronology

Murres: Based on the median hatch date (9 August, SD = 2.9 days; Table 1), hatching occurred two days earlier than in 1994 (11 August; Roseneau *et al.* 1995) and seven days earlier than in 1993 (16 August; Roseneau *et al.* 1996). Although no difference was found between the 1994 and 1995 estimates, the 1993 date was significantly later than the 1994-1995 dates (ANOVA, $P = 0.001$ in both cases).

Kittiwakes: The median hatch date was 8 July (SD = 1.7 days; Table 1). *[1994 nesting chronology data are still being analyzed.]*

Puffins: The median hatch date was 22 July (SD = 5.1 days; Table 1). *[1993-1994 nesting chronology data are still being analyzed.]*

Chick Growth Rates

Kittiwakes: The average growth rate of kittiwake chicks, based on all chicks combined (n = 15), was 19.0 grams per day (SD = 4.2 days; Table 1). "A" chicks (chicks in single-chick nests plus first chicks to hatch in 2-chick nests; n = 9) gained about 18.7 grams per day (SD = 3.8 days), while "B" chicks (the second to hatch chicks in 2-chick nests; n = 6) grew at a rate of about 19.6 grams per day (SD = 5.0 days). The average daily weight gain for chicks in single-chick nests (n = 6) was about 18.6 grams per day (SD = 4.3 days). No significant differences were found among these values.

Puffins: Based on a preliminary analysis of 34 nestlings in three study plots, puffin chicks grew at an average rate of 11.5 grams per day (SD = 3.3 grams; Table 1). *[Data from the 21 nestlings that were weighed and measured only three times during the nestling period, and information obtained during the 1993-1994 field seasons are still being analyzed.]*

Chick Food Types

Murres: Prey items delivered to murre chicks consisted solely of small fish (n = 460), most of which were capelin (86%, n= 356; Fig. 5). Adults also fed nestlings unidentified cods (Gadidae, probably primarily walleye pollock and Pacific cod), prowfish, and sand lance, but in much lower numbers (7%, 6%, and 1%, respectively). Based on the general sizes of fish brought to the chicks and the large numbers of capelin fed them, this forage fish species must have also dominated the diets by weight.

Kittiwakes: Kittiwakes fed their nestlings both fish and invertebrates, and on the basis of numbers alone (n = 629; Fig. 6a), invertebrates outranked fish (438 items = 70% vs. 191 items = 30%, respectively). However, invertebrates were present in only six (9%) regurgitations, and most of them (424 small euphausiids totaling 97% of all invertebrate prey) were found in two samples. When the samples were analyzed by weight (Fig. 6b), it was clear that fish dominated the diets (94% vs. 6% invertebrates) and capelin (65% by weight) outranked other species.

Puffins: Prey deliveries (screen samples; n = 139) to puffin chicks contained 346 items, most of which were fishes (87% by number vs. 13% invertebrates; Fig. 7a). By number, walleye pollock (26%), larval daubed shannies (21%), capelin (14%), and sand lance (12%) were the most common prey fed to nestlings (73% of the total). By weight, fishes were also clearly the most important prey (93%; Fig. 7b). However, in this analysis, capelin (28%), walleye pollock (24%), prowfish (22%), and sand lance (13%) made up the bulk of the chicks' diets (87% of the total).

Chick Feeding Frequencies

Murres: During the two all-day watches, chicks on the Cliff plot averaged 0.31 feedings per hour (SD = 0.11, n = 12; Table 1, Figs. 8 and 9). Feeding rates during the two 0630-1030 and three 0800-1200 hr morning blocks of time averaged 0.39 (SD = 0.22, n = 12) and 0.24 (SD = 0.16, n = 12) per-hour, respectively. No differences were found between the two 13-hr average values (0.35/hr, SD = 0.16 and 0.27/hr, SD = 0.11 on 24 and 26 August, respectively), or between the 0630-1030 average rates (0.42/hr, SD = 0.34 and 0.35/hr, SD = 0.23 on 24 and 26 August, respectively), or among the 0800-1200 average values (0.23/hr, SD = 0.21; 0.31/hr, SD = 0.28; and 0.19/hr, SD = 0.19 on 22, 23, and 26 August, respectively).

Kittiwakes: During the two all-day watches, single-chick nests averaged 0.28 feedings per hour (SD = 0.11, n = 11; Table 1, Figs. 10 and 11), and nests containing two chicks averaged 0.47 feedings per hour (SD = 0.19, n = 11). This difference was almost significant (two-tailed *t*-test, $P = 0.07$). Feeding rates during the four 0800-1200 hr blocks of time averaged 0.39 (SD = 0.18, n = 5) and 0.72 feedings per hour (SD = 0.50, n = 6) at 1-chick and 2-chick nests, respectively. This difference was barely significant (two-tailed *t*-test, $P = 0.05$). No differences were found between the two 13-hr average values (0.33/hr, SD = 0.19, and 0.44/hr, SD = 0.18 on 26 and 27 July, respectively), or among the four 0800-1200 average rates (0.39/hr, SD = 0.23; 0.48/hr, SD = 0.21; and 0.59/hr, SD = 0.34; and 0.82/hr, SD = 0.20 on 26 and 27 July, and 5 and 6 August, respectively).

Amounts of Food fed to Chicks

Kittiwakes: The weight of kittiwake chick regurgitations increased with collection date, until the nestlings were about 20 days old (from 10.9 g, SD = 5.1 on 17 July to 26.6 g, SD = 9.5 on 30 July). The average weight of the 44 regurgitation samples obtained from chicks that were about 20 days of age or older was 27.7 g (SD = 11.5; Table 1).

Puffins: The average weight of 110 screen samples collected during the nestling period was 10.3 g (SD = 12.8; Table 1).

Activity Budgets of Adults

Murres: *(Duration of Trips from Nest)* -- The average duration of murre foraging trips during the two dawn-to-dusk watches at the Cliff plot was 157.7 minutes (Table 1, Fig. 12); however, variation was high (SD = 131.3; Table 1, Fig. 13). *(Time Spent at Nest)* -- At least one adult was always present at each site, and both birds were present an average of 5.6 minutes per hour (SD = 4.4; Fig. 13). *[The duration of foraging trips at the Rubble plot are still being analyzed.]*

Kittiwakes: *(Duration of Trips from Nest)* -- Kittiwake foraging trip data are still being analyzed. *(Time Spent at Nest)* -- Average times spent at nests by adults were as follows: at 1- and 2-chick nests, both adults were present 0.3 minutes per hour (SD = 0.0, n = 11; Table 1, Fig. 15) and 0.3 minutes per hour (SD = 0.2, n = 11), respectively, and neither adult was present 1.1 minutes per hour (SD = 0.9) and 5.1 minutes per hour (SD = 5.0), respectively. No differences were found between days for amounts of time two adults spent at nests (26 and 27 July, 4.3 min/hr, SD = 7.1 and 2.2 min/hr, SD = 3.3, respectively), or for times both adults were absent from nests (26 and 27 July; 0.3 min/hr, SD = 0.1, and 0.4 min/hr, SD = 0.3, respectively).

Population Counts

Murres: The average number of murres counted on multicount plots BMP 1-8 was 5,224 individuals (SD = 583; Table 1, Fig 16a). In 1993 and 1994, these plots averaged 5,808 and 5,599 birds, respectively (Roseneau *et al.* 1995, 1996). Counts on productivity plots MPP 1-10 averaged 439 (SD = 32) murres (Fig. 16b), and in 1993 and 1994 scores were 481 and 456 birds, respectively. The multicount and productivity plot estimates will be tested for trends after 1996 data become available. [These data will be analyzed in conjunction with recently approved restoration monitoring Project 96144.]

Kittiwakes: Counts on kittiwake productivity plots KPP 1-12 averaged 199 birds (SD = 15). The 1993-1996 estimates will be tested for trends after completion of the 1996 field season.

Puffins: *[Data on burrow occupancy rates are still being analyzed.]*

DISCUSSION

Eventually, we will be able to compare all of our Barren Islands results among years and make both among- and within-year comparisons with information from other lower Cook Inlet - Kachemak Bay and Prince William Sound colonies to help test APEX hypotheses 7-9. However, at this point during the multiyear study, detailed discussions are premature. Data from previous Barren Islands studies were available for comparison with some of the parameters we measured in 1995 (e.g., reproductive success of all three species, puffin chick growth rates and prey samples), but for other variables (e.g., time-activity budgets of murres and kittiwakes), 1995 was the first year data were collected at the study site. Because some data analyses are still underway, the preliminary discussion provided here is limited to the analyses that have been completed to date.

Productivity

As suggested by APEX hypothesis 8, seabird productivity may reflect shifts in prey abundance near breeding colonies. During 1994 and 1995, murre and kittiwake productivity were high at East Amatuli Island - Light Rock, compared with values reported from 10 North Pacific common murre colonies (see Table 3 in Byrd *et al.* 1993) and 162 estimates from 28 North Pacific black-legged kittiwake colonies (see Table 2 in Hatch *et al.* 1993). In 1993, productivity of murres was within normal bounds; however, it was lower, and the variation among plots higher, than during 1994-1995. Most of the difference in productivity between 1993 and 1994-1995 was caused by the loss of chicks on two exposed study plots during a late August 1993 storm (Roseneau *et al.* 1995).

In contrast to murres, kittiwakes experienced an early, near-complete reproductive failure in 1993: no eggs were laid on the East Amatuli and Nord island study plots (FWS, unpubl. data), and only a few fledglings were seen at the colonies (Roseneau *et al.* 1995). Kittiwake failures have been relatively common events at Alaskan colonies in recent years, and no correlation's appear to exist between these failures and the productivity of diving species (e.g., murres, puffins, cormorants; see Hatch *et al.* 1993). This lack of concordance and the fact that productivity of diving birds has often been within normal ranges in years when surface-feeding kittiwakes fail to reproduce, suggest that the vertical distribution of prey, rather than overall prey abundance, has been responsible for these events (Hatch *et al.* 1993). Available evidence suggests that this was probably the case at the Barren Islands in 1993: although large schools of small fish were present at depth that year, kittiwake feeding melees were rare (Roseneau *et al.* 1995; D.G. Roseneau, pers. obs.)

APEX hypothesis 9 suggests that seabird productivity can be affected by the quality of prey. It is possible that the 1993 kittiwake breeding failure was related to only poor-quality prey being available to these birds, while murres had access to higher-quality food items.

There is some evidence that the frequency of kittiwake reproductive failures has increased recently in the Gulf of Alaska, and that if the current trend continues, colonies may not be able to sustain themselves (Hatch *et al.* 1993). As more data are obtained on seabird reproductive and feeding parameters among species, colonies, and years, and on the distribution and abundance of forage fishes near colonies, specific causes of these events may become more apparent.

In 1995, puffin productivity (defined in this report as the percent of occupied burrows containing chicks just before fledging) fell between the 1993 and 1995 levels, and appeared to be within normal limits, compared to information from other colonies (see Table 6 in Byrd *et al.* 1993; this table uses fledglings per egg as the measurement of productivity).

Nesting chronology

Although nesting chronology was not specifically mentioned in APEX hypotheses 7-9, this variable may be an indicator of changes in environmental conditions that might affect forage fish populations. The average laying dates of most seabird species tend to be timed so that their chick-rearing periods coincide with times when food is most abundant (e.g., Lack 1954). However, the timing of breeding also appears to respond to broad-scale water temperature changes that may alter the distribution, abundance and types of prey available to the nesting birds (e.g., see Boekelheide *et al.* 1990).

Murre nesting chronology often varies by up to 6-10 days among years within colonies (Harris and Birkhead 1985). Based on this information, the 1-week difference between the 1993 and 1994-1995 East Amatuli Island - Light Rock hatch dates was within the normal range of variability. As data are gathered over the next few years, we may be able to use the timing of murre, kittiwake, and puffin nesting events to help detect large-scale changes in environmental conditions.

Chick Growth Rates

Growth rates of seabird chicks may vary with adult foraging conditions, particularly when food abundance is low (Cairns 1987). Data on chick growth rates can be used to help address APEX hypotheses 7 and 8, because this variable can supply indirect information on the types and amounts of prey available to the breeding birds. Because growth rates of chicks can also affect their survival, this parameter may also apply to hypotheses 8 and 9, as a component of seabird productivity. During the course of our studies, we will compare chick growth rates with direct measurements of fish abundance and quality, and with data on feeding frequencies and meal sizes of chicks, types of prey fed to chicks, and adult time budgets. After these comparisons have been made over a few years among species and among colonies, they may help identify relationships between food availability and chick growth rates.

Variation in kittiwake chick growth rates was high. As a result, only large differences in growth rates between "A", "B", and single chicks, and between chicks at the East Amatuli Island and Prince William Sound colonies would have been statistically significant. Because study plots for collecting kittiwake growth rate data were set up in 1995, we will be able to begin making measurements earlier in 1996, and increase our sample size.

In 1995, puffin chicks at East Amatuli Island apparently grew more slowly than at Seal Island in Prince William Sound. This difference may have been caused by differences in the quantity, quality, and types of prey available to foraging adults. Although weights of screen-sampled chick meals were highly variable at the Barren Islands, the mean weight was similar to the Seal Island mean weight. However, the type of food fed to chicks was clearly different between the two locations: a high proportion of Pacific herring *(Clupea harengus pallasi)* was fed to chicks at Seal Island, but herring were absent from the Barren Islands samples. While the data were insufficient to rule out differences in abundance of food as the cause of the growth rate differences, it is possible that the availability of herring helped chicks grow more quickly at Seal Island.

Chick Food Types

As suggested in hypothesis 7, the type of food delivered to chicks may reflect the types of forage fish available in the water column. Because energy content varies among species and age classes of fishes, changes in types of fish available to foraging adults may affect the abilities of adults to perform breeding activities. Changes in prey types may also affect growth and survival of chicks, which may in turn affect the overall productivity of nesting populations, as stated in hypothesis 9.

The degree to which types of prey fed to chicks reflect the composition of forage fishes in surrounding waters probably varies among seabird species. Capelin, by both number and weight, were, by far, the largest components in the murre and kittiwake chick diets. In contrast, capelin, pollock, and prowfish were found in about equal proportions by weight in the puffin burrow screen samples. It is possible that puffin foraging areas differed from the foraging areas used by murres and kittiwakes, and that capelin were less abundant there. Other possibilities were that murres and kittiwakes selected capelin, while puffins did not discriminate among types of prey, or that when large numbers of capelin were present, puffins selected a variety of prey, while murres and kittiwakes took whatever was most abundant.

However, puffin-bill loads collected at East Amatuli Island during 1976 and 1979 were heavily dominated by capelin, and those obtained during 1977-1978 contained mostly capelin and sand lance (Manuwal 1980). Pollock was absent from the 1970's samples, and Pacific cod and prowfish were rare. These changes in prey types agree with results from shrimp trawl surveys conducted in the Gulf of Alaska that show that the abundance of capelin declined after the late 1970's, while the abundance of gadids increased (Piatt and Anderson 1995). This information suggests that the contents of puffin bill-loads may reflect the abundance and availability forage fish.

During the study, we plan to compare the types of prey fed to chicks with data from hydroacoustic and trawl surveys. Comparing these data will help clarify and quantify relationships between chick diets and the distribution and abundance of forage fishes near nesting colonies. We will also make comparisons between chick food types, productivity measurements, amounts of food fed to chicks, adult activity budgets, and chick growth rates, to help quantify the effects that chick food types may have on seabird breeding success.

Chick Feeding Frequencies

Hypothesis 8 suggests that chick feeding frequencies may be useful indicators of forage fish abundance, that may in turn be related to seabird productivity. Nineteen ninety-five was the first year murre and kittiwake chick feeding frequency data were collected at East Amatuli Island. After the 1996 field season is complete, we will compare changes in this variable with changes in productivity and other parameters among colonies and years.

Amounts of Food fed to Chicks

Hypothesis 7 indicates that the amount of food fed to chicks may reflect the abundance and distribution of forage fishes, and hypothesis 8 suggests that the amounts of food fed to chicks may affect seabird productivity.

It was not surprising to find that kittiwake chick regurgitation weights increased over time, because stomach capacities of younger chicks are smaller than stomach capacities of older chicks. However, because this variable does change over time, sampling protocols must be designed to ensure that regurgitation weights are comparable between years and study sites. One approach might be to collect samples during one or more specified age intervals (e.g., from nestlings that are known to be 20-30 days old, or from 5-10, 15-20, and 25-30 day-old chicks, respectively). Another approach may be to evenly distributing samples throughout the entire chick-rearing period. If samples can only be obtained from chicks with unknown hatch dates, estimating ages based on plumage development might improve the quality of comparisons made among years and sites.

Because variation in the Barren Islands puffin screen sample weights was high, only large differences between the mean weights of these samples and the Seal Island samples would have been significant. The mean weight of the Barren Islands samples was lower than the mean weights reported for puffin bill-loads collected at East Amatuli Island during 1976 (14.9 g) and 1977 (20.4 g). However, it is possible that the method used to collect bill-loads during those years (mist-netting adults returning to the colony) may have been more effective in obtaining higher proportions of complete loads. *[On occasion, we have see puffins drop partial bill-loads near their burrows and then fly off with some prey items after they encounter the screens.]*

By estimating the sizes of fish delivered to murre chicks, it may be possible to estimate the amount of food fed to nestlings. Although the size estimates may not be precise, the number of fish delivered to the chicks can be measured precisely. Therefore, the estimates of what nestlings are actually fed may be relatively accurate over periods of time.

Activity Budgets of Adults

At this point in the study, we cannot make correlation's between adult time budgets and productivity (as required to test hypothesis 8), because 1995 was the first year both parameters were measured simultaneously. After additional data have been collected at the Barren islands and other study sites, we will be able to begin exploring the relationship between these parameters.

As indicated in hypothesis 8, adult time budgets may reflect changes in food supplies. Cairns (1987) stated: "Most animals typically have a reserve of spare time which can be used for feeding as necessity demands (Herbers 1981), and direct measurements of foraging activity are probably linked more tightly to food availability than are other measurable seabird parameters." As data are obtained on the distribution and abundance of forage fishes (e.g., during hydroacoustic and trawl surveys), and on parameters that may respond to changes in food supplies among years and colonies, we will begin to explore the relationships between adult time budgets and food supplies in greater detail.

Population Counts

During 1993-1995, the murre multicount and productivity plot counts followed the same pattern. This similarity lends confidence to both sets of population numbers data. The count pattern suggests that murre numbers may be decreasing on both sets of plots. If this pattern persists, it may result in a negative trend. Counts made at the Barren Islands colonies in 1996 under Project 96144 (common murre population monitoring) will provide a fourth year of data that will allow us to test these count sets for trends.

Other Comparisons

During the course of the study, data (e.g., productivity, nesting chronology, chick growth rates and prey types) will be compared with pre-1995 information from the Barren Islands [e.g. Amaral (1977), Manuwal (1978, 1980), Manuwal and Boersma (1978), Boersma, *et al.* (1995), Dragoo, *et al.* (1994), Nysewander, *et al.* (1993)] and other colonies in the Gulf of Alaska (e.g., Puale Bay—Dewhurst 1991, Dewhurst and Moore 1992, McCarthy and Dewhurst 1993; Semidi Islands—Baggot *et al.* 1989, Dragoo *et al.* 1991a,b), whenever appropriate. Within- and among-years comparisons will also be made with information being collected by other APEX investigators at colonies in Prince William Sound (D. Irons, Project 96163E, Shoup Bay and Eleanor Island) and lower Cook Inlet - Kachemak Bay (J. Piatt, Project 96163M, Gull and Chisik Islands).

CONCLUSIONS

1. Sufficient quantities of the types of data that are needed to help test APEX hypotheses 7-9 can be obtained from the East Amatuli Island - Light Rock colony in a cost-effective manner.

ACKNOWLEDGMENTS

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Table 1. Preliminary results from Barren Islands Seabird Studies, 1995.

Variable	Common murre		Black-legged kittiwake		Tufted puffin	
Productivity	Eggs hatched / eggs laid	0.85 (0.07)[1]	Clutches / nests built:	0.95 (0.06)	Chicks / occupied burrow	0.52
	Chicks fledged / eggs hatched	0.91 (0.09)	Clutch size:	1.93 (0.16)		
	Chicks fledged / eggs laid	0.77 (0.09)	Eggs hatched / eggs laid	0.73 (0.10)		
			Chicks fledged / eggs hatched:	0.61 (0.14)		
			Chicks fledged / nests built:	0.82 (0.20)		
Nesting chronology	Median hatch date:	9 Aug (2.9)	Median hatch date:	8 Jul (1.7)	Median hatch date:	22 Jul (5.1)
Chick growth rate	*No data*		Grams/day (all chicks):	19.0 (4.2)	Grams per day:	11.5 (3.3)
			("A" chicks):	18.7 (3.8)		
			("B" chicks):	19.6 (5.0)		
			(single chicks):	18.6 (4.3)		
Chick feeding freq.	Feedings / chick / hr (0630-1930):	0.31 (0.11)	Feedings/nest/hr (0700-2000) (1 ch):	0.28 (0.11)	*No data*	
	(0630-1030):	0.39 (0.22)	(2 ch):	0.47 (0.19)		
	(0800-1200):	0.24 (0.16)	(0800-1200) (1 ch):	0.39 (0.18)		
			(2 ch):	0.72 (0.30)		
Adult trip duration	Minutes / trip:	157.7 (131.3)	*Analysis incomplete*		*No data*	
Time no ad. on nest	Minutes / hour:	0.0	Minutes / hour (1 chick):	1.1 (0.9)	*No data*	
			(2 chicks):	5.1 (5.0)		
Time 2 ad. on nest:	Minutes / hour:	5.6 (4.4)	Minutes / hour (1 chick):	0.3 (0.0)	*No data*	
			(2 chicks):	0.3 (0.2)		
Chick meal size	*no data*		Regurgitant weight (g):	27.7 (11.5)	Screen samp. wt. (g):	10.3 (12.8)
Population size	Multicount plots (no. of birds):	5224 (583)	Productivity plots (no. of birds):	198 (15)	*Analysis incomplete*	
	Productivity plots (no. of birds):	439 (32)				

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[1] Standard deviation in parentheses

Table 2. Results from searches of four tufted puffin transects at East Amatuli Island, Barren Islands, Alaska, 1993-1995. Total area = 270 m^2

Year	Burrows	Occupied burrows	Occupied / total burrows	Chicks	Chicks / occupied burrows
1993	58	25	43	15	0.60
1994	44	17	39	8	0.47
1995	63	25	40	13	0.52
Average	60	23	40.7	12.0	0.58
St. Dev.	16	3	2.1	4.0	0.15

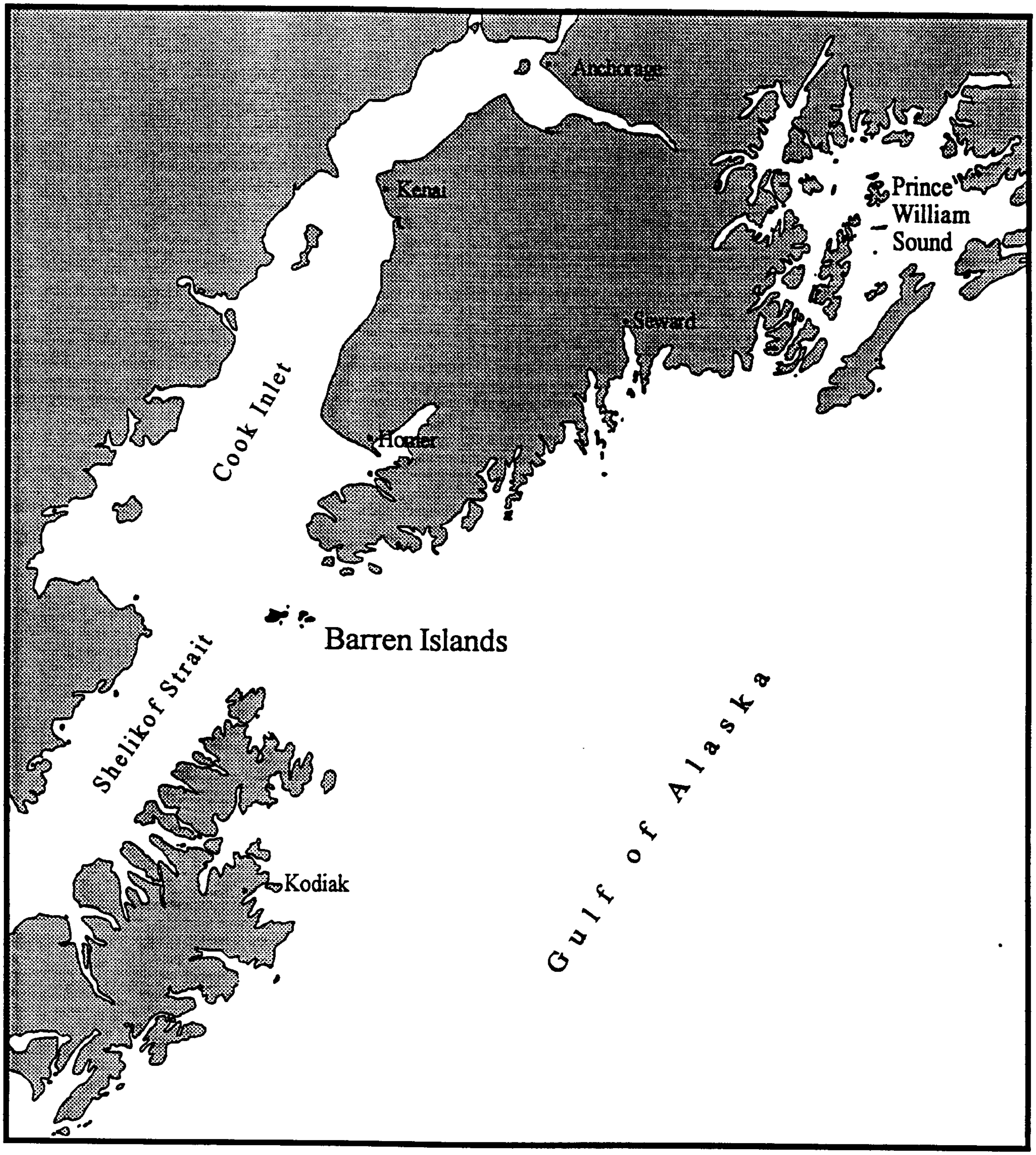


Figure 1. Location of the Barren Islands, Alaska.

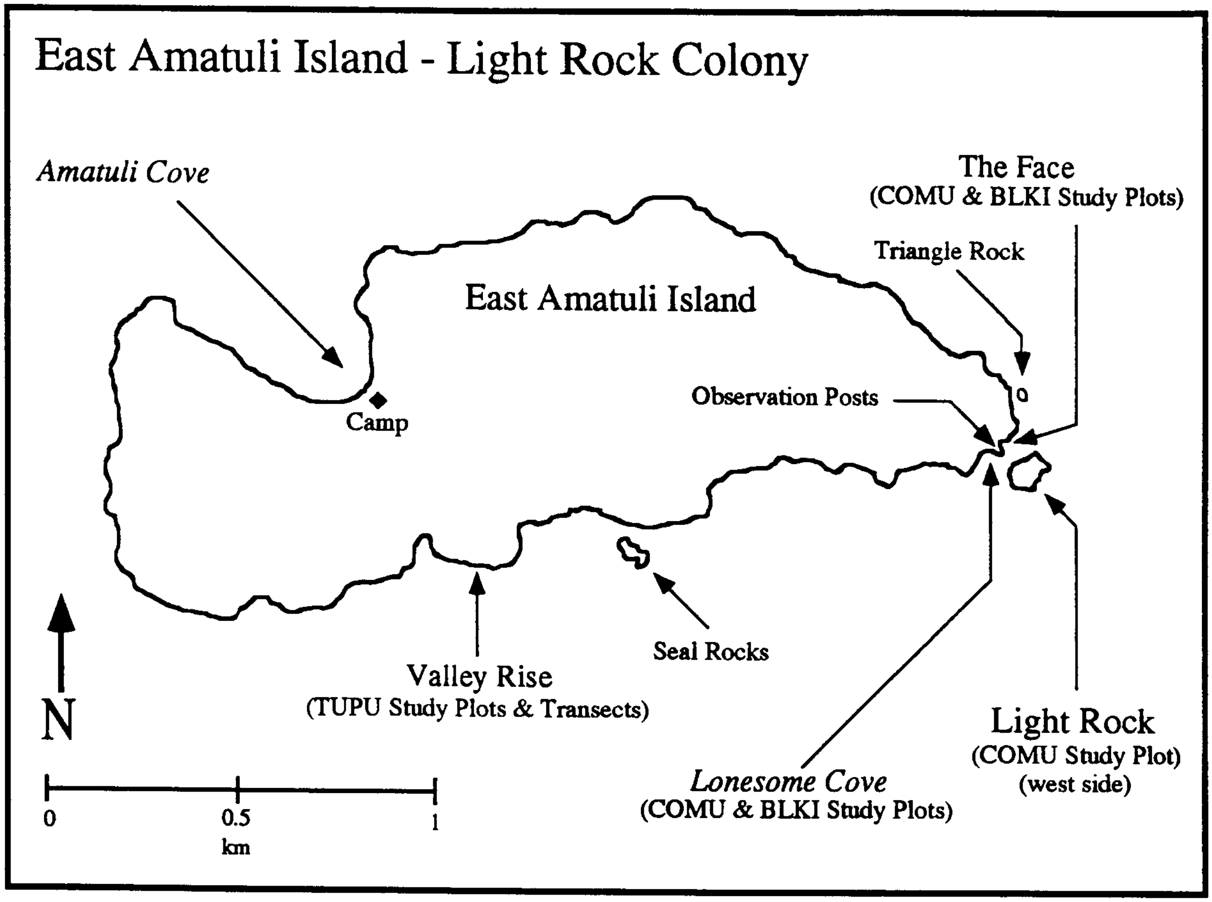
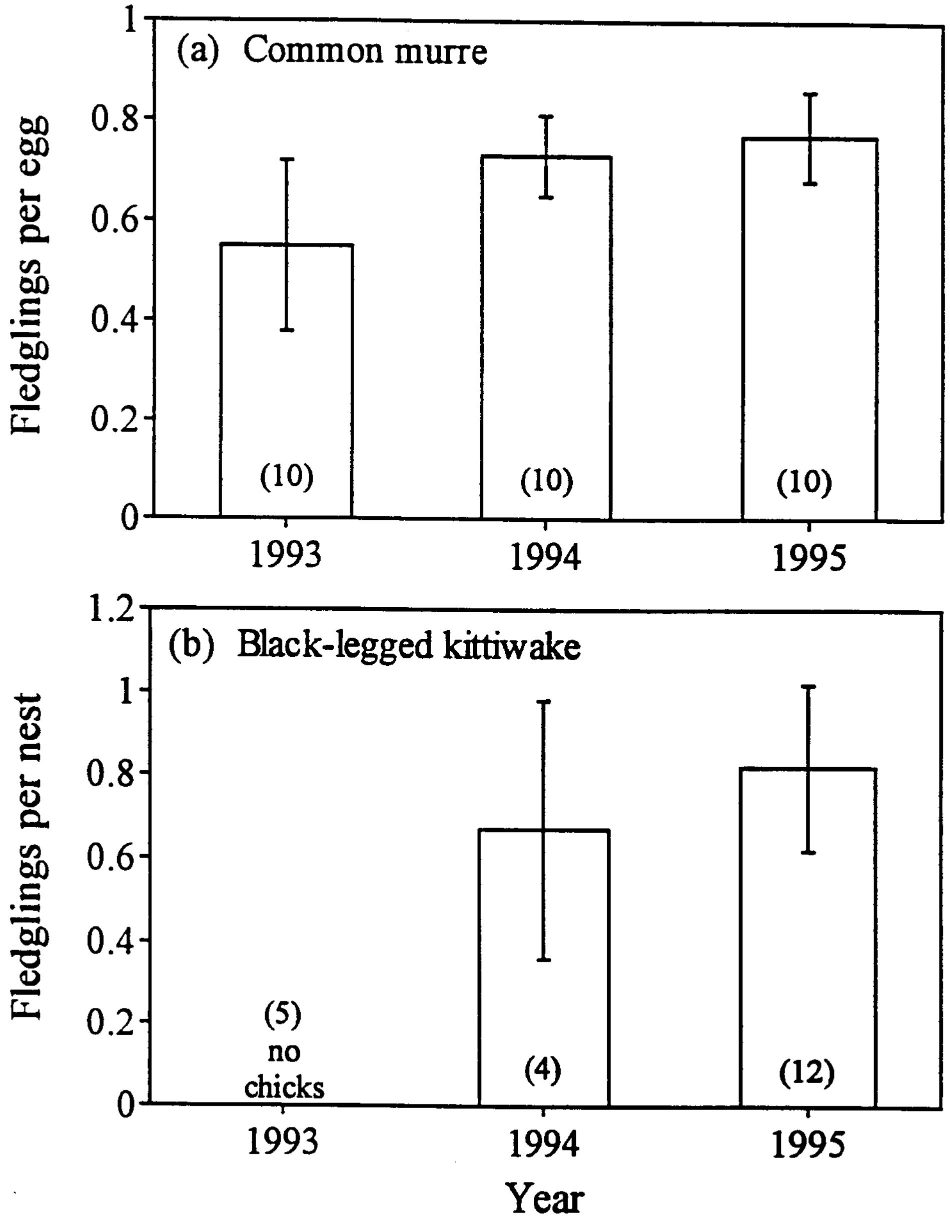


Figure 2. The 1995 Barren Islands study area showing the general locations of the common murre (COMU), black-legged kittiwake (BLKI), and tufted puffin (TUPU) study sites.



Productivity

Common Murre

Black-legged Kittiwake

Figure 3. Productivity of (a) common murres and (b) black-legged kittiwakes at East Amatuli Island, Barren Islands, Alaska, 1993-1995. Number of plots in parentheses.

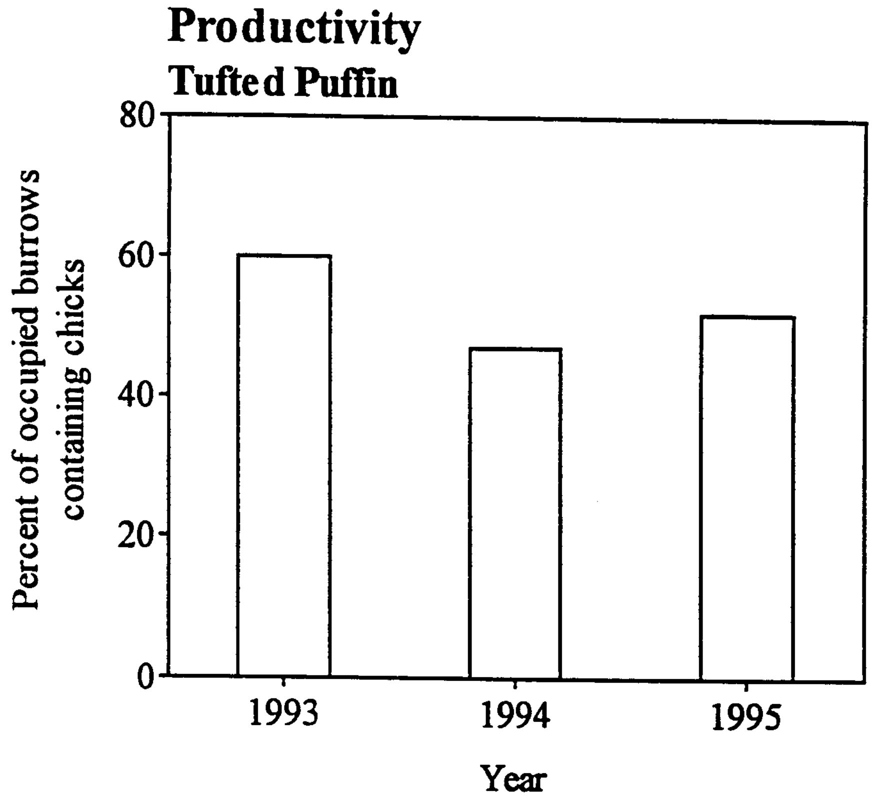


Figure 4. Percent of occupied tufted puffin burrows containing chicks in four transects totaling 270 m^2 at East Amatuli Island, Barren Islands, Alaska during late August-early September, 1993-1995.

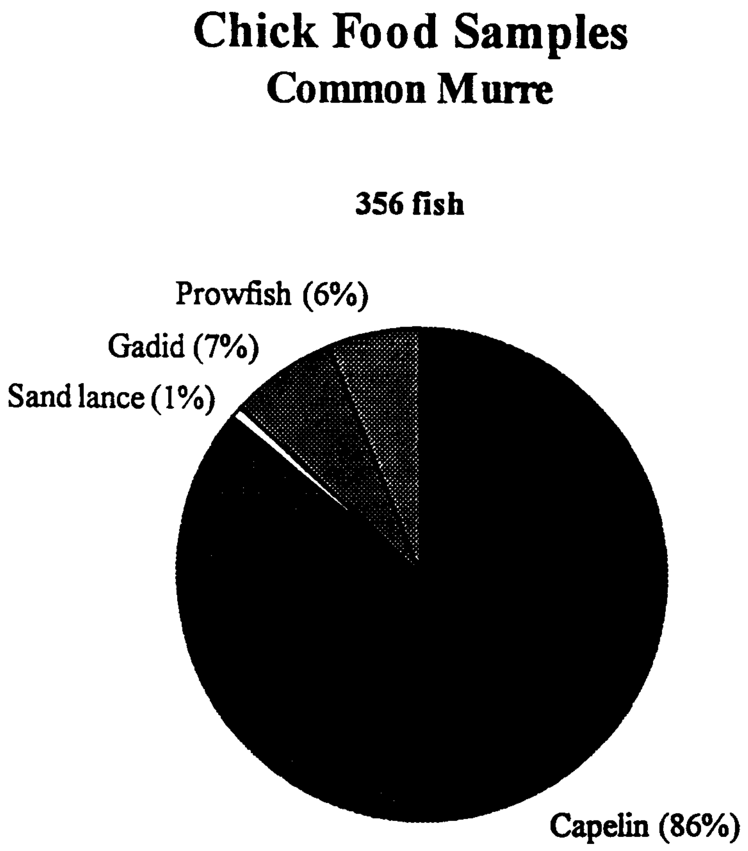


Figure 5. Types of prey fed to common murre chicks at East Amatuli Island, Barren Islands, Alaska, 1995.

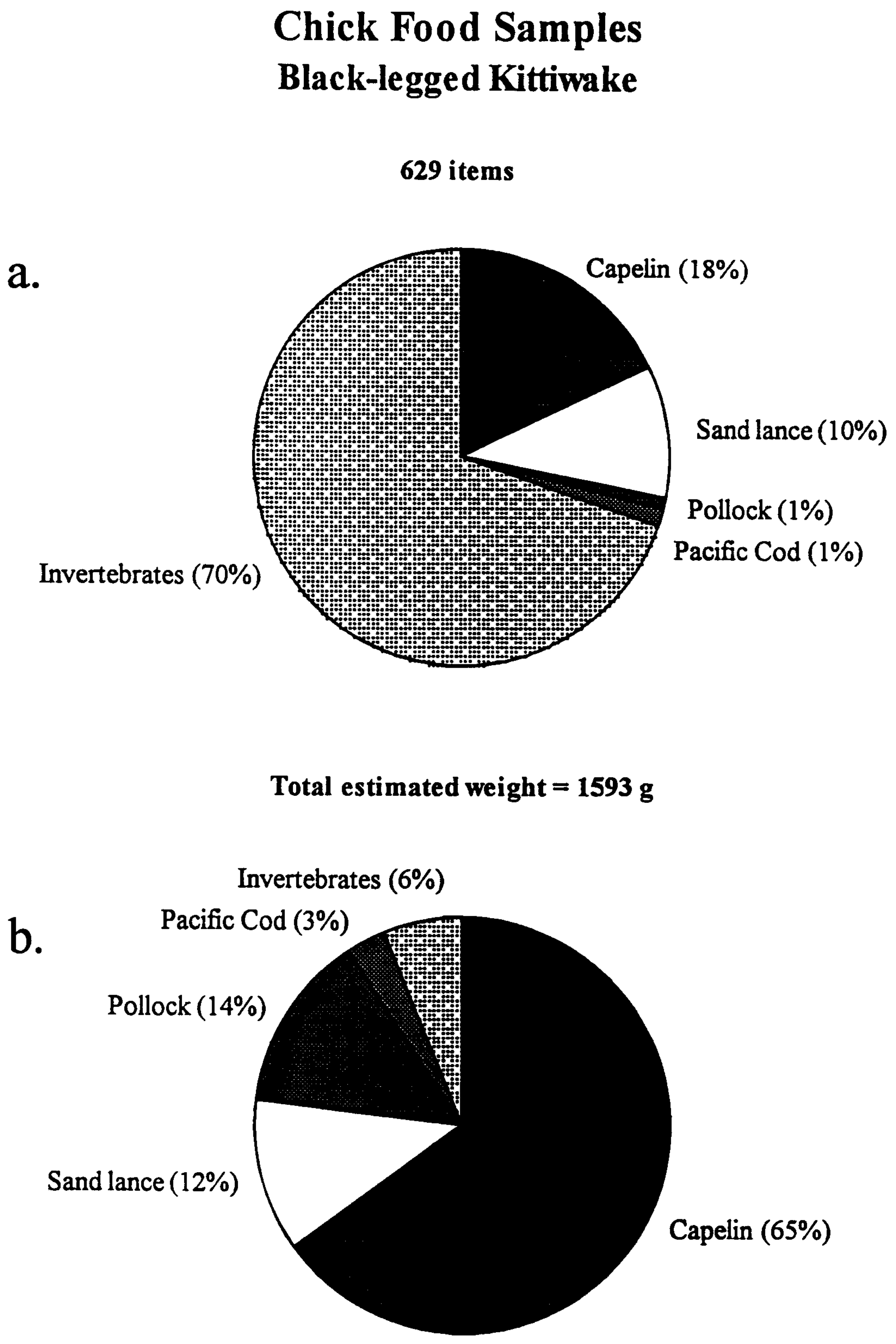
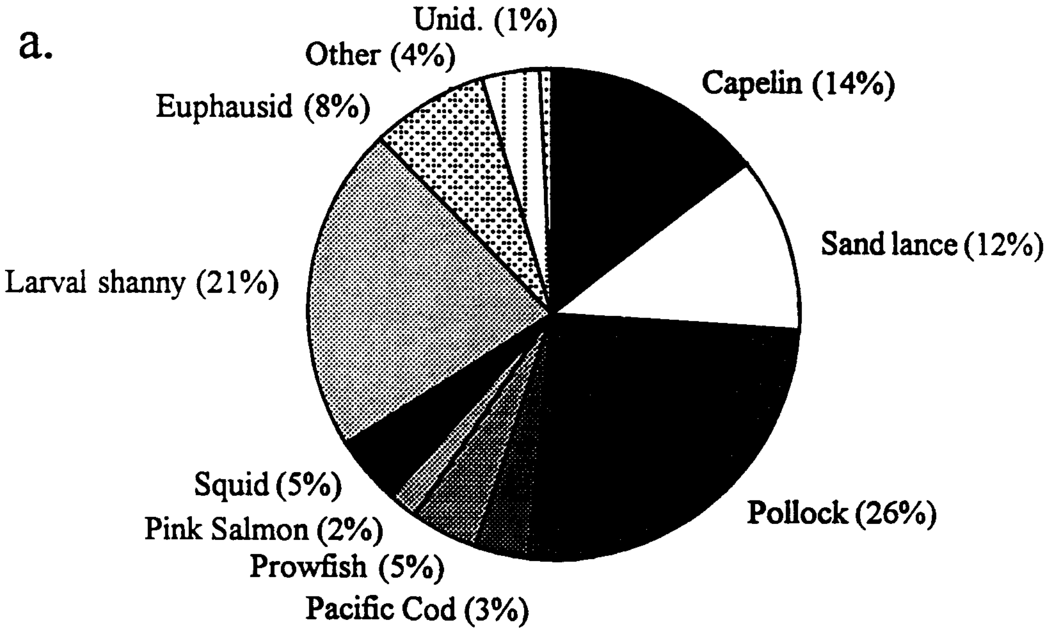


Figure 6. Types of prey fed to black-legged kittiwake chicks at East Amatuli Island, Barren Islands, Alaska, 1995. (a) Percent by number; (b) percent by weight.

Chick Food Samples

Tufted Puffin

346 items



Total estimated weight = 1103 g

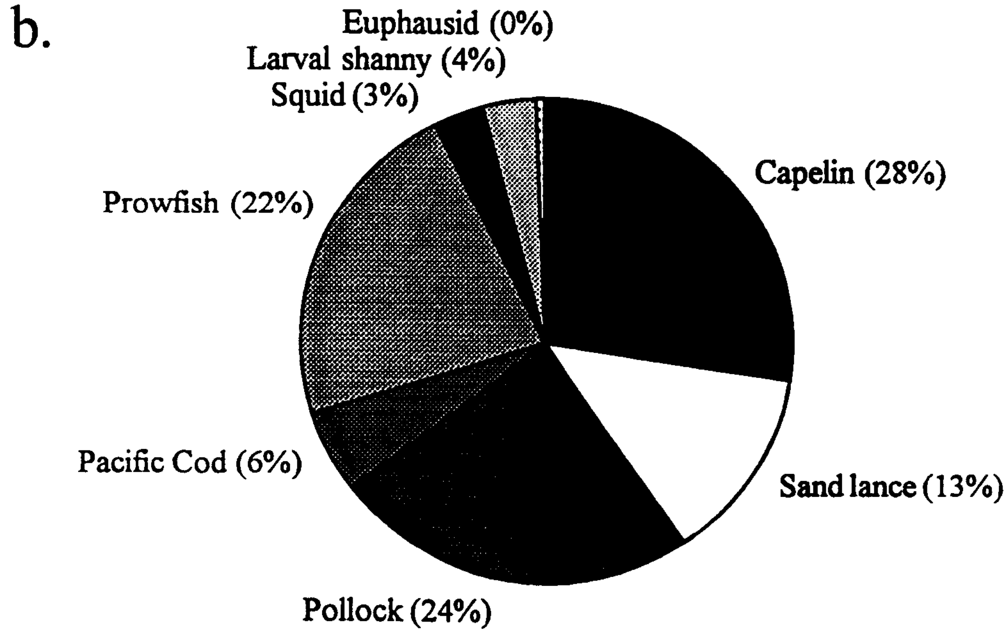
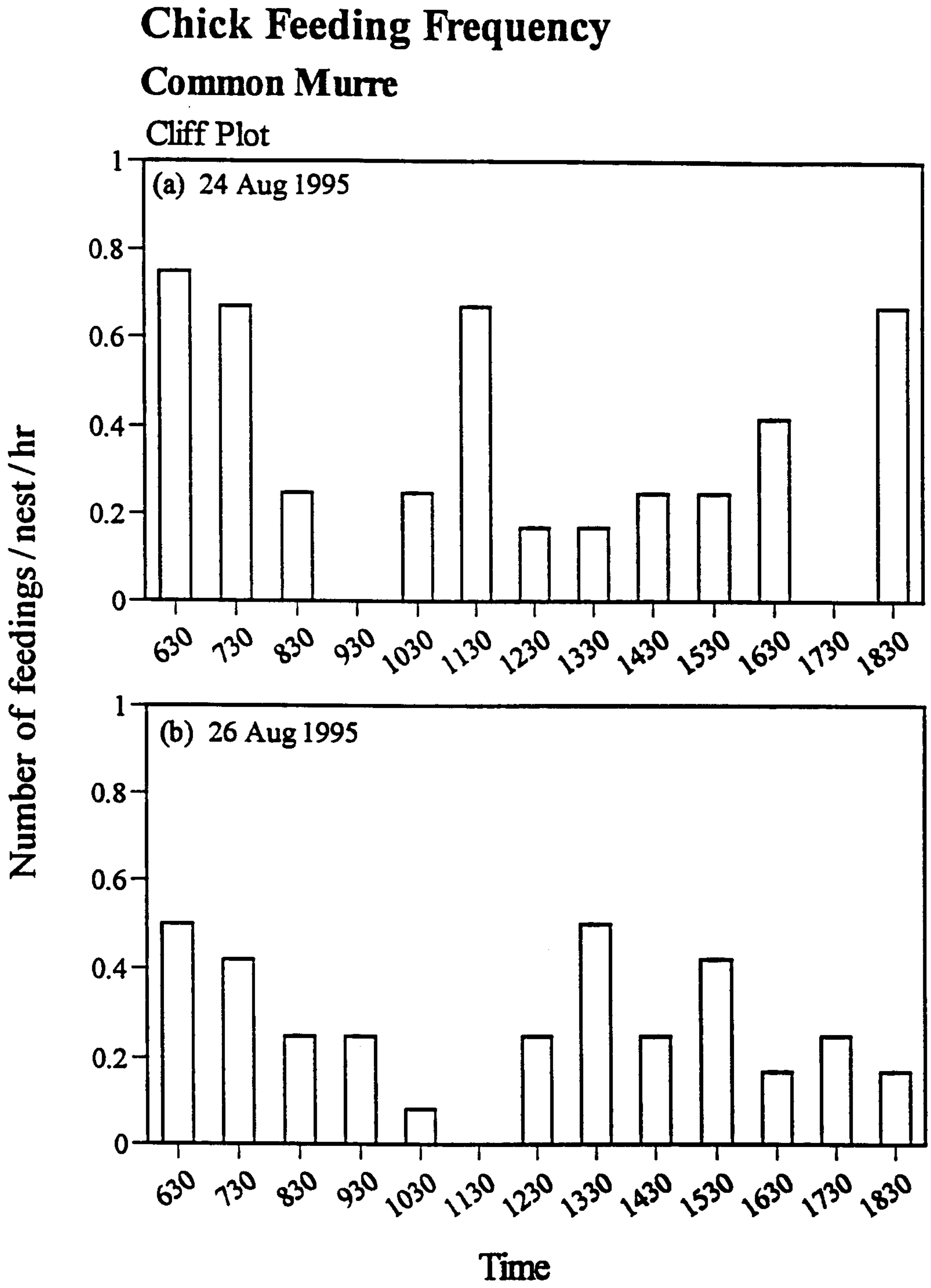


Figure 7. Types of prey brought to tufted puffin chicks at East Amatuli Island, Barren Islands, Alaska, 1995. (a) Percent by number; (b) percent by weight.



Chick Feeding Frequency

Common Murre

Cliff Plot

(a) 24 Aug 1995

(b) 26 Aug 1995

Figure 8. Number of feedings per nest per hour, by hour, during two dawn-to-dusk watches of common murres at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 24 August; (b) 26 August.

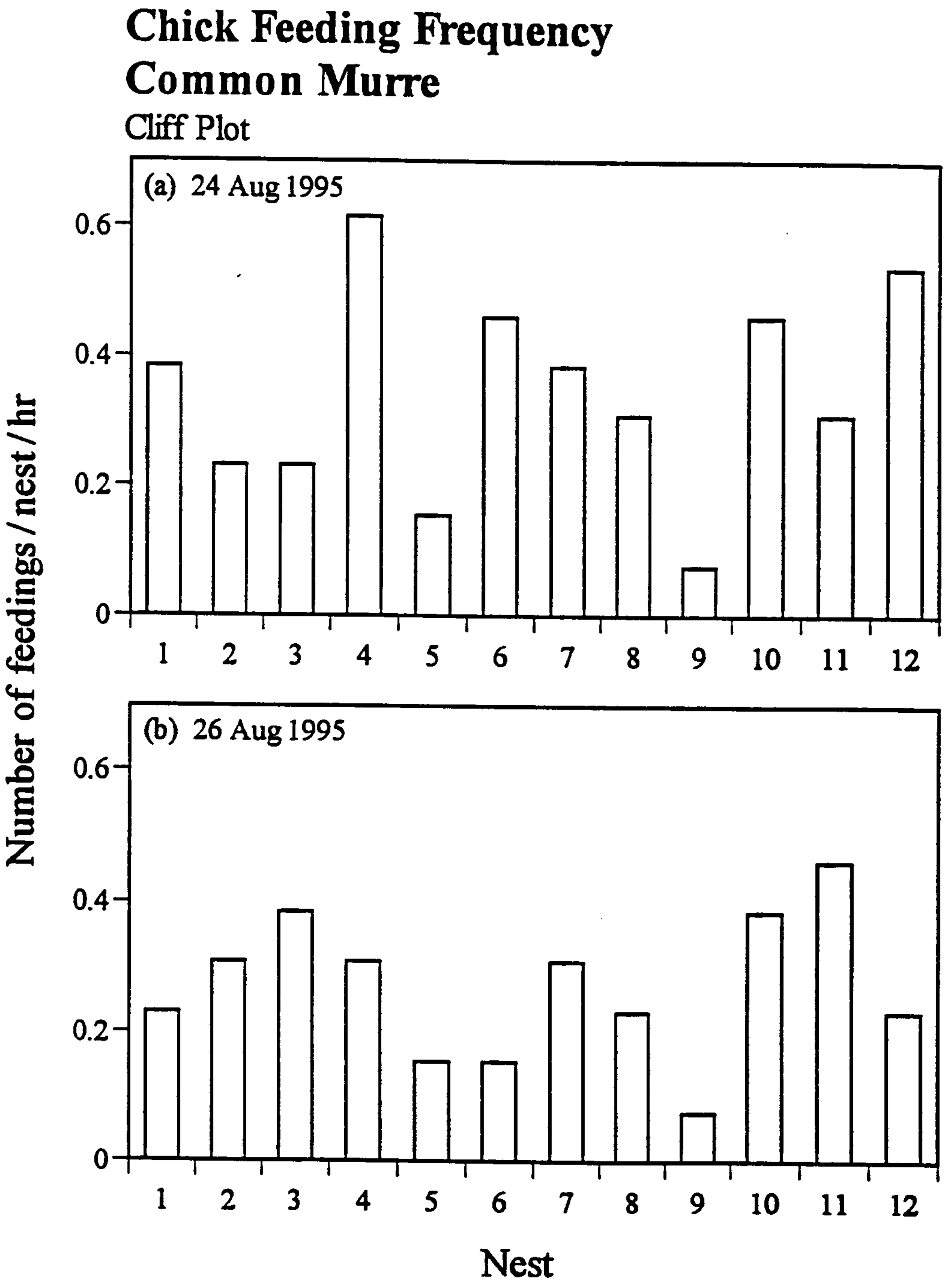


Figure 9. Number of feedings per nest per hour, by nest, during two dawn-to-dusk watches of common murres at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 24 August; (b) 26 August.

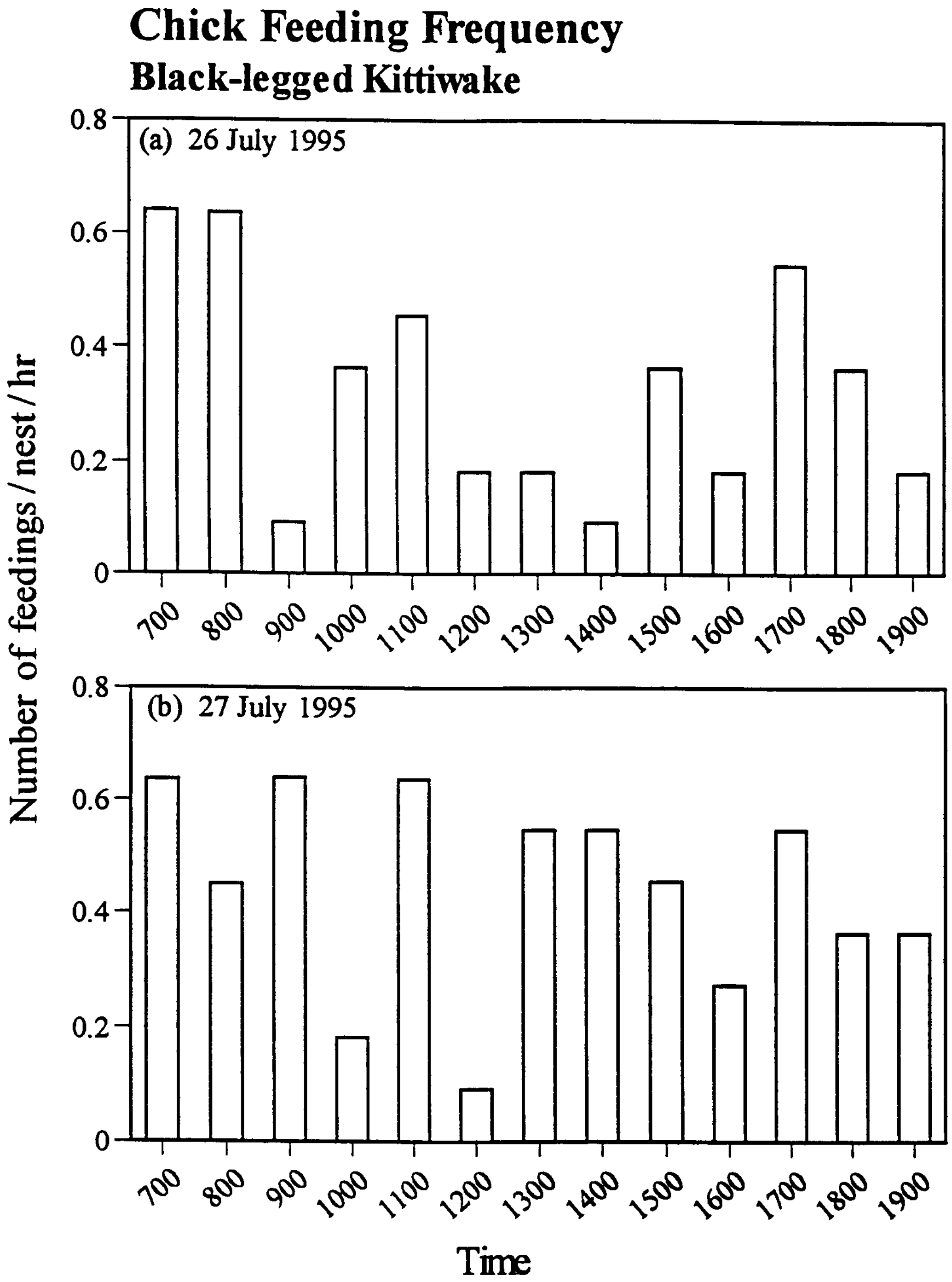


Figure 10. Number of feedings per nest per hour, by hour, during two dawn-to-dusk watches of black-legged kittiwakes at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 26 July; (b) 27 July.

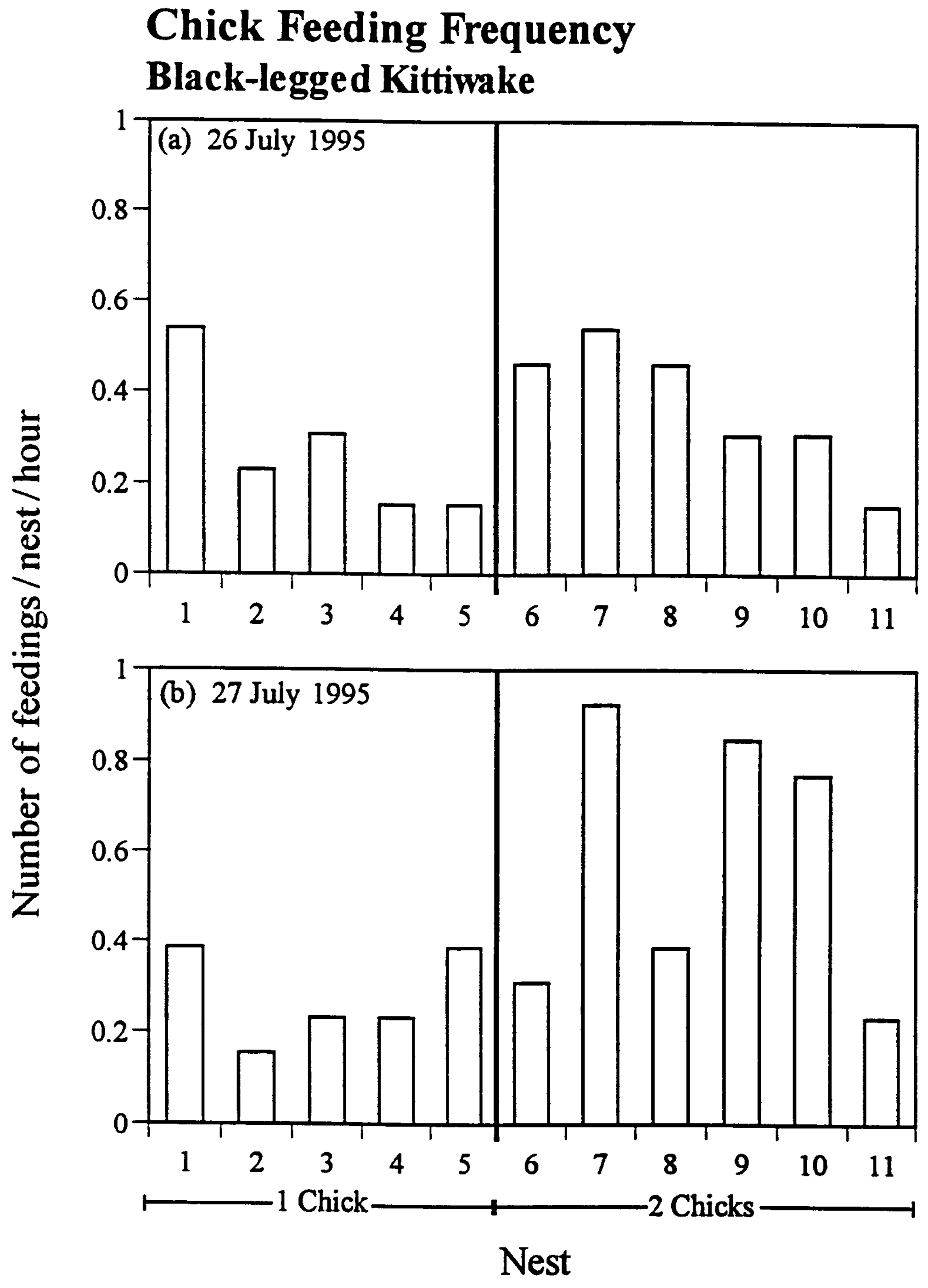


Figure 11. Number of feedings per nest per hour, by nest, during two dawn-to-dusk watches of black-legged kittiwakes at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 26 July; (b) 27 July. One- and 2-chick nests are indicated.

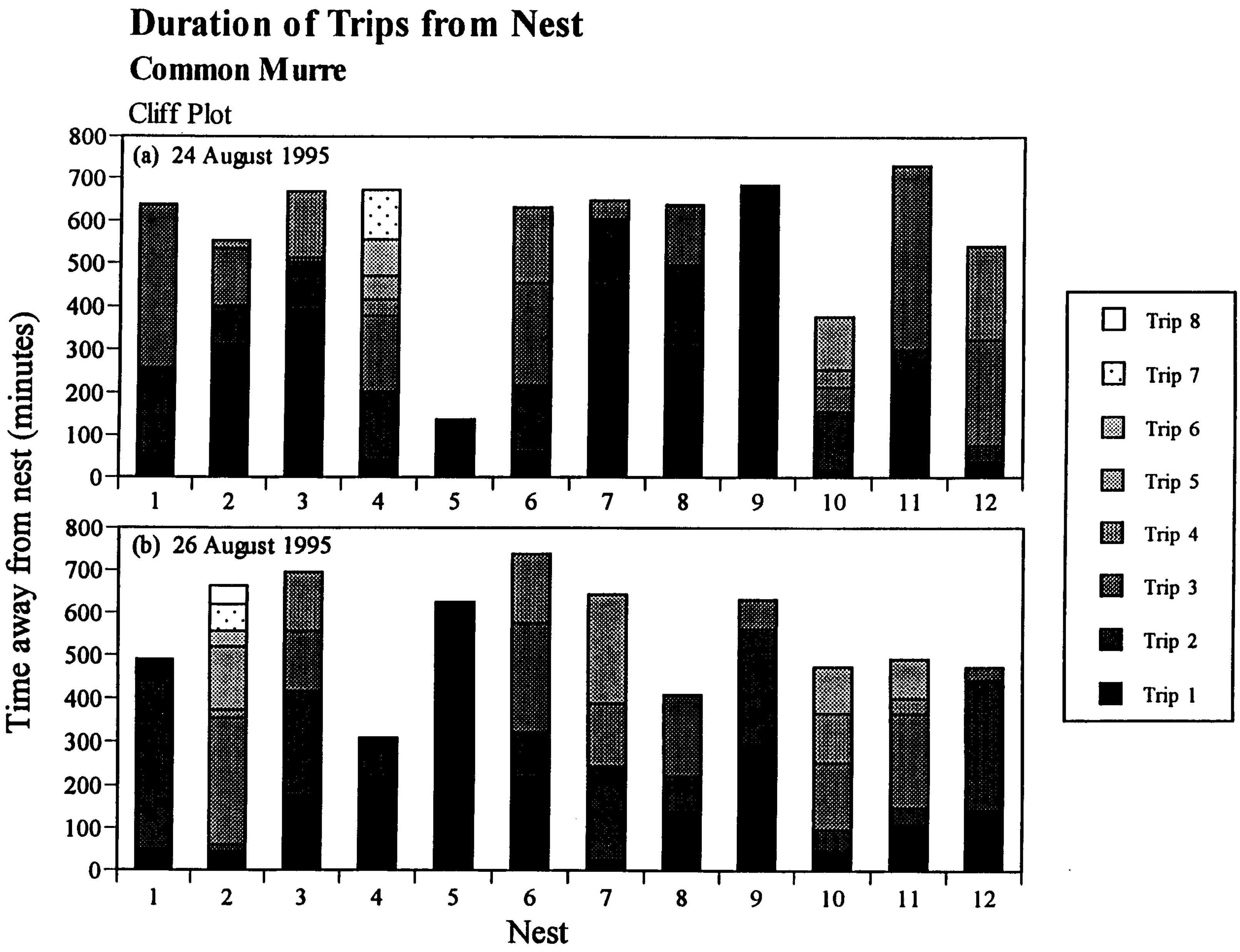


Figure 12. Duration of trips by common murres, by nest, during two dawn-to-dusk watches at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 24 August; (b) 26 August.

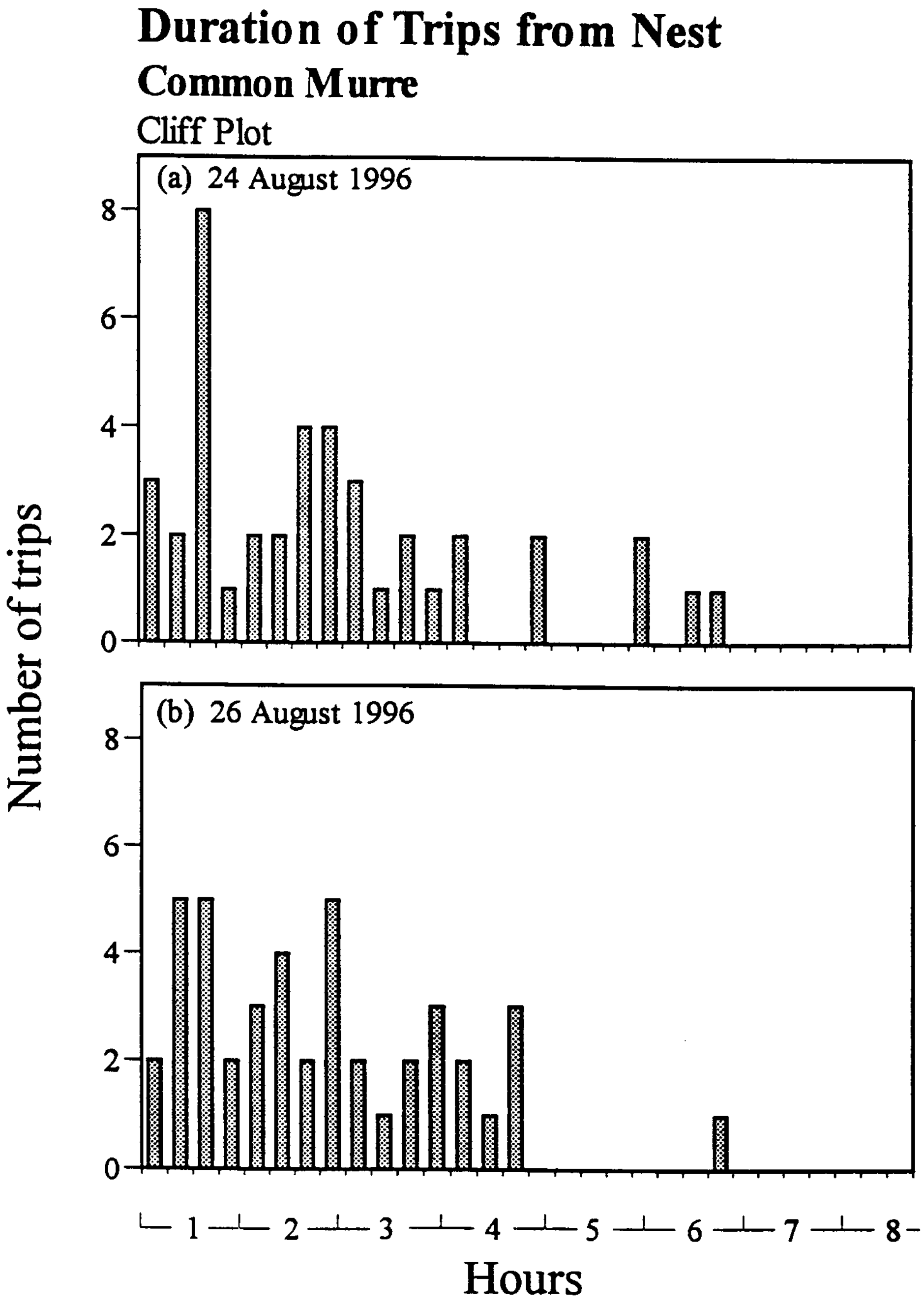


Figure 13. Duration of trips by common murres, by frequency of occurrence, from 12 nests at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 24 August and (b) 26 August, 1995.

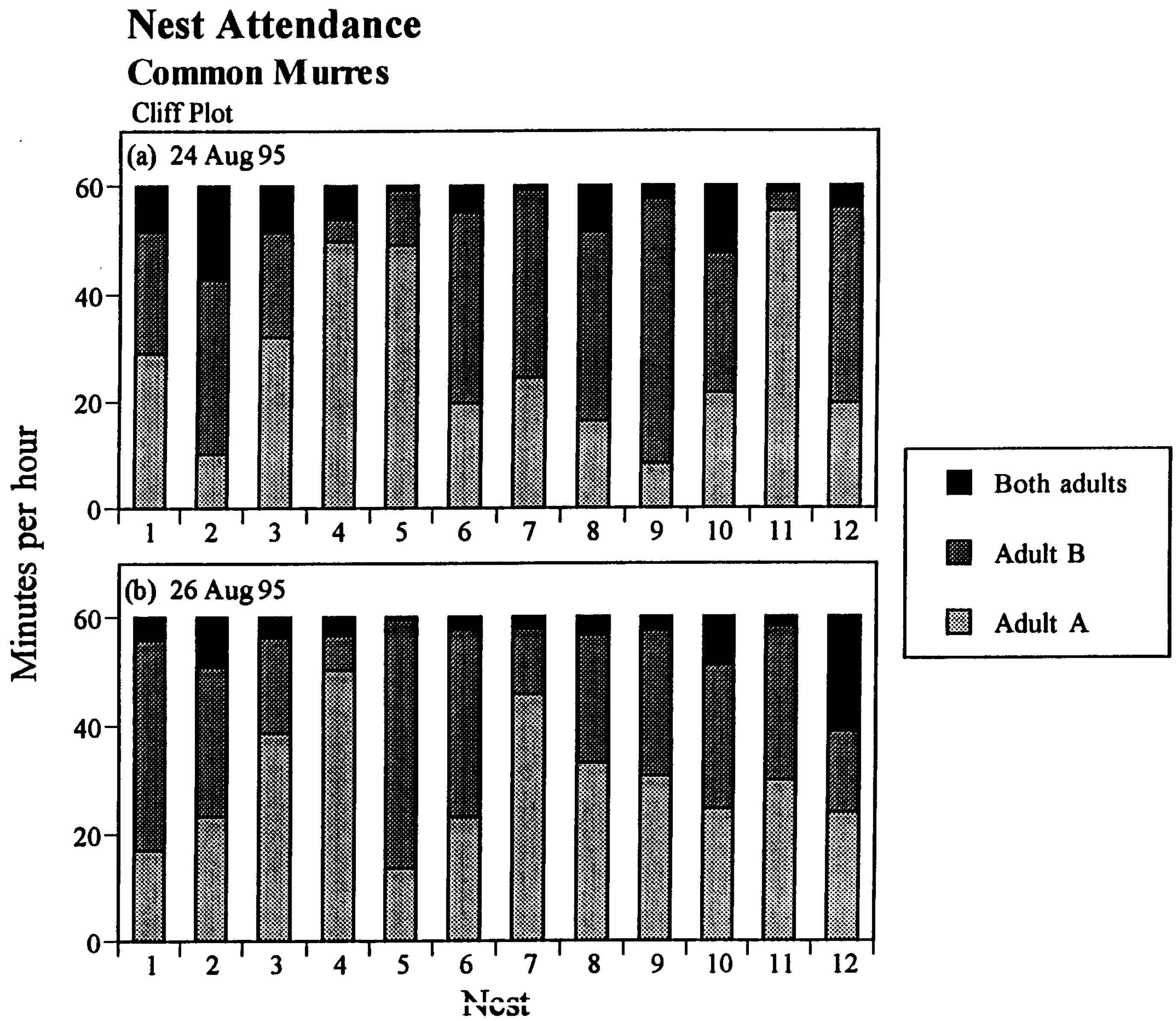


Figure 14. Minutes that one adult, two adults, and neither adult spent at the nest per hour of observation time, by nest, during two dawn-to-dusk watches of common murres at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 24 August; (b) 26 August.

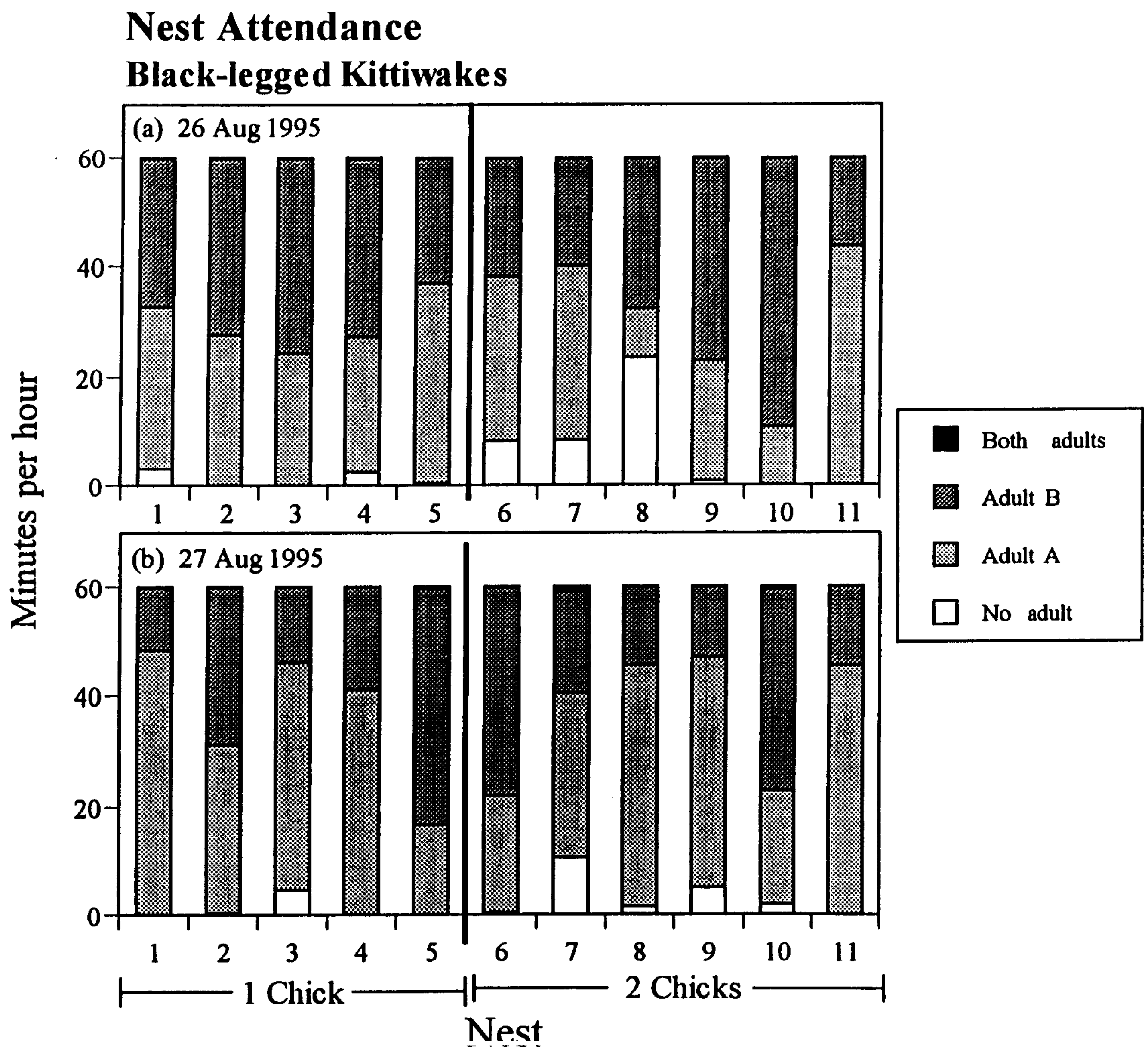


Figure 15. Minutes that one adult, two adults, and neither adult spent at the nest per hour of observation time, by nest, during two dawn-to-dusk observations of black-legged kittiwakes at East Amatuli Island, Barren Islands, Alaska, 1995: (a) 26 August; (b) 27 August. One- and 2-chick nests are indicated.

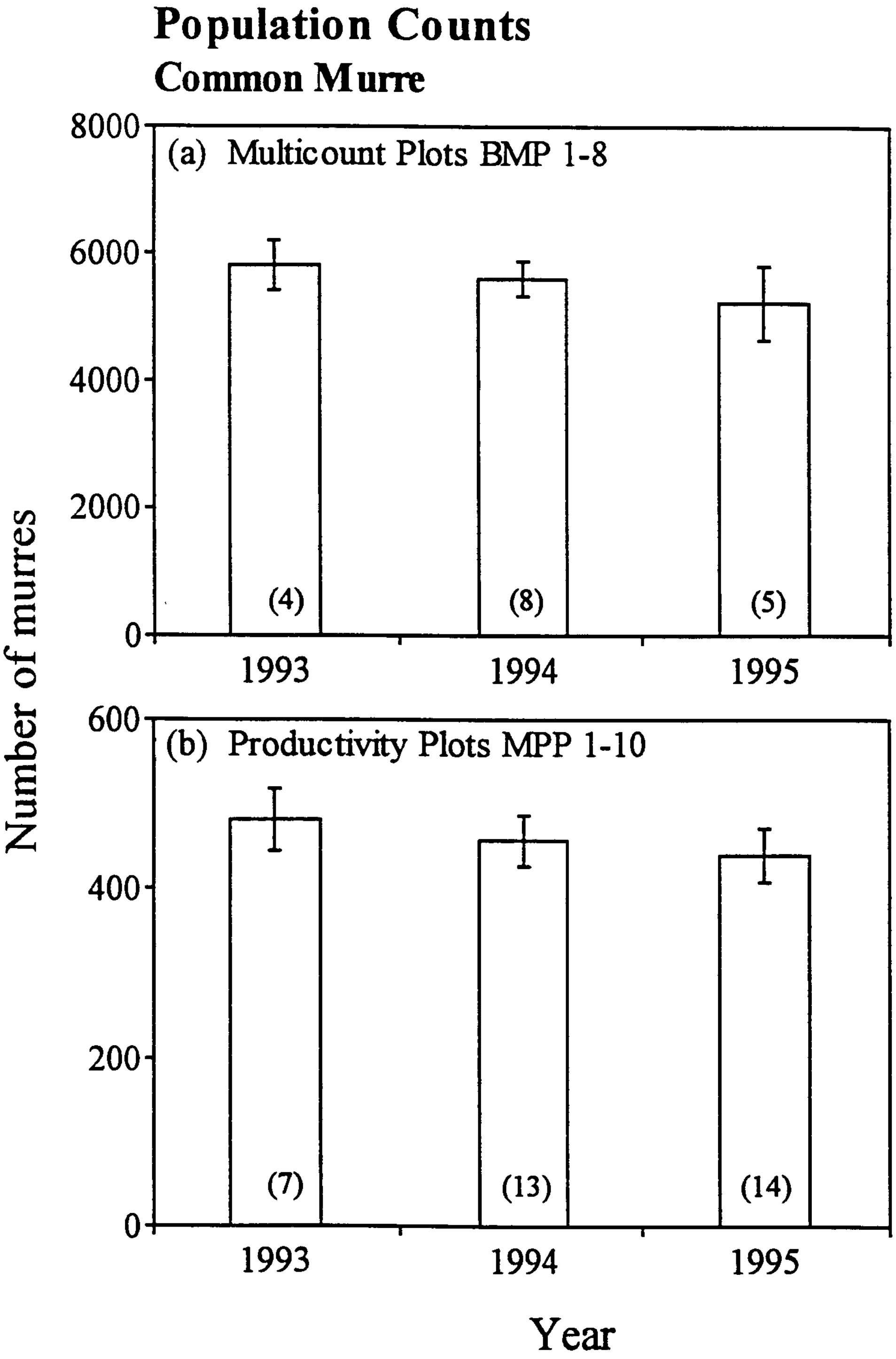


Figure 16. Number of murres on (a) multicount plots BMP 1-8 and productivity plots MPP 1-10 at East Amatuli Island, Barren Islands, Alaska, 1995. Number of counts in parentheses.

APPENDIX K

APEX: 95163 K

Exxon Valdez Oil Spill
APEX Project Annual Report

Using Predatory Fish to Sample Forage Fishes, 1995

APEX Project 95163K
Annual Report

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April 1996

Using Predatory Fish to Sample Forage Fishes, 1995

APEX Project 95163K
Annual Report

Study History: This project has no previous study history. It is a new project that was first implemented in 1995 as part of the larger *Exxon Valdez* Oil Spill Trustee Council-sponsored Alaska Predator Experiment (APEX).

Abstract: Evaluating the influence of fluctuating prey populations (e.g., forage fishes) is critical to understanding the recovery of seabirds injured by the T/V *Exxon Valdez* oil spill; however, it is expensive to conduct hydroacoustic and trawl surveys to assess forage fish stocks over broad regions. As part of the 1995 *Exxon Valdez* Oil Spill Trustee Council APEX ecosystem project, we tested the feasibility of using sport-caught Pacific halibut *(Hippoglossus stenolepis)* to obtain spatial and temporal information on capelin *(Mallotus villosus)* and Pacific sand lance *(Ammodytes hexapterus)*, two forage fishes important to piscivorous seabirds. We examined 586 halibut stomachs collected from cooperating vessels in a 150-200 charter boat fleet fishing throughout Cook Inlet waters during late May - early September. Catch locations and dates provided information on geographic and seasonal variation in the incidence of capelin and sand lance in seven eastern inlet subunits between Anchor Point and Shuyak Island. We also obtained data on prey brought to black-legged kittiwake *(Rissa tridactyla)*, common murre *(Uria aalge)*, and tufted puffin *(Fratercula cirrhata)* chicks at Cook Inlet colonies to help evaluate the sampling technique. At the Barren Islands, capelin were the most numerous fish in halibut stomachs, and they were the most common prey fed to murre and kittiwake chicks by both number and weight. They were also the largest prey group by weight in puffin chick diets. In the Point Adam area, where samples were collected throughout June - early August, we detected seasonal changes in the relative abundance of sand lance and capelin. Sand lance were most common in June, and capelin increased after early July. Based on our results, we conclude that this relatively simple cost-effective method can supply useful information on forage fish stocks in areas where seabird feeding and charter boat fishing activities overlap.

Key Words: *Ammodytes hexapterus*, Barren Islands, capelin, Cook Inlet, forage fish, halibut, *Hippoglossus stenolepis*, Kachemak Bay, *Mallotus villosus*, Pacific halibut, Sand lance.

Citation: Roseneau, D.G., and G.V. Byrd. 1996. Using Predatory Fish to Sample Forage Fishes, 1995. Unpubl. annual rept. by the Alaska Maritime National Wildlife Refuge, Homer, Alaska for the *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska (APEX Project 95163K). 13 pp.

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INTRODUCTION

This pilot study was developed and integrated into the APEX project because there was need for a cheap, cost-effective means of assessing presence-absence and relative abundance of important prey species, particularly forage fishes, near seabird nesting colonies. Evaluating the influence of fluctuating prey populations (e.g., forage fishes) is a crucial element in understanding annual variations in the productivity of several fish-eating marine birds, including both divers (e.g., common and thick-billed murres, *Uria aalge and U. lomvia*; tufted puffins, *Fratercula cirrhata*) and surface-feeders (black-legged kittiwakes, *Rissa tridactyla*). Knowledge of fluctuations in prey populations is also an important factor in understanding the recovery of seabirds injured by the T/V *Exxon Valdez* oil spill; however, it is expensive to conduct hydroacoustic and trawl surveys to assess forage fish stocks over such broad regions.

The presence of a large 150-200 charter boat fleet operating throughout Kachemak Bay and lower Cook Inlet during late May - early September offered a prime opportunity to explore the feasibility of using sport-caught Pacific halibut *(Hippoglossus stenolepis)* to obtain spatial and temporal information on capelin *(Mallotus villosus)* and Pacific sand lance *(Ammodytes hexapterus)*, two forage fishes important to piscivorous seabirds (e.g., Piatt *et al.* 1991, Springer 1991, Piatt 1993). Many of these vessels fish for halibut almost every fair-weather day in lower Cook Inlet between Anchor Point and the shelf break and between Seldovia and Elizabeth Island. They also fish in Kennedy Entrance between the Kenai Peninsula and the Barren Islands, in the Barren Islands (as many as 18-20 boats were seen in the West Amatuli - Ushagat - Nord islands vicinities on some days in 1993-1994), and occasionally as far south as Shuyak Island (R. Swenson, Homer Ocean Charters, pers. comm.; D.G. Roseneau, pers. obs.). Many of these areas are also used heavily by foraging seabirds, including those nesting in the Barren Islands and at the Gull and Chisik islands colonies (Piatt 1993; J.F. Piatt, pers. comm.; D.G. Roseneau, pers. obs.).

Halibut are opportunistic predators that take a wide range of both fish and invertebrate prey, and smaller individuals between about 30 and 70 cm long tend to feed on a variety of miscellaneous fishes, including both sand lance and capelin (see Yang 1990). Halibut are usually associated with the bottom. However, fish weighing less than about 13-18 kg (commonly referred to as "chicken" halibut) have also been observed pursuing prey higher in the water column (J. Martin, Alaska Maritime NWR, pers. comm.; S. Meyers, Alaska Department of Fish and Game, pers. comm.), and in some instances they have even been seen jumping out of the water in large surface shoals of "bait-fish" (e.g., capelin; R. Swenson, Homer Ocean Charters, pers. comm.).

Based on the above information and the spatial and temporal distribution of the charter vessel fleet, we designed and implemented a pilot program to collect halibut stomachs during late May - early September 1995 to test the concept that these sport-caught fish could be used as sampling tools to assess the presence or absence and relative abundance of capelin and sand lance in Kachemak Bay and lower Cook Inlet waters. Results from this initial effort indicate that this relatively simple inexpensive technique can supply useful information on forage fish stocks in areas where seabird feeding and charter boat fishing activities overlap.

OBJECTIVES

Project objectives were to: (a) Test the feasibility of using stomach contents from sport-caught Pacific halibut as a means of sampling forage fishes in the northern Gulf of Alaska; and (b) evaluate the effectiveness of this technique in obtaining information that could be useful to *Exxon Valdez* Oil Spill Trustee Council sponsored APEX studies of seabirds and forage fishes in the spill area (e.g., kittiwakes, murres, puffins, capelin, sand lance).

METHODS

We set up the Kachemak Bay - lower Cook Inlet study area in early May 1995 and divided it into 12 subunits (Fig. 1). During late May - early September, 586 halibut stomachs were collected from seven of these sampling areas by visiting several cooperating Homer-based sport fishing charter boat companies as vessel operators filleted fish for their passengers at public and private port-side fish-cleaning facilities (Table 1, Appendix 1). Lengths, weights, and catch locations were obtained as halibut were processed, and when carcasses were discarded, stomachs were removed and weighed, and contents were emptied into plastic trays and identified using taxonomic keys and photographs. Whole and partly digested, but still recognizable fish were sorted into seven categories: capelin, sand lance, herring, flatfish, sculpin, cod, and other species. Invertebrates were divided into six groups: crabs, shrimp, squid, octopus, mollusks, and other species. Empty stomachs were weighed to calculate content weight, and undigested forage fish were also weighed and measured to obtain size information on target species (i.e., capelin and sand lance). Samples of whole capelin and sand lance were preserved in 10% buffered formaldehyde and 75% ethanol - 2% glycerin solutions for later analysis by other investigators. Data, including dates and catch locations, were entered into computer spreadsheets. Analysis consisted of examining numbers and frequencies of occurrence of fish and invertebrates in different geographic areas and time periods.

RESULTS

Fish were present in about 50% of the 586 stomachs (Fig. 2), and capelin and sand lance were found in 30% and 11% of the 380 stomachs containing prey, respectively (Fig. 3). As a group, fish dominated prey items by number (77%; Fig. 4), and most of the fish were capelin and sand lance (72% and 24%, respectively; see Fig. 4). When numbers of fish were compared in six of the subunits (Figs. 5a and 5b; area 2 was dropped from the analysis because of inadequate sample size), sand lance appeared to be most numerous in the Homer and Kennedy Entrance vicinities (41% and 63% by number, respectively), and capelin appeared to be particularly abundant in the Point Adam area near the southern tip of the Kenai Peninsula (85% by number), and in the Barren Islands and Shuyak Island subunits (94% and 100% by number, respectively). By analyzing numbers of capelin and sand lance per stomach in the Point Adam area (the subunit with the best June-August data series), it was apparent that the relative abundance of these species changed over time (Fig. 6). Sand lance averaged 1.2 fish per stomach in this area during June, but were nearly absent from the July - early August samples (< 0.1 individual per stomach). In contrast, numbers of capelin increased markedly after late June, rising from an average of only 0.9 fish per stomach that month, to 2.4 individuals during July and 7.7 fish by early August.

DISCUSSION

Results from the pilot study supported our general hypothesis that the contents of halibut stomachs could be used to obtain information on relative abundance of forage fishes in the lower Cook Inlet region. The high incidence of capelin in the Point Adam, Barren Islands, and Shuyak Island samples was consistent with reports from charter boat operators that large schools of "bait fish" were present in these areas. For example, in the Point Adam area (Area 6; see Fig. 1), schools of small fish more than 1 km long were noted on vessel fish finders throughout early June - mid-August, and on several occasions large concentrations of capelin were observed in surface waters (R. Swenson, Homer Ocean Charters, pers. comm.). In several instances, small halibut (in the order of 9-10 kg or less) jumped out of the water in the midst of these dense surface shoals of fish (R. Swenson, Homer Ocean Charters, pers. comm.). Similar large, dense schools of capelin were also seen in surface waters near the north end of Shuyak Island on 20 June, and at depth and on the surface near Nord, Ushagat, and West Amatuli islands in the Barren Islands during 17 June

- 2 July (R. Swenson, Homer Ocean Charters, pers. comm.). In both of these subunits, the schools of fish were associated with large numbers of feeding humpback whales *(Megaptera novaeangliae)* and seabirds (R. Swenson, Homer Ocean Charters, pers. comm.).

The high proportion of capelin in halibut stomachs from the Barren Islands area was also consistent with information obtained on types of prey fed to black-legged kittiwake, common murre, and tufted puffin chicks at the East Amatuli Island - Light Rock colony during late July - August (see APEX project 95163J, Barren Islands seabird studies). By number, 86% of all identifiable fishes (n = 356) brought to murre chicks were capelin, and by weight, capelin also dominated kittiwake chick diets (65%, based on 629 items). By weight, capelin were also the dominant prey fed to puffin chicks (28%, based on 346 items).

During the feasibility study, the level of cooperation received from Homer charter vessel operators was high; we could have easily obtained two to three times as many samples with little additional effort. Based on the operators' responses to the study and overall distribution of fishing activities in the region, a modest program with larger sample sizes (e.g., 20-40 stomachs containing prey per area per week) could be easily set up to monitor changes in relative abundance of capelin and sand lance in areas near seabird colonies in lower Cook Inlet and Kachemak Bay (i.e., the Barren Islands, Gull and Chisik islands).

CONCLUSIONS

1. Results from the Kachemak Bay - lower Cook Inlet study area indicate that real-time analysis of stomachs from sport-caught halibut can provide useful low-cost information on the occurrence of forage fishes in areas where charter boat fleets operate on a regular basis.

2. Based on the apparent ability of the sampling method to detect changes in the relative abundance of capelin and sand lance in the Point Adam area, we also believe that this relatively simple cost-effective technique can provide useful information on seasonal and interannual variations in populations of forage fishes in areas where seabird feeding and charter vessel activities overlap (e.g., Barren Islands and Chisik Island vicinities).

RECOMMENDATIONS

Based on our initial results and the level of cooperation received from Homer charter vessel operators, we recommend implementing a small program to continue collecting information on forage fish stocks via halibut stomachs in the Kachemak Bay - lower Cook Inlet region during 1996-1999. This type of study will almost certainly provide useful data on overall presence-absence and relative abundance of capelin and sand lance for APEX related seabird studies in the Barren Islands and at the Chisik and Gull island colonies, and it would compliment other APEX work on forage fishes in Kachemak Bay - lower Cook Inlet (e.g., hydroacoustic and trawl studies by J. Piatt, 96163M).

ACKNOWLEDGMENTS

We would like to thank our hard-working Homer volunteers, Jill Aho and Daniel Boone, for helping make the 1995 pilot study a success. They consistently met returning charter vessels, collected and processed halibut stomachs, identified prey items, and entered data on an ever changing schedule throughout the summer without complaint. We would also like to thank Captain Rick Swenson of Homer Ocean Charters. Captain Swenson provided us with a steady stream of halibut carcasses and facilities for processing them. He also helped encourage other skippers to join in the study and gave us important information on locations of capelin schools. Without his help, collecting data would have been more difficult and less efficient. Silver Fox Charters also deserves special thanks. Several Silver Fox skippers participated in the study on a regular basis; their contributions rounded out our sampling efforts and helped ensure the success of the experimental program. John F. Piatt, National Biological Services, Anchorage; Alan M. Springer, Institute of Marine Sciences, University of Alaska-Fairbanks; and Bruce A. Wright, National Marine Fisheries Service, Auke Bay, provided helpful suggestions during conceptual phases of the work.

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Kachemak Bay - lower Cook Inlet Study Area

(Summary of Halibut Stomach Collection Efforts)

Total number of sample areas: 12

Number of areas sampled: 7 (58%) Areas 1, 2, 4, 6, 8, 10, and 12
Number of areas not sampled: 5 (42%) Areas 3, 5, 7, 9, and 11

Total number of days sampled: 53 (during late May - early September)

May: 2 days (27 and 31)
Jun: 20 days (1, 2, 3, 8, 9, 10, 14, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, and 29)
Jul: 18 days (1, 2, 3, 5, 7, 8, 10, 11, 15, 16, 17, 18, 20, 21, 23, 24, 27, and 31)
Aug: 11 days (3, 5, 6, 9, 12, 14, 18, 19, 21, 26, and 30)
Sep: 2 days (1 and 3)

Total number of halibut stomachs sampled: 586

Number of empty halibut stomachs: 206 (35%)
Number of halibut stomachs containing prey: 380 (65%)

Table 1. General information on halibut stomach collections made in the Kachemak Bay - lower Cook Inlet study area during late May - early September 1995.

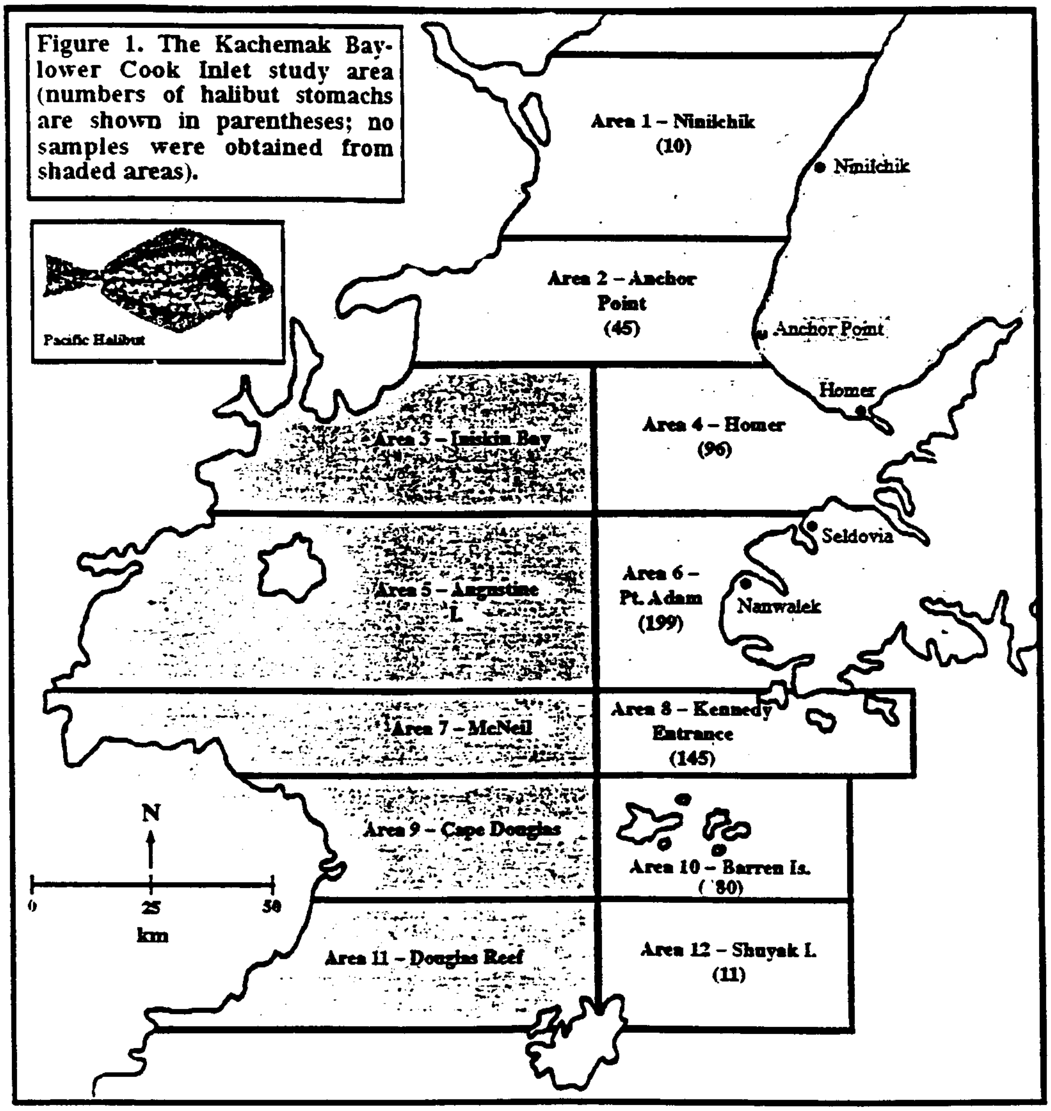

Figure 1. The Kachemak Bay-lower Cook Inlet study area (numbers of halibut stomachs are shown in parentheses; no samples were obtained from shaded areas).

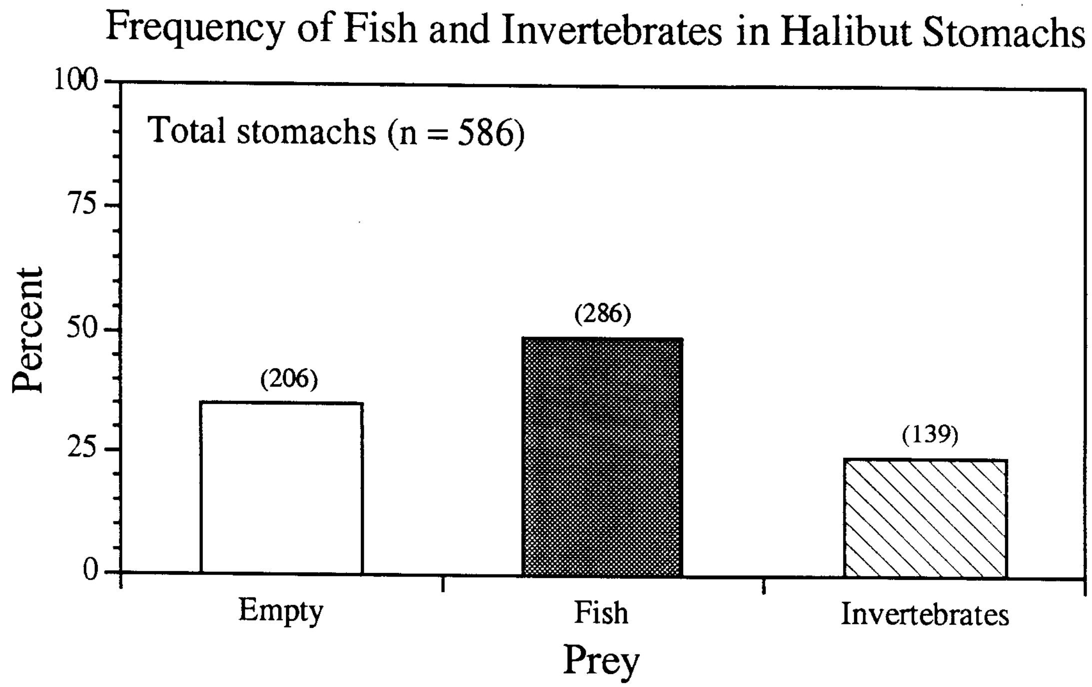

Figure 2. Frequency of occurrence of fish and invertebrates in 586 halibut stomachs collected in Kachemak Bay - lower Cook Inlet (numbers of stomachs are shown in parentheses).

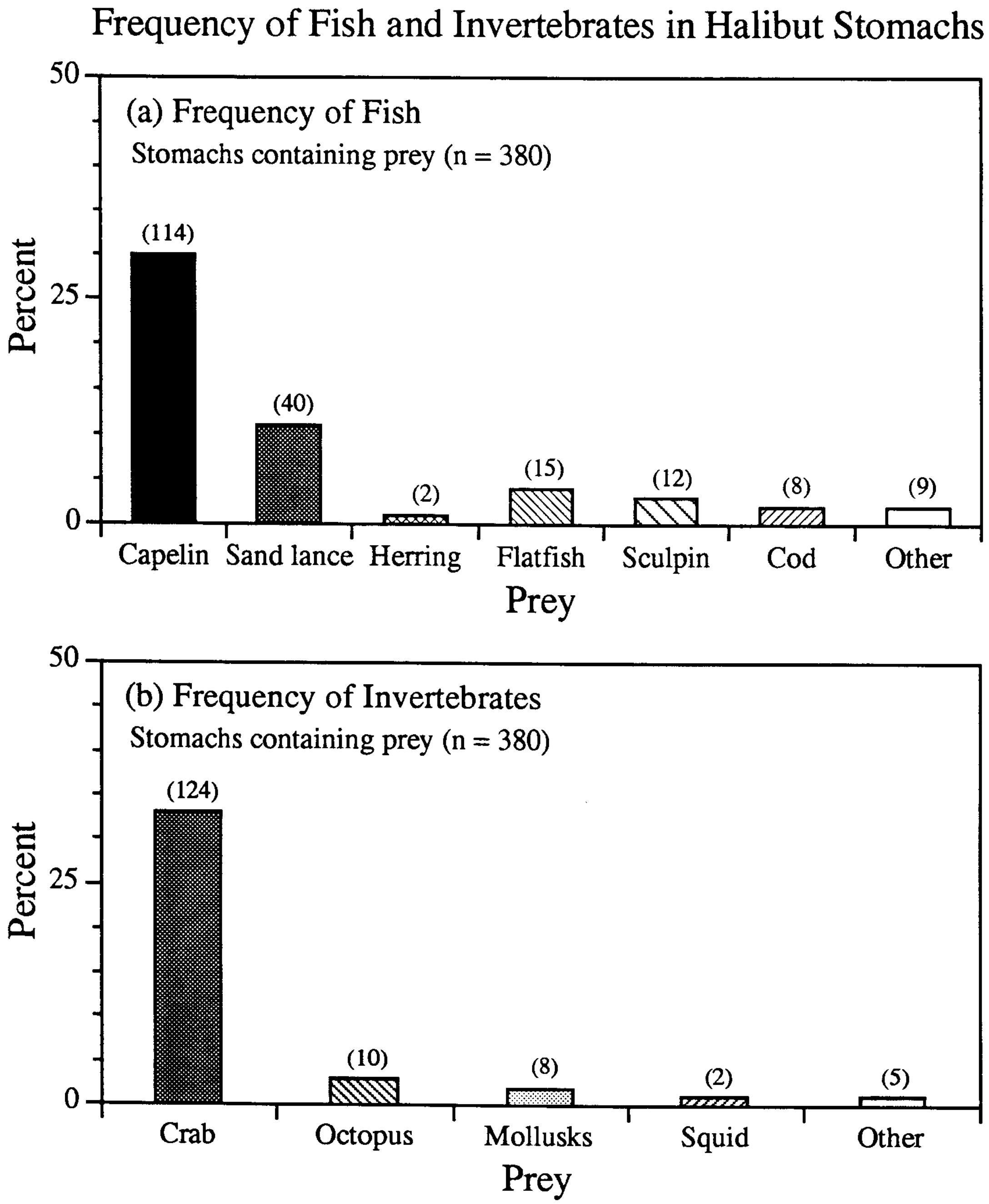

Figure 3. Frequencies of occurrence of (a) fish and (b) invertebrates in 380 Kachemak Bay - lower Cook Inlet halibut stomachs containing prey (numbers of stomachs are shown in parentheses).

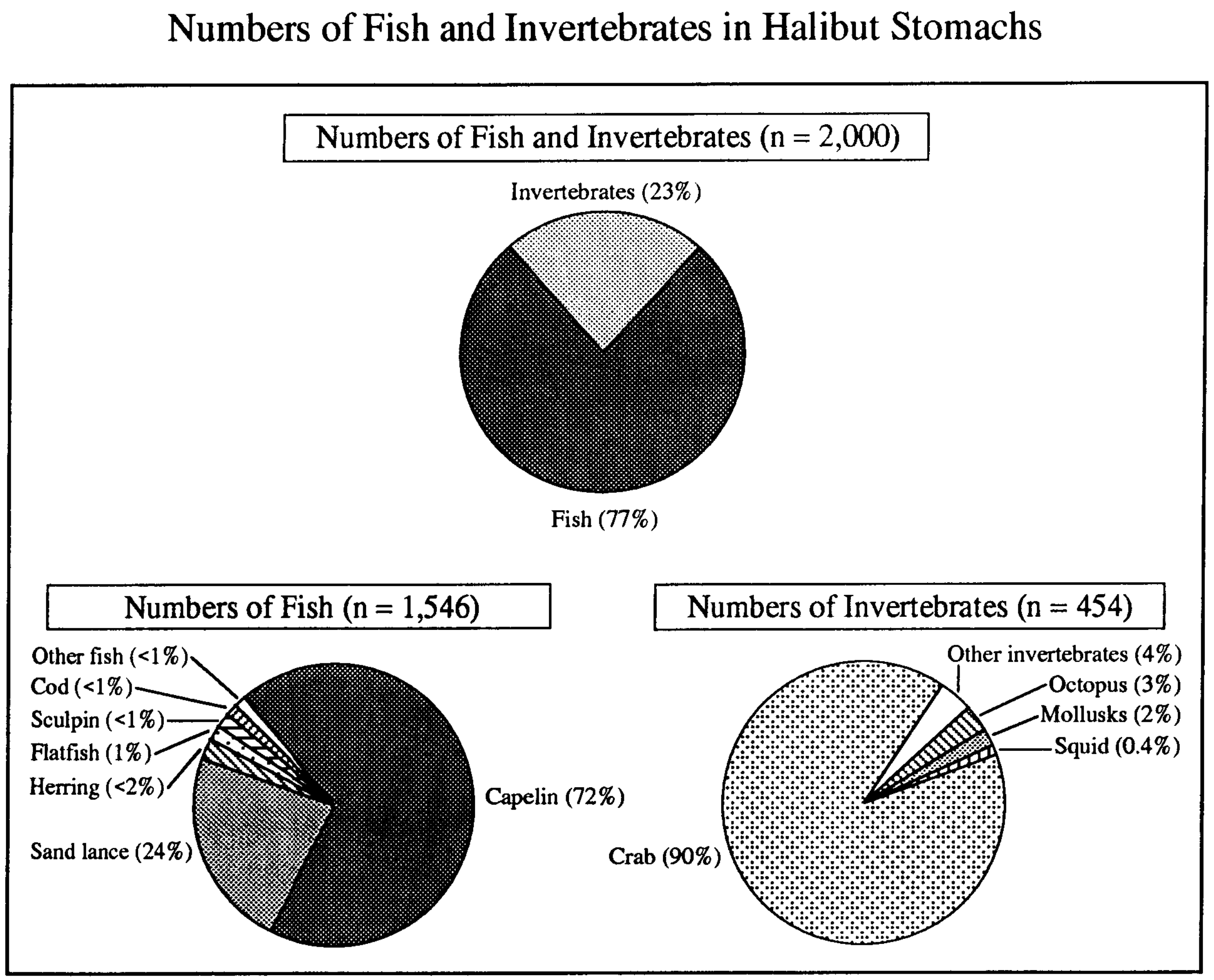

Figure 4. Numbers of fish and invertebrates in 380 Kachemak Bay - lower Cook Inlet halibut stomachs containing prey.

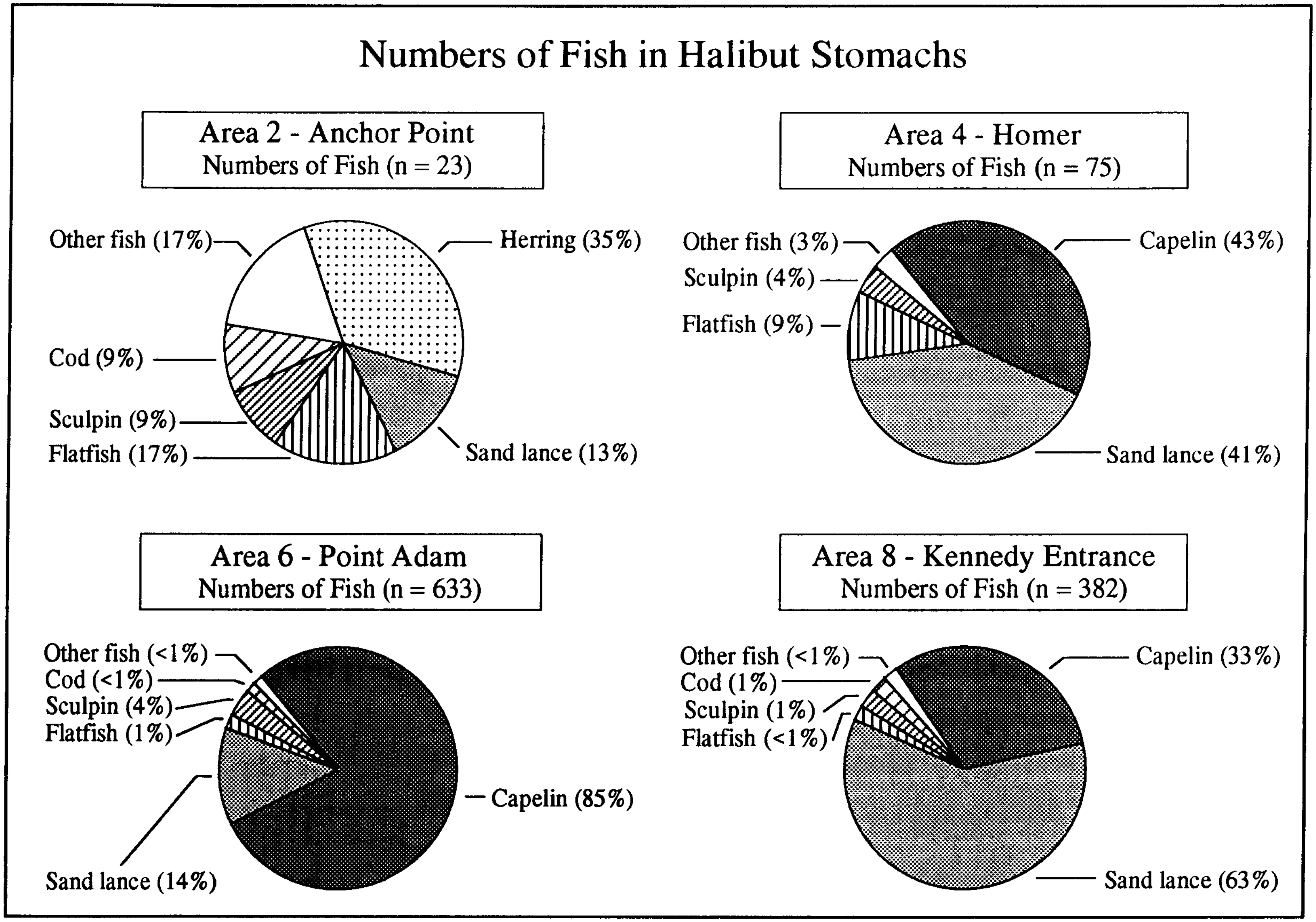

Figure 5a. Numbers of fish in halibut stomachs from Areas 2, 4, 6, and 8 in Kachemak Bay - lower Cook Inlet.

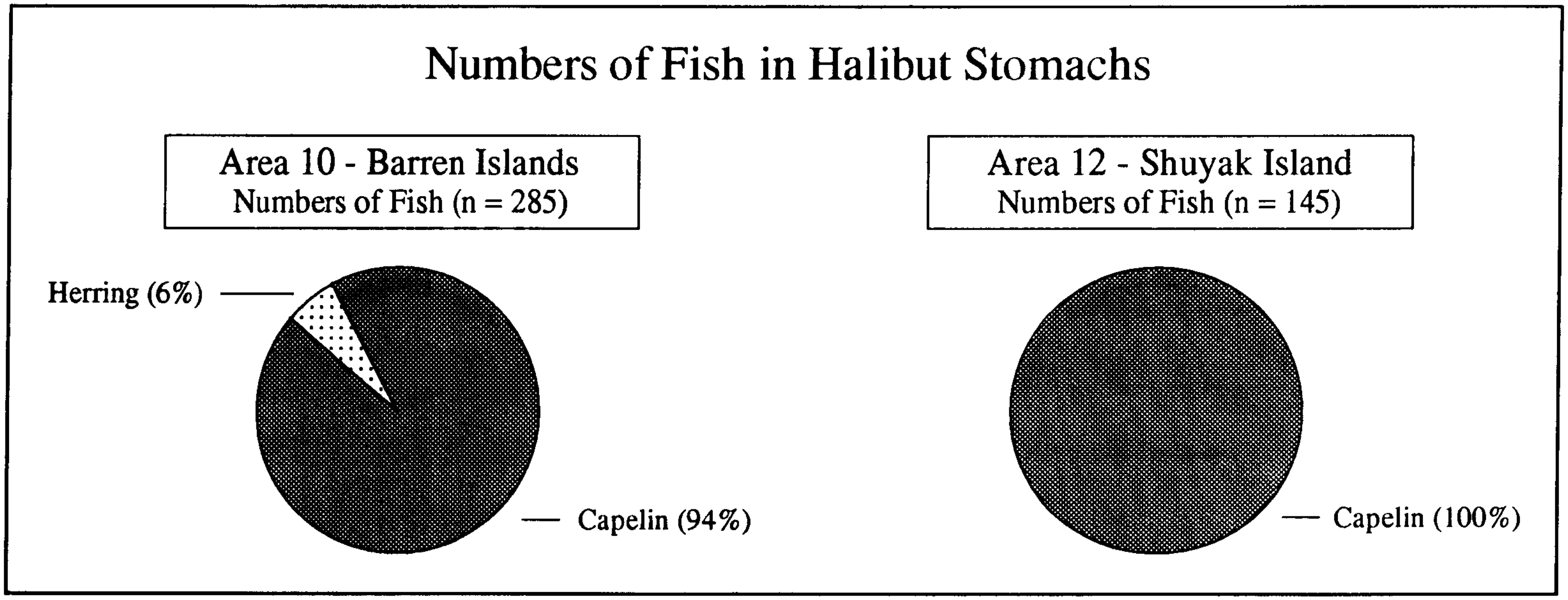

Figure 5b. Numbers of fish in halibut stomachs from Areas 10 and 12 in Kachemak Bay - lower Cook Inlet.

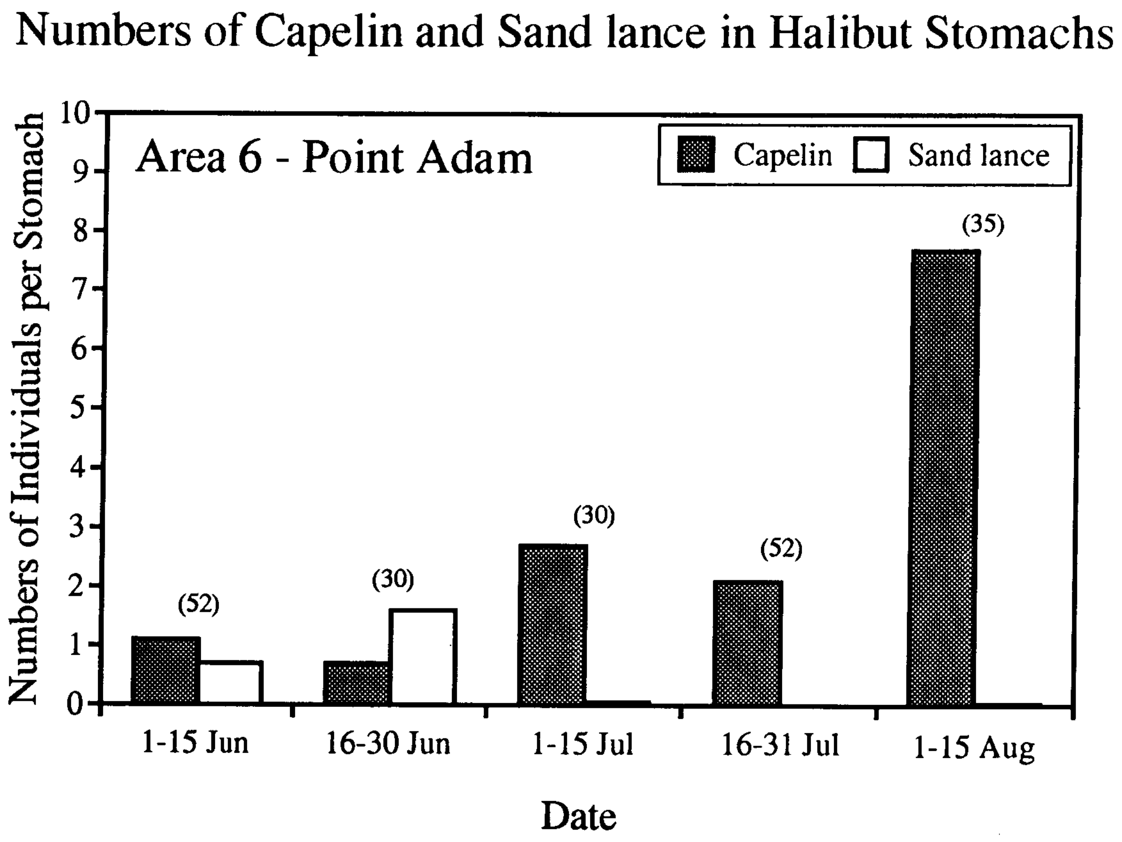

Figure 6. Average numbers of capelin and sand lance in halibut stomachs collected during two week intervals in Area 6 (Point Adam), Kachemak Bay - lower Cook Inlet (numbers of stomachs are shown in parentheses).

Appendix 1. Summary of Kachemak Bay - lower Cook Inlet halibut stomach collections by sample area (1995).

Area 1 (Ninilchik)

Sample dates: 1 Jul
Total stomachs sampled: 10; number empty = 5 (50%) & number with prey = 5 (50%)

Area 2 (Anchor Point)

Sample dates: 27, 31 May; 28, 29 Jun; 8 Jul
Total stomachs sampled: 45; number empty = 10 (22%) & number with prey = 35 (78%)

Area 4 (Homer)

sample dates: 27 May; 9 & 28 Jun; 7, 10, 17, & 18 Jul; 12, 18, & 19 Aug
Total stomachs sampled: 96; number empty = 41 (43%) & number with prey = 55 (57%)

Area 6 (Point Adam)

Sample dates: 1, 3, 8, 14, 16, 26, & 27 Jun; 8, 11, 15, 21, 23, 27, & 31 Jul; 5. 6, 9, & 14 Aug
Total stomachs sampled: 199; number empty = 54 (27%) & number with prey = 145 (73%)

Area 8 (Kennedy Entrance)

Sample dates: 1, 2, 10, 14, 21, & 22 Jun; 3, 5, 16, 20, & 24 Jul; 3 & 21 Aug; 1 & 3 Sep
Total stomachs sampled: 145; number empty = 61 (42%) & number with prey = 84 (58%)

Area 10 (Barren Islands)

Sample dates: 17, 18, 23, 24, & 25 Jun; 2 Jul; 26 & 30 Aug
Total stomachs sampled: 80; number empty = 33 (41%) & number with prey = 47 (59%)

Area 12 (Shuyak Island)

Sample dates: 20 Jun
Total stomachs sampled: 11; number empty = 2 (18%) & number with prey = 9 (82%)

APPENDIX L

APEX: 95163 L

Appendix L-1

APEX: 96163L

SYNTHESIS AND ANALYSIS OF GULF OF ALASKA SMALL-MESH TRAWL DATA: 1953 to 1995

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ABSTRACT

Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in the composition and abundance of forage species may be responsible for the decline of these predator populations. In an effort to delineate changes in the trophic regime and forage species, if any, over the last several decades, we have gathered together scientific survey data covering a long time span and large area. This report includes a preliminary historical review of information and data from small–meshed trawl studies conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service and its predecessor agencies from 1953 through 1995. Over 10,000 individual sampling tows are in the current database of the two agencies (ADF&G — 5,836; NMFS — 4,352). For preliminary analysis, the entire region sampled was divided into six sub–areas representing geographical, oceanographic, and biological domains. Where possible, the occurrence and relative abundance of five major species or species groups was studied to detect change in the forage ecosystem over the four decades of past sampling with small–mesh trawls and beam trawls.

Appendix L-2

INTRODUCTION

This report provides a historical review of small–mesh trawl sampling results from near–shore surveys in the Gulf of Alaska conducted by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G). The data for analysis was collected starting in 1953 and continues to 1995. In this report we discuss the methodology of data collection and how it changed through the years. The nature of the survey areas are discussed. A preliminary analysis is presented along with discussion of analytical procedures and assumptions.

Recently there has been information presented that the Gulf of Alaska ecosystem has undergone some abrupt and significant changes (Piatt and Anderson, 1995). The extent and degree of these changes is poorly documented and is important in determining future strategies for management of the marine ecosystem. Analysis of the historic data is a first step in gaining an appreciation for the rapid and abrupt changes that have occurred in the marine species complex in the last five decades. The data from small–mesh shrimp trawl cruises provides an opportunity to review changes in the composition of forage species that occurred through time in the Gulf of Alaska.

Historically, there is evidence of major abundance changes in the fish/crustacean community in the western Gulf of Alaska. Fluctuations in Pacific cod availability on a generational scale was reported for coastal Aleutian communities by Turner (1886). Similarly, landings from the near–shore Shumagin Islands cod fishery (Cobb, 1927) showed definite periods of high and low catches with the fishery peaking in late 1870s. King crab commercial catches in the Gulf of Alaska show two major peaks of landings, one in the mid 1960s and another in 1978–1980 (Blau, 1985). All of the area was closed to fishing in response to low population levels in 1983 (Blau, 1986) and has yet to reopen. By the 1960s there was evidence of high pandalid shrimp abundance in these same areas (Ronholt 1963). One of the highest densities of pandalid shrimp known in the world was to spur the development of a major shrimp fishery (Anderson and Gaffney, 1977). By the late 1970s the shrimp population density had declined radically and was accompanied by a closure of the shrimp fishery and the return of cod to inshore areas (Albers and Anderson, 1985). Catches of almost all salmon stocks of Alaskan origin suddenly increased to unprecedented levels in the 1980's (Francis and Hare, 1994, Hare and Francis, 1995). These changes, witnessed over the last century, imply dynamic fluctuations in abundance of commercially fished species. Managers, fisherman, and processors should be aware of these dynamics and their impacts on the ecology and economy.

Evidence from long–term small–mesh trawl surveys in the Gulf of Alaska imply that a number of non–commercial species also have undergone significant change in abundance during the past 25 years. Major groups of species nearly disappeared or have become virtuallyextinct in some areas and demonstrate that huge changes have occurred in the near–bottom species complex. The abrupt decline of species that have never been commercially harvested in the Gulf of Alaska such as capelin, Pacific sandfish, and certain species of Lumpenella suggest that fishing pressure is not entirely to blame for the changes which have occurred. Based on the results obtained from the longest continually conducted trawl survey series (Piatt and Anderson, 1995) have lead to the recognition that the entire small–mesh trawl survey data collected as far back as possible be used to put a historical perspective on these changes and give direction to future research. With these ideas in mind, we have assembled and are continuing to assemble, data from small–mesh surveys in order to help understand the ecological dynamics of this abrupt change in the ecosystem.

Area of Coverage

The study area includes the continental shelf (0 – 200 m.) and upper slope (201 – 400 m.) from 144^0 W. longitude (in the vicinity of Kayak Island) westward to 168^0 W. longitude (vicinity of

Unalaska Island, eastern Aleutians). This area is characterized as having a relatively broad shelf which is punctuated with numerous islands, separated by deep gullies and large inlets, sounds, and fjords. Most of the data was collected in trawlable locations associated with the numerous gullys and bays that are associated with this bathymetry.

The area of coverage for the entire historical data set was divided into regions based on three guiding principles. First, areas within geographic proximity were included as groups taking into account the sampling coverage through the time series. If gaps in sampling were evident in geographic plots of the data then these were frequently used as rational for dividing the area. Second, general knowledge of the biological regimes in each area were also used as guides when defining areas for analysis. Third, oceanographic domains were used when knowledge of these domains was known. Based on the above principles the entire area covered was divided into 6 regions (Figure 1) for analysis of time series data. A description of each of the sub–areas follows.

1. Prince William Sound — Includes area west from Kayak Island to the vicinity of Cape Puget and includes all offshore sampling on the adjacent shelf area. A prominent gully intersects the shelf running from the head of Prince William Sound between Montague and Hinchinbrook Islands. A large reef area, Wessels Reef is located between Hinchinbrook and Middleton Islands. Bottom sediments in the area include soft mud, firm mud, mud with boulders, gravel and rock. Because large portions of the survey area are covered with rocky substrate, much of the area is unsuitable for sampling by trawls.

2. Kenai — Includes the region along the outer Kenai coast from the vicinity of Port Graham north and east along the coast to vicinity of Cape Puget. This area is influenced by Alaska CoastalCurrent (Reed and Shumacher, 1986). This area is also characterized by rocky areas which hinder trawl sampling in some areas.

3. Lower Cook Inlet — Includes areas north of Cape Douglas north of the a line drawn beneath the Barren Islands and intersecting with the coast near Chugach Passage. This area includes all waters of Kachemak and Kamishak Bays. This area has extremely limited flow of northern Gulf water into lower Cook Inlet (Hood and Zimmerman, 1986).

4. Kodiak — Includes all of the bays along the eastern side of the Kodiak Island group to south of the Barren Islands. This area is characterized by wind driven oceanic regime and under the direct influence of the Alaska Stream (Favorite et al., 1976).

5. Shelikof— The Shelikof region includes all waters north of Castle Cape and a line drawn to Chirikof Island and thence a line drawn to the southern tip of Tugidak Island in Trinity Island group. The region includes the bays along the western side of Kodiak Island including Alitak, Uganik, and Uyak Bays. The region also includes the bays from Chignik northeast along the Alaska Peninsula to Cape Douglas. The major oceanic feature in this area is the extreme tidal flow out of Cook Inlet and the strong winds that blow up and down the strait.

6. Shumagin — The Shumagin region encompasses the area from Unimak Island in the eastern Aleutians along the south side of theAlaska Peninsula in a northeasterly direction to Castle Cape. The area includes major embayments and straits associated with the Shumagin Island, Pavlof Island, and Sanak Island groups. The area includes Pavlof Bay the site of the longest continually conducted trawl survey in the entire Gulf of Alaska. The area also includes bays associated with Unalaska Island.

Time Series Description

The earliest sampling by small mesh gear in the Gulf of Alaska probably dates to the 1891 when the steamer RV Albatross conducted a cruise on the general biology of the Gulf of Alaska (Harriman Expedition, 1910). Small mesh studies directed at defining commercial quantities of shrimp were initiated in 1950 by the Bureau of Commercial Fisheries, the shelf region from Ketchikan to Unalaska Island was sampled in the period 1950–1957 (Ronholt, 1963). The series continues with the systematic collection of shrimp surveys that started in the GOA in 1970. In response to information needed to manage the rapidly expanding shrimp fishery both NMFS and ADF&G adopted survey methodology that was similar (Anderson and Gaffney, 1977).

Since 1971 both agencies have used the same high opening sampling gear and similar sampling methodology. Figure 2 shows the total number of tows in the data sets for each agency.

METHODS

Gear

Small–meshed sampling gears used during the studies are summarized below in Table 1. Basically, all small mesh gear was deemed to fit in this category if it was used for shrimp surveys. Also included for analysis were hauls conducted by the International Pacific Halibut Commission (IPHC) when small mesh liners were added to their standard sampling gear. Almost all of the small mesh tows of ADF&G and NMFS since 1971 have been conducted with the same sampling gear the 61' high–opening shrimp trawl. This gear as described by Wathne, 1977 is designed to sample the water column from .4 to 5 meters above the sea floor and has an opening of approximately 10 m wide.

Catch and Sample Handling

The surveys were designed to sample shrimp (biomass) abundance, however other benthic and pelagic species were quantified by weight and, in later years, by numbers as well. Seasonally, during the survey months dense aggregations of pandalid shrimp form in relatively deep water prior to mating and spawning (Anderson 1991). Earlier surveys had shown that shrimp concentrate in depths greater than 70 m (Ronholt 1963, Anderson, 1991). As a consequence, all survey tows were restricted to depths greater than 55 m in years after 1970 in order to adequately target primarily on shrimp.

Stations were sampled during daylight using a 50 to 32 mm mesh trawls. Tow duration was approximately 30 minutes; average tow length for the forty years (NMFS database) being 2.1783 km with a standard deviation of 0.463. Index of biomass estimates are conservative for the small species because small animals are not fully vulnerable to capture (Anderson, 1991)

Survey catches were sorted by species and all species were weighed separately. Occasionally catches were so large that sub–sampling of the catch was employed after the method described by Hughes, (1976). Subsamples were counted to obtain the average weight of individuals. All shrimp, juvenile fish (mostly pleuronectidae) were combined, weighed, and subsampled for species composition. The subsampled species groups were then counted and weighed using an triple–beam scale to the nearest gram. The extrapolated weights of each species were added to those of the adults of the same species.

Level of Species Sort

In the early years 1953 – 1962 only primary commercial species were enumerated, usually the top four or five species in a catch were recorded. Gradually as the surveys were designed to provide more useful information to a broader user group, catch sort and information collected was improved. Since 1970 everything in survey catches has been sorted, identified to the lowest possible taxon, weighed, and enumerated.

Data Structure

Two general data tables are used in the small–mesh sampling database. The haul table structure is given in table 2. Generally the haul table contains details on the location, time, depth, temperature, and gear type employed for a given sampling. The catch table structure is given in table 3. The catch record contains a species code usually identified to the lowest taxon possible, the total weight of the species caught and the number of individuals of the subject species.

Data Limitations

Fishes and invertebrates observed during these small–mesh surveys and the relative importance of species and species groups within the areas surveyed is largely a function of the sampling gear deployed. Trawls, as most sampling apparatus, employed to sample marine biota, are selective. Sizes and even species of fish captured are influenced by the mesh size used, particularly that in the end of the net or cod end. Species within the size range which theoretically would be retained if engulfed by the trawl, may differ substantially in their ability to escape through the mouth of the trawl or avoid capture altogether. The selective features of trawls thus alter the observed species composition and size frequencies which occur in the swept sampling area. The degree to which the "apparent" distribution and abundance differ from the actual is unknown. Therefore it is important to note thatsubsequent discussion in this report will deal with distribution and relative abundance obtained with the small mesh sampling gears used during the time period. The estimates presented and trends observed are representative only for those species, and sizes of species which are vulnerable to the trawl (Alverson et al., 1964).

Some of the earlier collected data does not have good position information represented in the on–line data sets, however original working charts and copies of them are available. If further funding is available these on–line data will be upgraded for future use by other investigators and will also increase the accuracy of historic catch–per–unit of effort values for important species in the time line analysis.

RESULTS

Species Occurrence and Composition

In general, preliminary results from the analysis of the entire trawl survey data set showed a change, beginning in the late 1970's, from catches being dominated by shrimps to a swift and abrupt change to higher fish proportions in catches. Coincident with changes observed in the composition of survey catches dramatic declines in the commercial fisheries for shrimp and later crab also indicated drastically smaller landings and closures of these fisheries. Just as quickly, fisheries for pollock and cod were beginning to increase in importance and catch levels. These changes witnessed during the past two decades show no sign of reverting tothe crustacean dominated fishery regime.

In all, over 411 species and specie groups were identified in survey samples from 1953 to 1994 in small–mesh trawl survey sampling. Ranking these species by total catch weight in the data base gives the relation of species occurrence in the data set (Table 4). Not surprisingly, several shrimp species are well represented in the top rankings. In addition to several shrimp species many other important forage species are represented in the top 20 entries on the rank order list. Among those that are of principle interest in this study are; capelin, sandfish, pollock, eulachon, cod, and possibly jellyfish (Scyphoza).

The focus of this study is directed towards the relative abundance and distribution of the five species mentioned above and a group of flatfish species. Many of the principle study species are true forage species such as capelin, sandfish, and eulachon. Many others serve a dual role acting as forage when juveniles and then becoming predators as they grow. Examples of this later group are cod, pollock, and flatfish. One of the declining species that has been studied is the longsnout prickleback which may be an important forage species only during its juvenile phase. Other species, including jellyfish, are probably indicators of productivity changes in the environment and their distribution and relative abundance will be studied as well.

Changes in Forage Species Abundance and Distribution

Capelin

Capelin are primarily planktivores with a relatively short life span. Their abundance is highly variable from year to year and is linked to zooplankton availability and to the feeding influence of their competitors or predators (Gerasimova, 1994). Capelin play a key role in the trophic interaction of species, transferring energy from primary production to higher level predators, including cod, marine mammals, and birds.

Data from shrimp cruises in the Gulf of Alaska starting in 1953 and continuing to the present showed no capelin present in catches prior to 1963. A possible reason for this observation may be explained by survey techniques which ignored "non–commercial" species in the early years when the emphasis was entirely directed toward commercial species. A review of what written material that still remains from these tows revealed that species were simply identified as "smelt" in the early data sets. We believe that many of these records most undoubtedly refer to capelin and eulachon since both of these species have high occurrences in the entire data set. Unfortunately we have no way of telling for sure, except that they are in the family Osmeridae. With the advent of MARMAP program in the early 1970's a more through approach to analyzing catch components in surveys was adopted. In the analysis of the data the year 1970 is useful as a baseline for comparison purposes due to this weakness in the data. Occurrences of capelin between 1963 and 1970 will be used in analyzing distributional patterns only.

Capelin showed two peaks in abundance since 1970 in the GOA Figure 3 (top). The first peak in abundance occurred in 1974 at little over 4 kg/km in survey catches. The second peak in relative abundance was in 1980 at 7.22 kg/km. In 1980 and 1981 the catch rates dropped to around 1 kg/km and has remained below a tenth of a kg/km since 1985. ADF&G data also clearly shows the peak value of 1980, mostly represented in the Kodiak region Figure 3 (bottom). The peaks in relative abundance observed in the mid 1970's and at the late 1970's and 1980 probably reflect strong cohorts or year classes of capelin during those times. Unfortunately data prior to 1970 frequently lacked specificity as discussed above so accurate trends in the data prior to 1970 cannot be assessed.

Mapping of relative densities of capelin showed defined areas of relative high abundance. The Shelikof region showed relative high catches in Kujulik, Alitak, and Olga Bays. Most catches of capelin were closely associated with bays with the exception of high catches offshore of Cape Ikolik at the southwest end of Kodiak Island Figure 4. Isolated offshore areas east of Kodiak Island showed some high catches, most of the high catches were associated with Ugak and Kazakof Bays (Figure 5; bottom). Only isolated catches of less than 50 kilograms were evident in the database from Prince William Sound, Kenai Coast, and Lower Cook Inlet regions (Figure 5 top). More detailed analysis of these areas of historical high relative abundance will be analyzed in the future.

Eulachon

Eulachon showed a peak in abundance in 1981 with an abrupt decline thereafter. Another subsequent peak in abundance at over 1 kg/km occurred in 1986. Since 1987 eulachon has remained at a low level of relative abundance in the data (Figure 6 top). Eulachon are known to be relatively abundant in areas adjacent to spawning rivers. Subsequent analysis will rely on mapping to better define areas of relative high abundance and abundance trends in those areas.

Longsnout Prickleback and Pacific Sandfish

Longsnout prickleback and the Pacific sandfish were two non–commercial species that showed decreased abundance in the 1980's. Longsnout prickleback abundance was variable showing a peak abundance in 1973 and a subsequent decline and increasing to a lesser peak in 1979 (Figure 6 middle). The abundance of longsnout pricklebacks has remained relatively low since 1984. Pacific sandfish peaked in abundance in 1980 and subsequently declined to relative low abundance since 1982 (Figure 6 bottom).

Juvenile and Adult Gadoids

Walleye pollock are pelagic throughout their life. Young–of–the–year occur in the upper 100 m and older juveniles are found down to 400 m. Adult fish are usually found in the upper 300 m in the water column. Pollock undergo diel vertical migration in thewater column, coming off bottom during darker periods of the day and settling down to near bottom depths during the brighter periods. Seasonal movements of fish also occur with movement offshore during the winter and returning inshore during the spring were they remain through the late summer and fall. Pollock are known for forming large pelagic spawning schools in the late winter and spring period. One of the most important areas for this mass spawning is the Shelikof Strait. Walleye pollock feed mostly on free–swimming pelagic animals. Juveniles and small adults feed on euphasids, copepods, amphipods, and isopods. Larger fish feed primarily on euphasids and pollock. Pollock are preyed on by pinnipeds, cetaceans, diving birds, and larger fishes.

Pacific cod are considered a demersal species along the continental shelf of the GOA from inshore to the upper slope. During the winter and spring cod concentrate in the gullys and canyons that cut across the shelf. Most spawning occurs in late winter to early spring at depths of 150 –200m. In summer they move to shallower depths of usually less than 100m. Pacific cod are a fast–growing and short–lived species attaining a maximum age of 10 to 13 years. Juveniles feed on benthic amphipods and worms, adult fish feed on crabs, shrimp, benthic and pelagic fishes. Pacific cod are preyed on by Pacific halibut and some cetaceans.

Pollock and Pacific cod abundance was highly variable but showed a trend to general overall higher relative abundance through the time series (Figure 7 top and middle). An unusually strong peak in cod abundance occurred in 1979. Recent data suggest an overall lower level of abundance averaging around 21 to 45 kg/km since1991, these values are much higher than those prior to 1975. Pollock exhibit several peaks in abundance 1973, 1977, 1979, 1983, 1989, and relatively high sustained abundance since 1991. The peak abundance in 1991 is the highest recorded in the data series at nearly 300 kg/km.

Flatfish Complex

The flatfish complex comprised of five pleuronectid species, arrowtooth flounder, flathead sole, yellowfin sole, rock sole, and Pacific halibut are all considered demersal species with varying depth ranges, but all are commonly found in the entire study area. Arrowtooth flounder and Pacific halibut are usually found over a broader depth range 100 – 500m than the other species. All spawn on or near the bottom with arrowtooth and Pacific halibut spawning during the winter and the other species spawning during the spring. The small–mouthed soles (rock and yellowfin) feed primarily on detrital–consuming invertebrates, polychaete worms, clams, amphipods, shrimp, snails, and brittlestars. Flathead sole are primarily benthic feeders but also feed on small nektonic animals such as shrimp, herring, and smelt. Arrowtooth feed primarily on nektonic prey. Halibut feed primarily on fishes, crabs, and other invertebrates.

A group of five pleuronectid species, arrowtooth flounder, flathead sole, yellowfin sole, rock sole, and Pacific halibut showed an almost continual increase in the data series from 1970(Figure 7 bottom). These trends are different than any of the other species groups studied. Questions yet to be answered revolve around the possibility of inshore migration of species and possible displacement or competition with other species groups.

Shrimp

Recent declines in shrimp abundance throughout the Gulf of Alaska have mirrored the decline of other species as well (Piatt and Anderson, 1995). Caredian shrimp of four major families; Pandalidae, Crangonidae, Hippolytidae, and Phasapheidiae occupy an important niche in the pelagic realm in Alaskan waters. There is a long history of commercial harvesting of several species in the Pandalidae family in the Bering Sea and Gulf of Alaska, no known harvests of members of the other families has occurred. Most of the available biological information in Alaskan waters relates to the commercially important shrimps in the family Pandalidae. With out exception Pandalid shrimps have declined in the entire central and western GOA. One species, the humpy shrimp, which was second in relative abundance to the northern pink shrimp has become nearly extinct since the late 1970's.

Commercially important pandalid shrimp first hatch as larvae in the spring (April) through early June. Shrimp larvae remain in near–surface waters until undergoing metamorphosis to the juvenile phase and settle into a semi–benthic existence. Pandalid shrimp are protandric hermaphrodites maturing first as males and thenundergoing a transformation to female depending on growth rate of the individual (Charnov and Anderson, 1989). Massive swarms of shrimp take part in diel migration up into near surface water at night to feed. During daylight shrimp are mostly near bottom. Females which bear eggs on attachments to the pleopods after spawning do not actively migrate up in the water column until after eggs hatch.

Shrimp are a major food item for important commercial fish species, birds and marine mammals. Albers and Anderson (1985) found that pandalid shrimp were a dominant food item by frequency of occurrence (63%) in Pacific cod diet in Pavlof Bay. Jewett (1978) and Hunter (1979) found significant amounts of shrimp in cod taken from offshore areas but not as high as that found in inshore populations. Shrimp are also important in the diet of almost all fishes where they co–occur with shrimp. Shrimp larvae and juveniles are preyed on by pink, sockeye and coho salmon, sand lance, walleye pollock, longfin smelt, surf smelt, juvenile great sculpin, starry flounder, and rock sole taken from near–shore samples (Blackburn et al., 1983). MacDonald and Peterson (1976) report shrimp in the diet of Beluga whales, Steller's sea lion, and harbor seal. Hatch et al. (1978) reported glacous–winged gulls, kittiwakes, and tufted puffins preyed on shrimp. Shrimp therefore are a major forage species that is an important source of food when available.

CONCLUSIONS ON SPECIES' CHANGES IN RELATIVE ABUNDANCE

During the late 1970's to early 1980's an abrupt reorganization of species groups occurred in the demersal ecosystem in the Gulf of Alaska. A crustacean dominated species complex abruptly declined while round and flatfishes uniformly have increased over a short span of time in the late 1970's and early 1980's (Piatt and Anderson, 1995). Commercially fished crustaceans both of shrimps and crabs have declined to very low levels and the fisheries have remained closed for many years (Blau, 1986; Anderson, 1991). Pollock and Pacific cod abundance is variable probably due to influxes of strong year–classes but in a general up trend. Strong year–classes of cod moved into inshore areas in the late 1970's where they had been absent before. This influx of predators is responsible for the initial decline of many species (Albers and Anderson, 1985). Five species of pleuronectids have been in a general up trend from beginning of the 1970's, increasing to the highest recorded level in 1994. In turn many non–commercial species such as capelin, eulachon, longsnout prickleback, and Pacific sandfish declined and have remained in relative low abundance similar to that experienced by the crustacean populations. These general trends may obscure the effects of distributional patterns that may have also changed during the time period. Future studies will concentrate on changes by mapping distribution patterns and define trends in isolated areas were persistent populations of forage species occur.

Seasonal Component

A review of the data reveals that the most consistent time series are usually those taken from the late–summer and fall periods. An example is the data from Kachemak Bay which showed much more variability in the spring or early summer than the fall or late–summer period (Fig 8). This is probably not a function of this one single location. It was found that late–summer/fall sampling period was beneficial for the sampling of in–shore bays in the western GOA (Anderson, 1991). The reason for this is not enterly clear however the fall period is the time of year when spawning aggregations of shrimp form prior to matting and spawning, it is also the period of maximum bottom temperature for these areas. It could be that a stable temperature regime as found during this time period also leads to stability in the fish populations as well. Future analysis will focus on this apparent relationship.

FUTURE DIRECTION OF RESEARCH AND ANALYSIS

1. Monitor critical forage species

Capelin

Monitor known spawning beaches for eggs and larvae. Much easier than sampling for the adults (Mangel and Smith, 1990). An indication of shoal spawning of capelin in the GOA is illuded to in this study, this deserves further investigation.
Predator stomach sampling, including birds, mammal and fishes. Continuation of hydroacoustic and trawl surveys in areas ofdemonstrated high historical abundance.

Eulachon

Monitor spawning rivers for abundance, probably concentrate on larval out–migration indexing.

Sandlance

Monitor spawning beaches after late–summer inshore migration.
Predator sampling conducted on selected species, index on frequency of occurrence. Trawl surveys inadequate but hydroaccoustic surveys may prove viable for estimating abundance of inshore migrating schools in late summer. Surface tow nets are also a possible sampling tool for inshore migrating schools and offshore migrating larval fish.

Shrimp

Monitor selected bays where shrimp densities were high during the crustacean regime era. Pay particular attention to recovery of near–extinct shrimp species.

2. Compile complete integrated database which combines all elements of each data set to provide a database for more complete analysis.

3. Creating a geographic information system (GIS) on forage species for the GOA that can be used by other researchers and serve as a repository for future data collection.

4. Spatial analysis of historic data to analyze for changes in distribution patterns over time and employing spatial analysis models in order to understand the dynamics of the changes that have occurred (once GIS database has been developed).

5. Prepare bibliography of forage species.

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Appendix L-12

Figure 1. Distribution of small–mesh survey sampling 1953 to 1994 in the Gulf of Alaska with sub–area delineation.

Figure 1

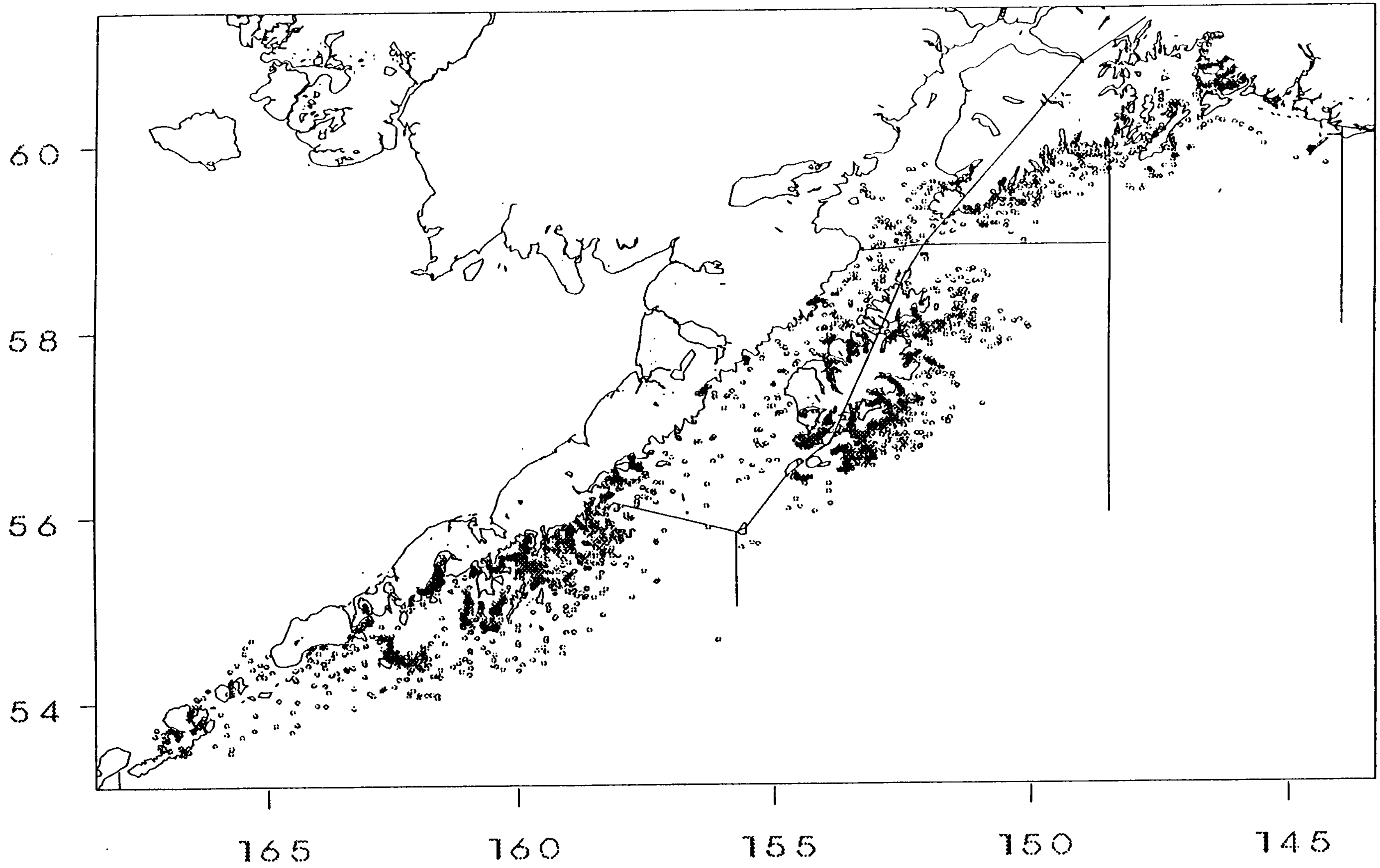


Figure 2. Number of small–mesh survey tows by year currently in ADF&G and NMFS databases.

Figure 2

SMALL-MESH SURVEY TOWS
GULF OF ALASKA

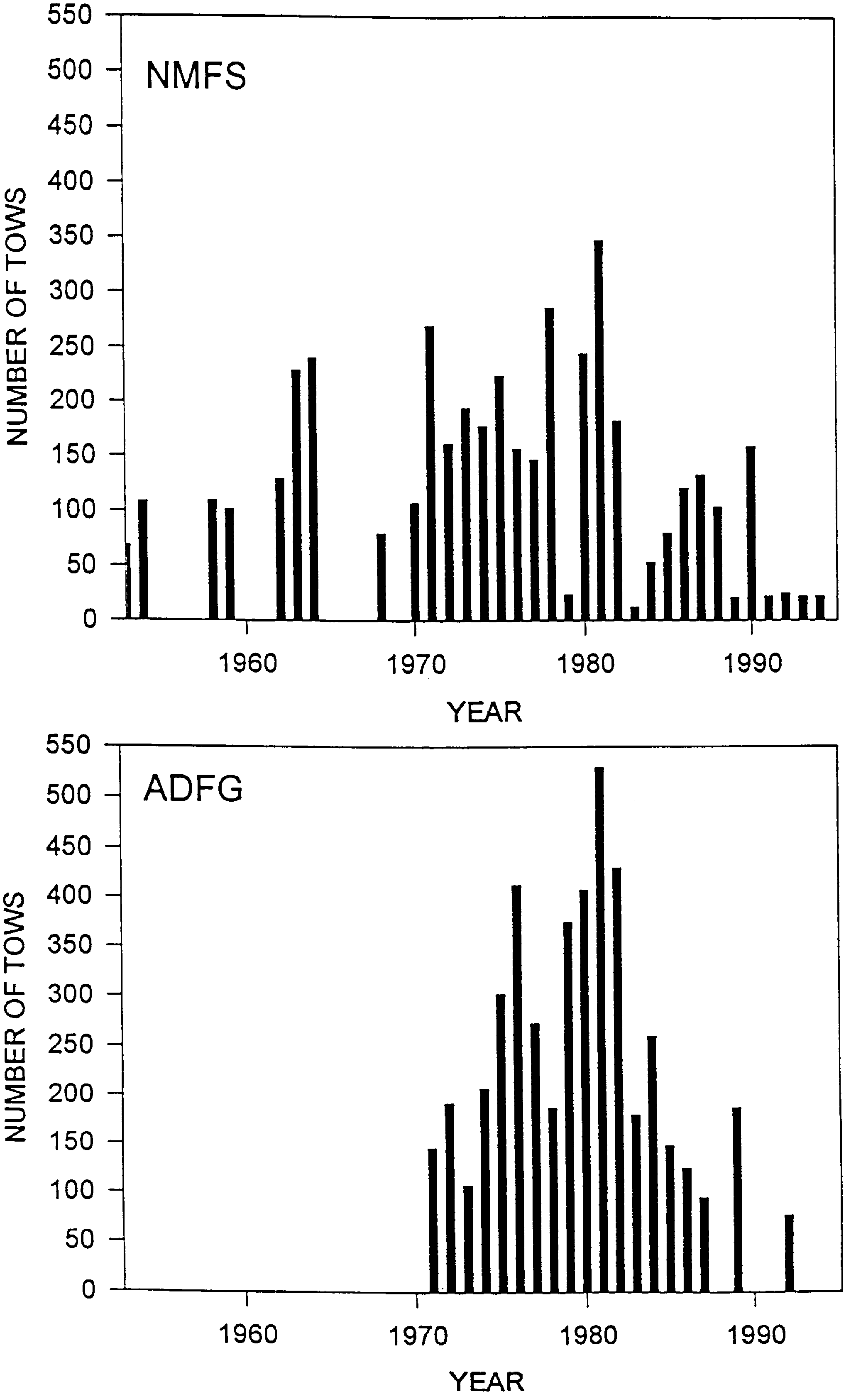
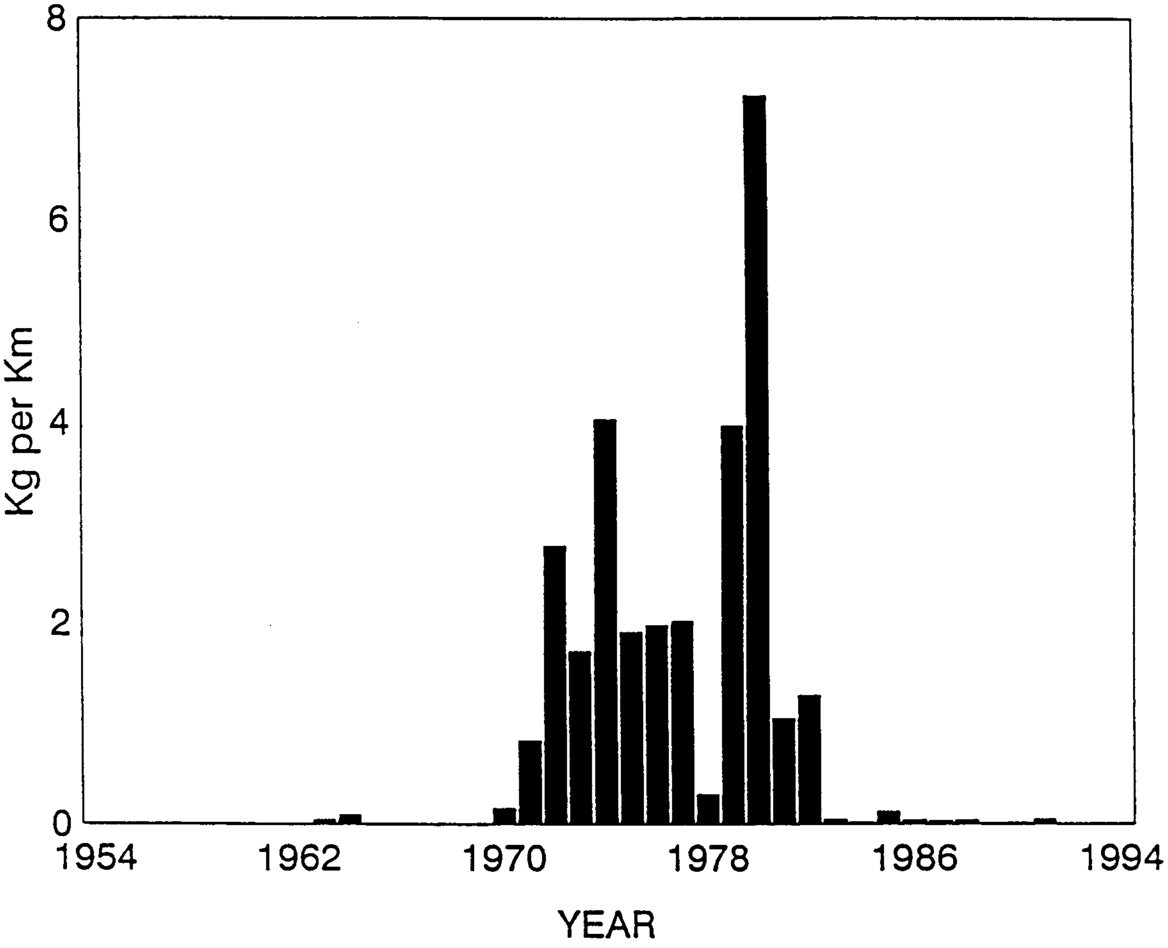
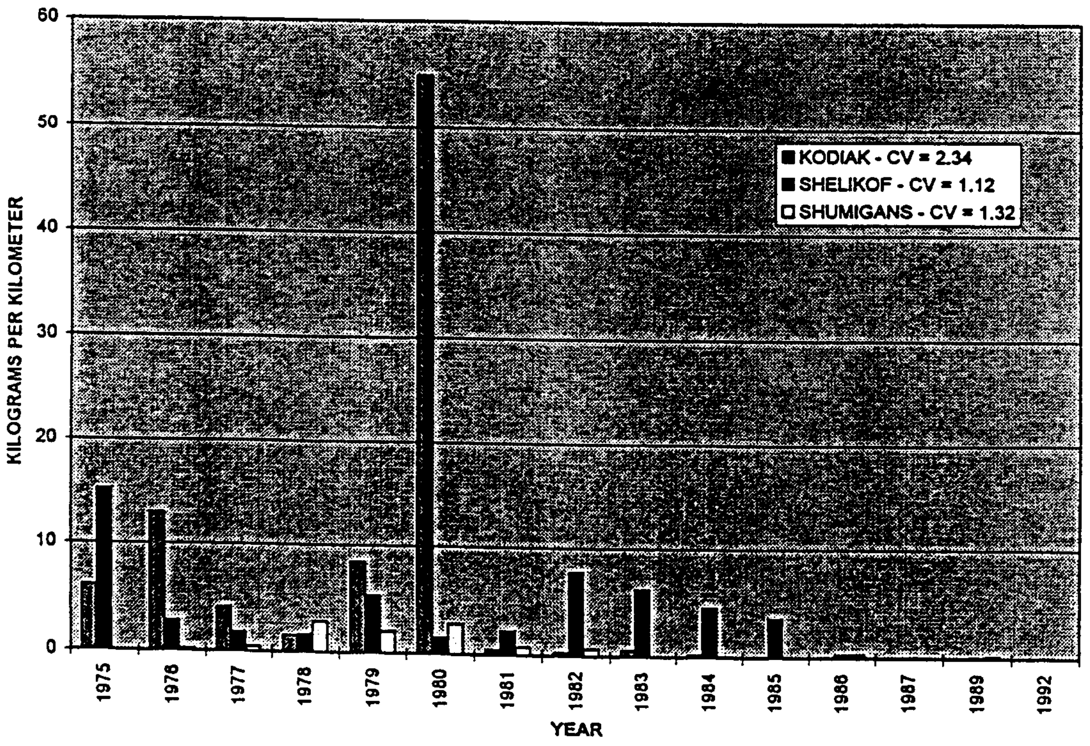


Figure 3. Capelin relative abundance in Gulf of Alaska small-mesh trawl samples expressed as kilograms caught per kilometer towed (NMFS database top). Capelin relative abundance for three regions (ADFG database bottom).

Figure 3



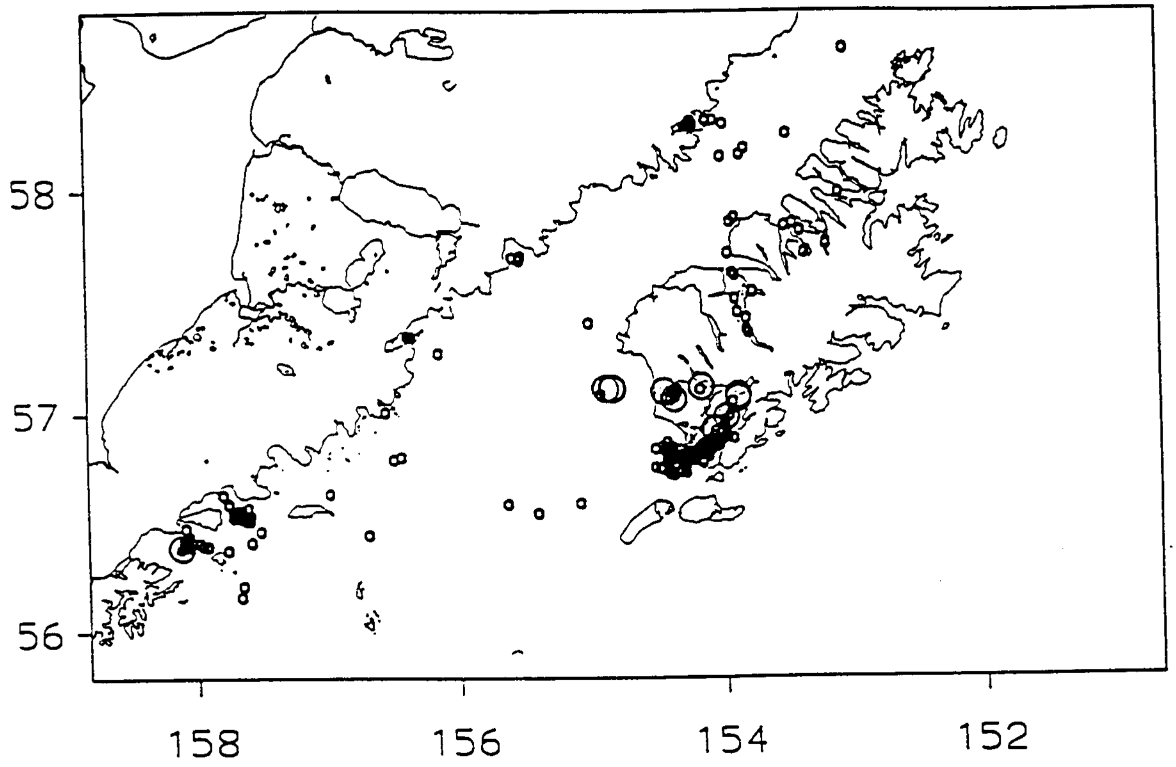
CAPELIN CATCH RATE BY YEAR AND AREA



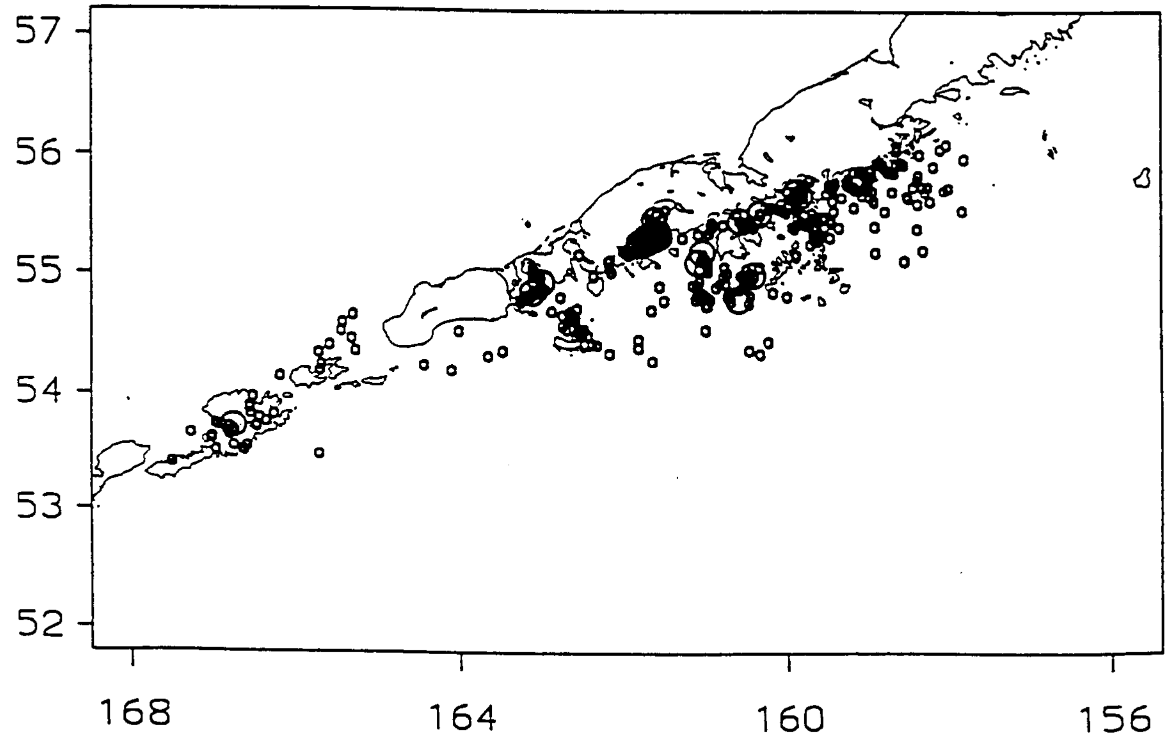
Appendix L-15

Figure 4. Maps of relative catch density of capelin in the Shelikof and Shumagin areas. Large circles represent catches greater than 50 kilograms; small circles less than 49 kilograms.

Figure 4



Capelin

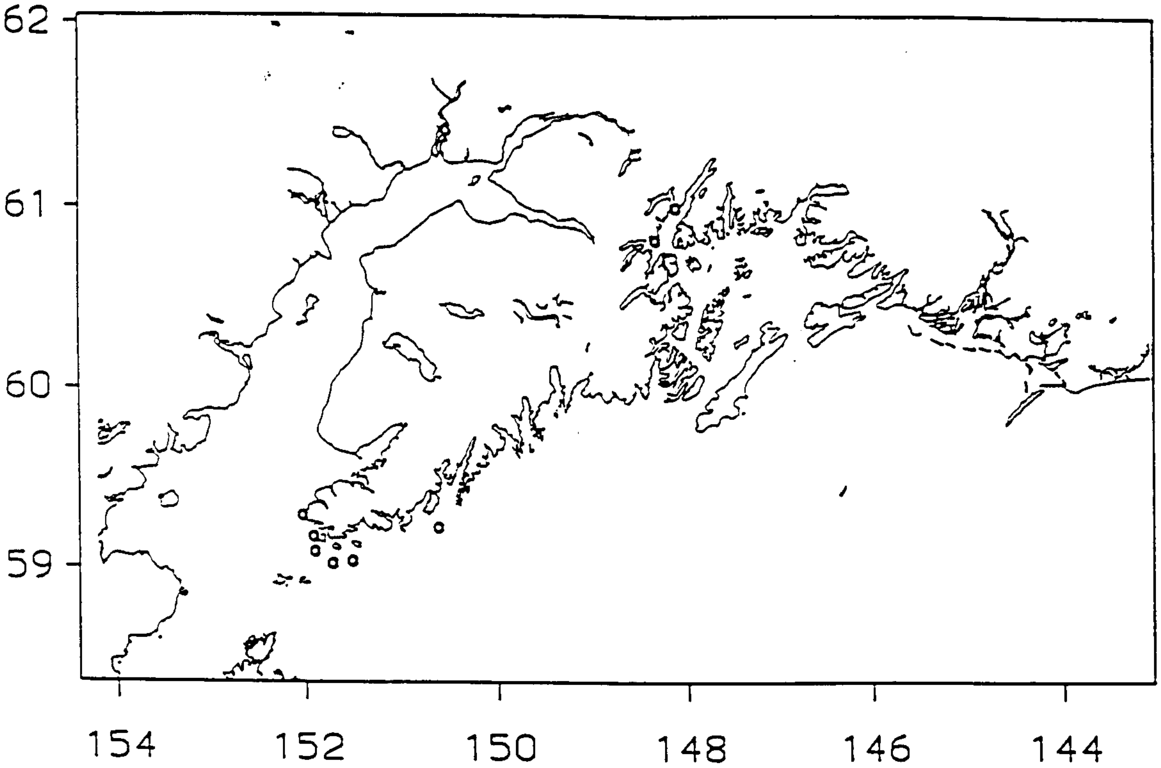


Capelin

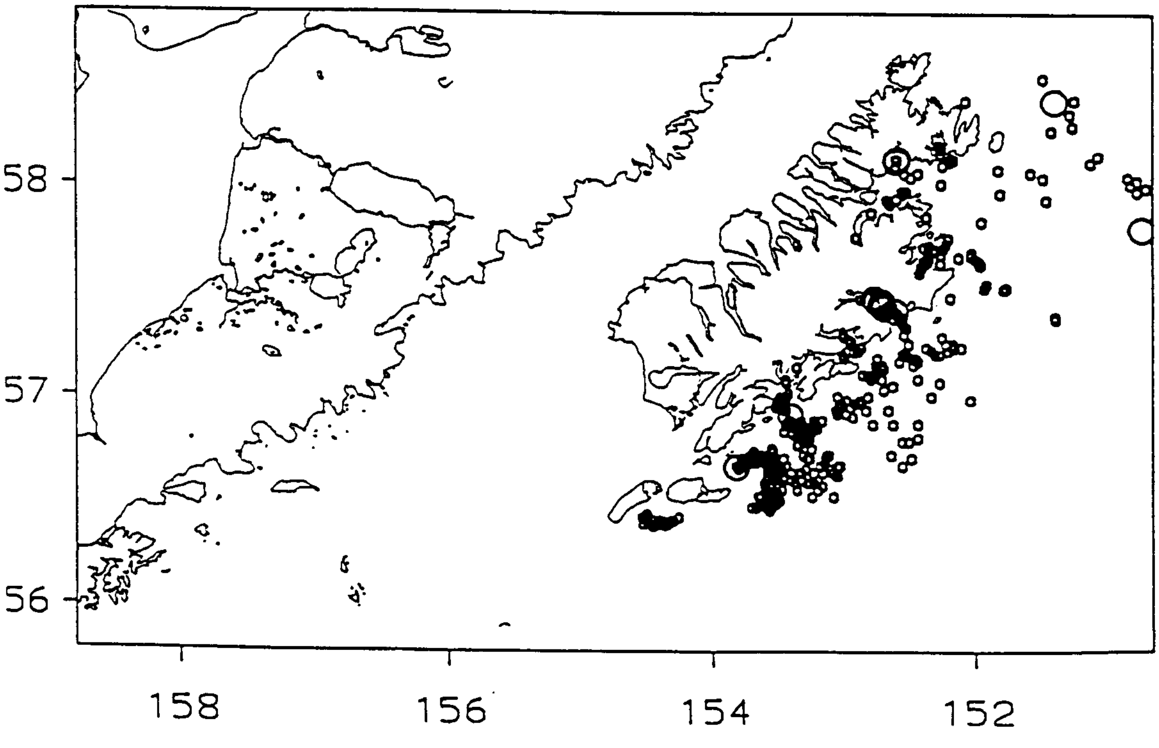
Appendix L-16

Figure 5. Maps of relative catch density of capelin in the Lower Cook, Kenai, and Prince William Sound (top) and Kodiak areas (bottom). Large circles represent catches greater than 50 kilograms; small circles less than 49 kilograms.

Figure 5



Capelin

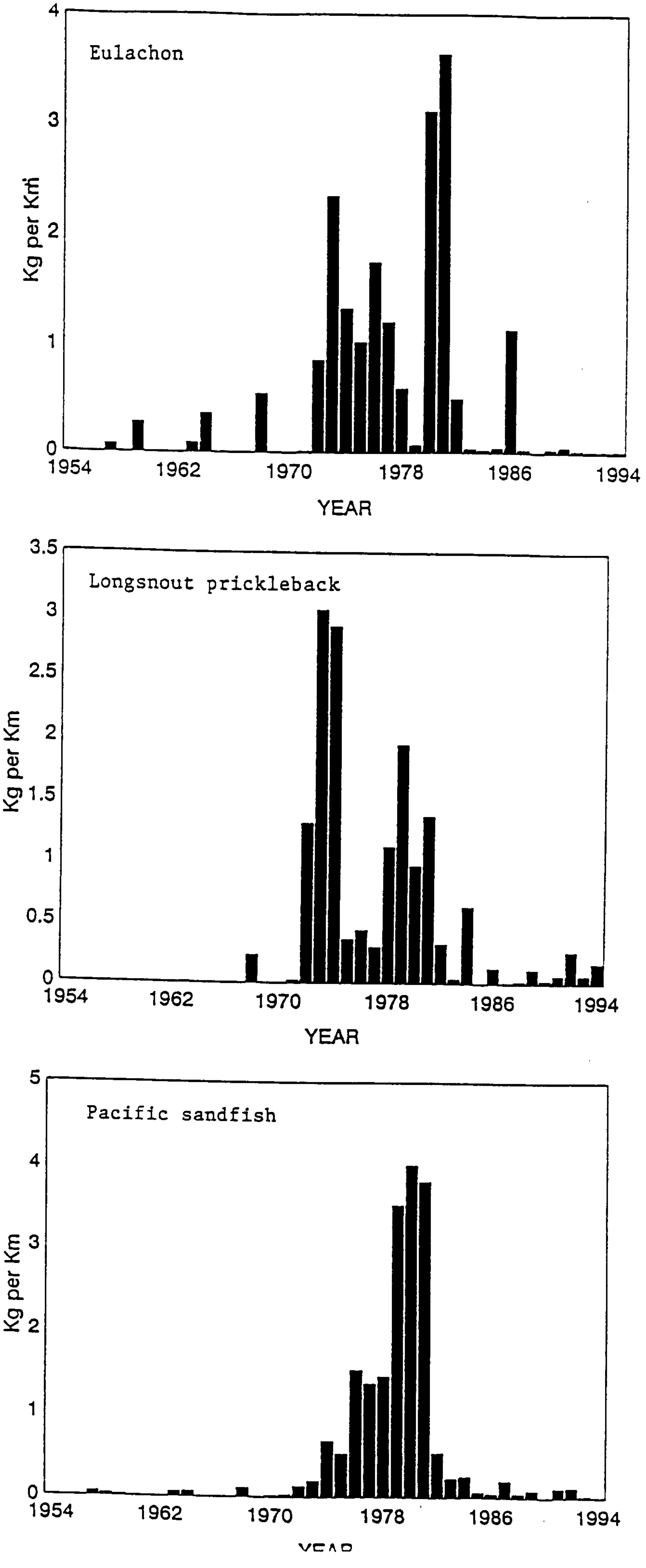


Capelin

Appendix L-17

Figure 6.Relative abundance of eulachon (top), longsnout prickleback (middle), and Pacific sandfish (bottom).

Figure 6


Eulachon
Kg per Km
0
1
2
3
4
1954
1962
1970
1978
1986
1994
YEAR
Longsnout prickleback
Kg per Km
0
0.5
1
1.5
2
2.5
3
3.5
1954
1962
1970
1978
1986
1994
YEAR
Pacific sandfish
Kg per Km
0
1
2
3
4
5
1954
1962
1970
1978
1986
1994

Appendix L-18

Figure 7. Relative abundance of Pacific cod (top), walleye pollock (middle), and a group of faltfish (bottom).

Figure 7

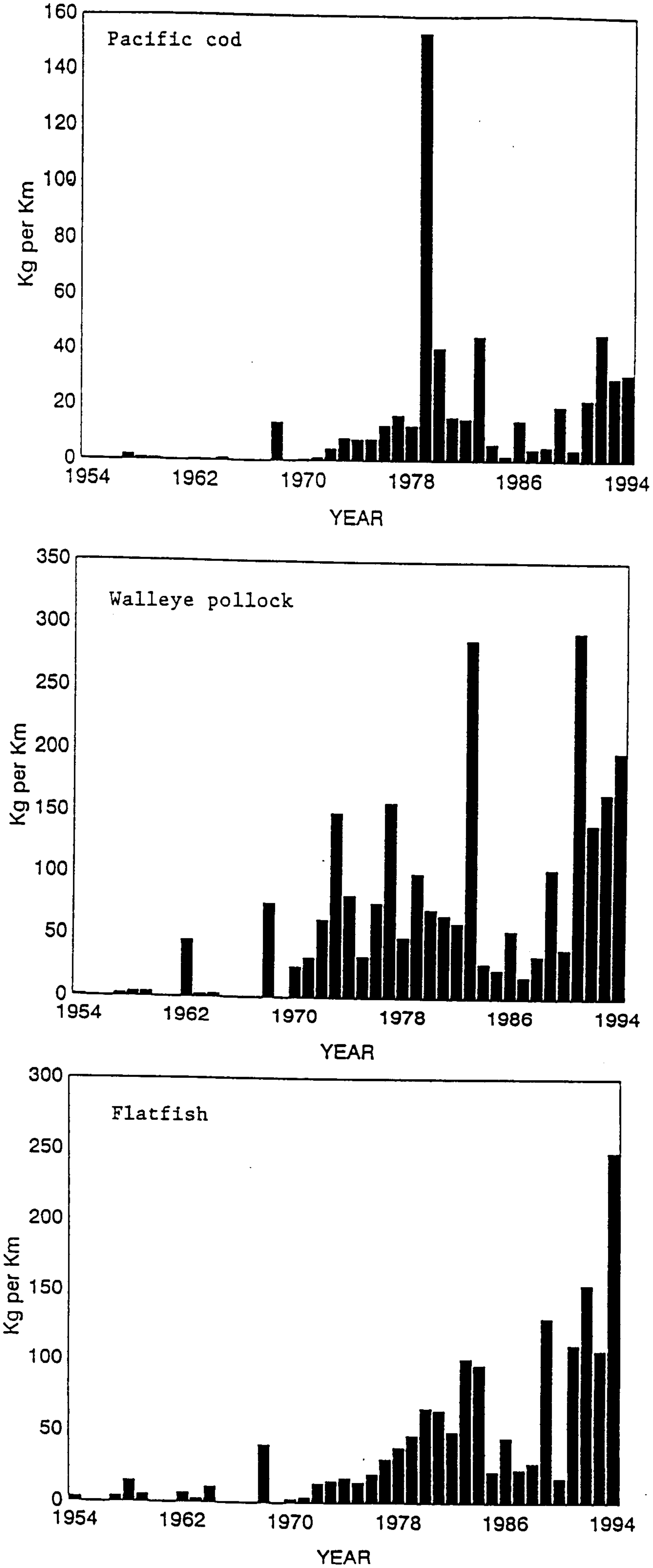

Pacific cod
Kg per Km
0
20
40
60
80
100
120
140
160
1954
1962
1970
1978
1986
1994
YEAR
Walleye pollock
Kg per Km
0
50
100
150
200
250
300
350
1954
1962
1970
1978
1986
1994
YEAR
Flatfish
Kg per Km
0
50
100
150
200
250
300
1954
1962
1970
1978
1986
1994
YEAR

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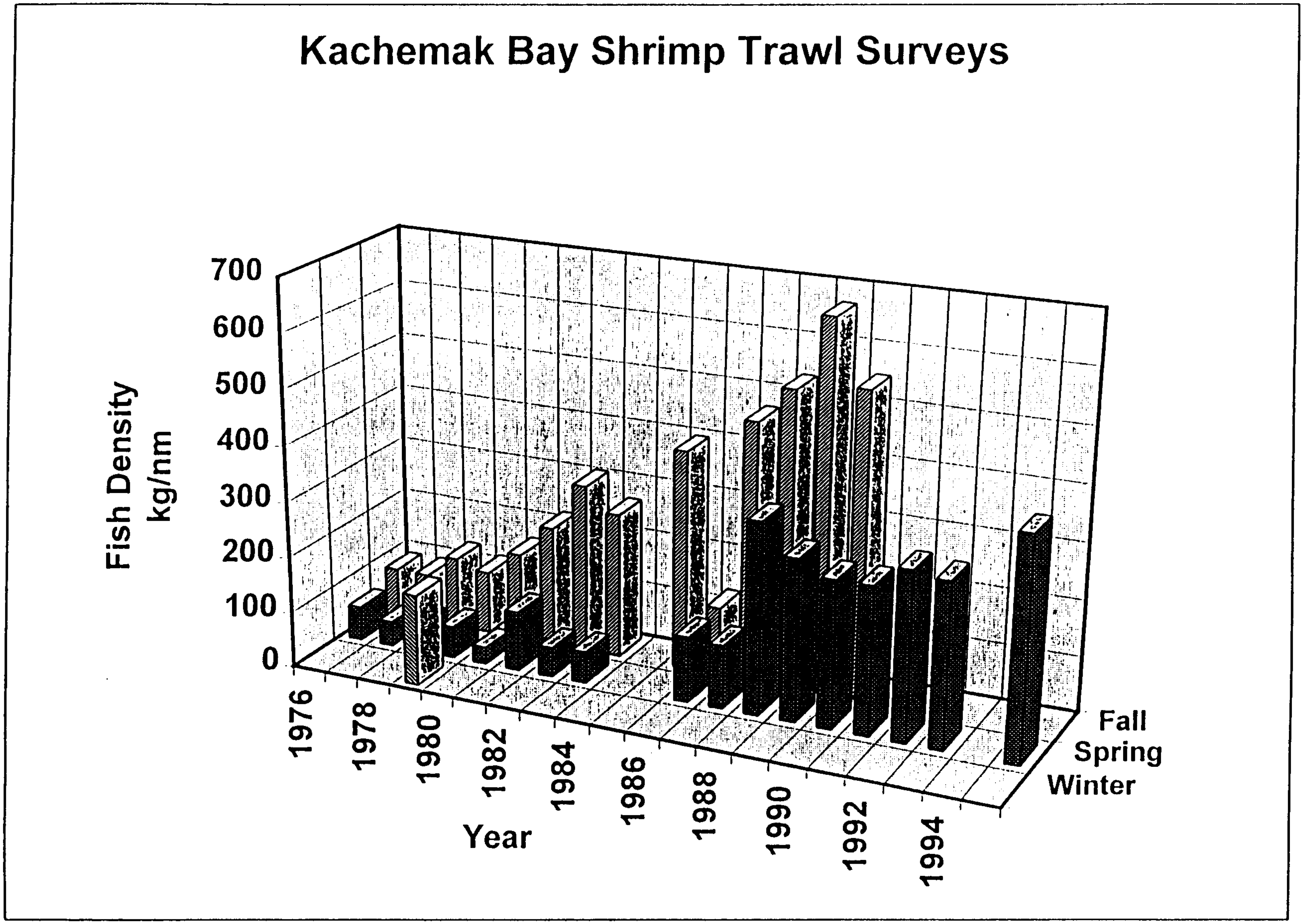
Figure 8. Fish catch (kg/km) in Cook Inlet trawl shrimp surveys from 1976 to 1995.

Figure 8



Fish catch (kg/nm) in Cook Inlet trawl shrimp surveys from 1976 to 1995.

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Table 1. Cruises by vessel that includes most small-mesh survey sampling as of 11/13/95 in NMFS database.

VESSEL	CRUISE	STARTDATE	ENDDATE	SURVEY TYPE	GEAR CODES
1	8104	08/31/81	09/14/81	SHRMP PAV	508
1	8404	08/29/84	08/30/84	SHRMP PAV	508
1	8405	09/04/84	09/12/84	Y OF YR	508, 507, 509
2	5301	03/10/53	04/07/53	SHRMP YAKUT	610
2	5401	02/26/54	04/06/54	SHRMP PR.WM	610
2	5402	07/13/54	09/08/54	SHRMP PR.WM	610
2	5801	07/22/58	08/26/58	SHRMP KODK	506
2	5902	10/14/59	11/11/59	SHRMP KENAI	506
2	7205	05/10/72	05/31/72	SHRMP KODK	516
2	8203	08/14/82	08/21/82	SHRMP KOD-PAV	508
2	8605	08/28/86	09/01/86	SHRMP PAV	508
2	8606	09/03/86	10/08/86	Y OF YR	508, 507, 305
3	8001	06/16/80	08/06/80	IPHC	751
3	8101	06/11/81	07/30/81	IPHC	751
4	7103	06/09/71	07/20/71	SHRMP KODK	514
4	7302	05/23/73	06/14/73	SHRMP KODK	508
9	6306	07/13/63	08/01/63	ROCK	761
14	7102	04/17/71	05/24/71	SHRMP KODK	516
14	7203	08/25/72	09/28/72	SHRMP SHUM	508
14	7305	08/29/73	10/23/73	SHRMP SHUM	508
14	7401	04/15/74	05/22/74	SHRMP KODK	508
14	7403	09/01/74	10/27/74	SHRMP SHUM	508
14	7501	04/01/75	05/22/75	SHRMP KODK	508
14	7503	09/07/75	10/31/75	SHRMP SHUM	508
14	7603	09/08/76	10/28/76	SHRMP SHUM	508
14	7704	08/21/77	09/23/77	SHRMP SHUM	508
14	7803	08/25/78	10/16/78	SHRMP SHUM/AL	508
14	7903	09/01/79	09/07/79	SHRMP PAV/AL	508
14	8003	08/12/80	09/16/80	SHRMP PAV/AL	508
15	7003	08/30/70	10/10/70	SHRMP KODK	510
21	9009	09/07/90	09/22/90	Y OF YR	507, 302
24	8201	06/11/82	07/17/82	IPHC	751
27	7801	06/18/78	07/06/78	SHRIMP/PLK	508
33	6202	08/21/62	10/02/62	SHRMP PR.WM	506, 512
33	6302	07/12/63	09/10/63	SHRMP PR.WM	506
34	6802	07/03/68	09/26/68	SHRMP KODK	506, 510, 605
37	8102	08/30/81	09/23/81	ADFG SHRMP	508
37	8302	08/11/83	08/12/83	SHRMP PAV	508
37	8502	08/12/85	08/15/85	SHRMP PAV	508
37	8503	08/21/85	09/09/85	Y OF YR	508
37	8702	08/05/87	08/08/87	SHRMP PAV	508
37	8703	08/13/87	09/19/87	Y OF YR	508
37	8802	08/10/88	08/15/88	SHRMP PAV	508
37	8803	08/18/88	09/10/88	Y OF YR	508
37	8902	08/18/89	08/21/89	SHRMP PAV	508
37	9002	08/09/90	08/16/90	SHRMP PAV/KOD	508
37	9102	08/19/91	08/21/91	SHRMP PAV	508

Table 1 Cont.

VESSEL	CRUISE	STARTDATE	ENDDATE	SURVEY TYPE	GEAR CODES
38	6402	08/13/64	09/04/64	SHRMP KODK	506
38	6402	06/16/64	09/15/64	SHRMP KODK	506, 512
41	8001	09/09/80	09/23/80	ADFG SHRMP	508
41	8101	09/03/81	10/03/81	ADFG SHRMP	508
42	8001	08/23/80	09/16/80	ADFG SHRMP	508
43	8001	08/23/80	09/05/80	ADFG SHRMP	508
43	8201	08/24/82	09/23/82	ADFG SHRMP	508
87	9202	08/09/92	08/13/92	SHRMP PAV	508
88	9302	08/04/93	08/06/93	SHRMP PAV	508
89	9402	08/04/94	08/06/94	SHRMP PAV	508
88	9502	08/05/95	08/09/95	SHRMP PAV	508
620	5702	09/06/57	09/30/57	SHRMP SHUM	506
620	7801	06/23/78	08/17/78	IPHC	751

GEAR CODES:

305 --Marinovitch mid-water; 32 mm mesh.
506 --Gulf Shrimp Trawl; 38 mm mesh.
507 --High-opening Shrimp Trawl; 32 mm mesh.
508 --High-opening Shrimp Trawl; 32 mm mesh.
509 --High-opening Shrimp Trawl; 32 mm mesh.
510 --Kodiak Shrimp Trawl; 32 mm mesh with 19 mm mesh liner
512 --Gulf Semi-balloon Shrimp Trawl; 38 - 41 mm mesh.
514 --Kodiak Shrimp Trawl; 32 mm mesh with 19 mm mesh liner.
516 --Nordby Shrimp Trawl; 32 mm mesh.
610 --Beam Trawl; 32 mm mesh.
751 --INPHC Samll-mesh Trawl; 32 mm mesh.
761 --Semi-balloon Shrimp Trawl; 38 mm mesh with 13 mm mesh liner.

Table 2. Structure for haul table in NMFS and ADF&G small-mesh database.

NMFS Field	Field Name	Type	Width	Decimals	Definition
1	CRUVESHAL	Numeric	12		Identification
2	THEREGION	Character	3		Region Code
3	VESSEL	Numeric	4		Vessel Code
4	CRUISE	Numeric	4		Cruise Number
5	HAUL	Numeric	4		Haul Number
6	HAULTYPE	Numeric	4		Haul Type Code
7	PERFORMANC	Character	2		Performance Code
8	STARTDATE	Date	8		Date of Haul
9	STARTHOUR	Numeric	4		Time of Haul
10	DURATION	Numeric	7	3	Duration Time
11	DISTANCE	Numeric	8	4	Distance Kilometers
12	NETWIDTH	Numeric	7	3	Net Width Meters
13	NETMEASURD	Character	2		Measurement Code
14	NETHEIGHT	Numeric	7	3	Net Height Meters
15	STRATUM	Numeric	4		Stratum Code
16	STARTLAT	Numeric	10	6	Starting Latitude
17	ENDLAT	Numeric	10	6	Ending Latitude
18	STARTLON	Numeric	11	6	Starting Longitude
19	ENDLON	Numeric	11	6	Ending Longitude
20	STATIONID	Character	10		Identification
21	GEARDEPTH	Numeric	6		Gear Depth Meters
22	BOTTOMDEPT	Numeric	6		Bottom Depth Meters
23	BOTTOMTYPE	Character	3		Bottom Type Code
24	SURFTEMP	Numeric	5	1	Surface ^{0}C
25	GEARTEMP	Numeric	5	1	Gear ^{0}C
26	WIRELENGTH	Numeric	7		Trawl Warp Meters
27	GEAR	Character	4		Gear Code
28	ACCESSORIE	Character	3		Gear Accessory Code
29	SUBSAMPLE	Character	2		Subsample Code

ADFG No.	Column Name	Attributes	Definition
1	Cruise	INTEGER, Index:MULTI-COLUMN	Cruise Number
2	Haul	INTEGER, Index:MULTI-COLUMN	Haul Number
3	Region	INTEGER	Region Code
4	Area	INTEGER	Area Code
5	Stratum	INTEGER	Stratum Code
6	Station	TEXT 4	Station Code
7	Vessel	TEXT 2	Vessel Code
8	Dateup	DATE	Date
9	LatDeg	INTEGER	Start Latitude
10	LatMin	REAL	"
11	LongDeg	INTEGER	Start Longitude
12	LongMin	REAL	"

13	TowHeading	INTEGER	Heading Degrees

Table 2. Structure for haul table in NMFS and ADF&G small-mesh database. CONT.

ADFG Cont.

No.	Column Name	Attributes	Definition
14	StartHaul	TIME	Start Time
15	EndHaul	TIME	End Time
16	Minutes	INTEGER	Duration Time
17	Distance	REAL	Distance Naut. Mi.
18	Loranx	INTEGER	Loran Position
19	Lorany	INTEGER	"
20	DepthMax	INTEGER	Maximum Depth Fm
21	DepthMin	INTEGER	Minimum Depth Fm
22	Weather	TEXT 3	Weather Code
23	Scope	INTEGER	Trawl Warp Fathoms
24	Perform	INTEGER	Performance Code
25	DepthAvg	INTEGER	Average Depth Fthms
26	Temperature	REAL	Gear Temperature ?C
27	Latitude	REAL	End Latitude
28	Longitude	REAL	End Longitude
29	The Area	TEXT 4	Area Code

Table 3. Structure of catch table in NMFS and ADF&G small-mesh database.

NMFS

Field	Field Name	Type	Width	Decimals	Definition
1	CRUVESHAL	Numeric	12		Numeric ID
2	THEREGION	Character	3		Region Seperator
3	VESSEL	Numeric	4		Vessel Code
4	CRUISE	Numeric	4		Cruise Number
5	HAUL	Numeric	4		Haul Number
6	SPECIES	Numeric	10		Species Code
7	WEIGHT	Numeric	12	4	Weight Kg
8	NUMBERS	Numeric	7		Number Caught
9	SUBSAMPLE	Numeric	2		Sub-sample Code

ADFG

No.	Column Name	Attributes	Definition
1	Cruise	INTEGER	Cruise Number
2	haul	INTEGER	Haul Number
3	region	INTEGER	Region Code (Different than NMFS)
4	area	INTEGER	Area Designator
5	spcode	INTEGER	Species Code (Same as NMFS)
6	catchlbs	INTEGER	Weight Pounds
7	lbseach	INTEGER	Number Caught

Table 4. Rank order by weight of species and species groups caught in NMFS small-mesh surveys 1953 to 1994 in the Gulf of Alaska (Partial listing).

Species Name	Total Weight
Pandalus borealis	579290.6243
Theragra chalcogramma	461348.0636
Hippoglossoides elassodon	127052.4604
Gadus macrocephalus	93530.7165
Scyphozoa (class)	89143.0956
Pandalus goniurus	84706.3639
Atheresthes stomias	54169.9554
Pandalopsis dispar	52019.9269
Pleuronectes asper (prev. Limanda aspera)	45522.9413
Chionoecetes bairdi	20388.2346
Pandalus hypsinotus	19428.4267
Paralithodes camtschatica	18234.4558
Hippoglossus stenolepis	14911.9423
Hemilepidotus jordani	12287.4737
Pleuronectes bilineatus (prev. Lepidopsetta bilineata)	11816.2032
Mallotus villosus	11301.6434
Myoxocephalus sp.	9363.9947
Thaleichthys pacificus	8785.2017
Lycodes brevipes	8717.7221
Trichodon trichodon	7750.9781
Anoplopoma fimbria	7735.5310
Clupea pallasi (=Clupea harengus pallasi)	6205.9402
Lumpenella longirostris	5376.1010
Starfish unident.	5028.5994
Microgadus proximus	4954.5920
Myoxocephalus polyacanthocephalus	4816.4318
Ophiuroid unident.	4451.8761
Cottidae	3805.1354
Chionoecetes tanneri	3242.5600
Crangonidae (family)	3241.7790
Platichthys stellatus	3027.6931
Zoarcidae	2905.3840
Sebastes alutus	2875.0132
Chionoecetes sp.	2813.5810
Shrimp unident.	2352.5960
Dasycottus setiger	2166.7533
Cancer magister	2137.0568
Rajidae unident.	1967.5116
Psettichthys melanostictus	1944.2313
Asterias amurensis	1851.8155
Myoxocephalus jaok	1807.6141
Isopsetta isolepis (=Pleuronectes isolepis)	1737.5801
Pleuronectes quadrituberculatus	1597.1843
Porifera	1588.5310
Argis dentata	1456.5558

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Lumpenus sagitta	1430.0163
Pandalus jordani	1396.2030

APPENDIX L

APEX: 95163 L

Appendix L-1

APEX: 96163L

SYNTHESIS AND ANALYSIS OF GULF OF ALASKA SMALL-MESH TRAWL DATA: 1953 to 1995

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ABSTRACT

Large declines of apex predator populations (murres, kittiwakes, harbor seals, and Steller sea lion) have occurred in the Gulf of Alaska since the 1970s. Changes in the composition and abundance of forage species may be responsible for the decline of these predator populations. In an effort to delineate changes in the trophic regime and forage species, if any, over the last several decades, we have gathered together scientific survey data covering a long time span and large area. This report includes a preliminary historical review of information and data from small–meshed trawl studies conducted in the Gulf of Alaska by the Alaska Department of Fish and Game and the National Marine Fisheries Service and its predecessor agencies from 1953 through 1995. Over 10,000 individual sampling tows are in the current database of the two agencies (ADF&G — 5,836; NMFS — 4,352). For preliminary analysis, the entire region sampled was divided into six sub–areas representing geographical, oceanographic, and biological domains. Where possible, the occurrence and relative abundance of five major species or species groups was studied to detect change in the forage ecosystem over the four decades of past sampling with small–mesh trawls and beam trawls.

Appendix L-2

INTRODUCTION

This report provides a historical review of small–mesh trawl sampling results from near–shore surveys in the Gulf of Alaska conducted by the National Marine Fisheries Service (NMFS) and the Alaska Department of Fish and Game (ADF&G). The data for analysis was collected starting in 1953 and continues to 1995. In this report we discuss the methodology of data collection and how it changed through the years. The nature of the survey areas are discussed. A preliminary analysis is presented along with discussion of analytical procedures and assumptions.

Recently there has been information presented that the Gulf of Alaska ecosystem has undergone some abrupt and significant changes (Piatt and Anderson, 1995). The extent and degree of these changes is poorly documented and is important in determining future strategies for management of the marine ecosystem. Analysis of the historic data is a first step in gaining an appreciation for the rapid and abrupt changes that have occurred in the marine species complex in the last five decades. The data from small–mesh shrimp trawl cruises provides an opportunity to review changes in the composition of forage species that occurred through time in the Gulf of Alaska.

Historically, there is evidence of major abundance changes in the fish/crustacean community in the western Gulf of Alaska. Fluctuations in Pacific cod availability on a generational scale was reported for coastal Aleutian communities by Turner (1886). Similarly, landings from the near–shore Shumagin Islands cod fishery (Cobb, 1927) showed definite periods of high and low catches with the fishery peaking in late 1870s. King crab commercial catches in the Gulf of Alaska show two major peaks of landings, one in the mid 1960s and another in 1978–1980 (Blau, 1985). All of the area was closed to fishing in response to low population levels in 1983 (Blau, 1986) and has yet to reopen. By the 1960s there was evidence of high pandalid shrimp abundance in these same areas (Ronholt 1963). One of the highest densities of pandalid shrimp known in the world was to spur the development of a major shrimp fishery (Anderson and Gaffney, 1977). By the late 1970s the shrimp population density had declined radically and was accompanied by a closure of the shrimp fishery and the return of cod to inshore areas (Albers and Anderson, 1985). Catches of almost all salmon stocks of Alaskan origin suddenly increased to unprecedented levels in the 1980's (Francis and Hare, 1994, Hare and Francis, 1995). These changes, witnessed over the last century, imply dynamic fluctuations in abundance of commercially fished species. Managers, fisherman, and processors should be aware of these dynamics and their impacts on the ecology and economy.

Evidence from long–term small–mesh trawl surveys in the Gulf of Alaska imply that a number of non–commercial species also have undergone significant change in abundance during the past 25 years. Major groups of species nearly disappeared or have become virtuallyextinct in some areas and demonstrate that huge changes have occurred in the near–bottom species complex. The abrupt decline of species that have never been commercially harvested in the Gulf of Alaska such as capelin, Pacific sandfish, and certain species of Lumpenella suggest that fishing pressure is not entirely to blame for the changes which have occurred. Based on the results obtained from the longest continually conducted trawl survey series (Piatt and Anderson, 1995) have lead to the recognition that the entire small–mesh trawl survey data collected as far back as possible be used to put a historical perspective on these changes and give direction to future research. With these ideas in mind, we have assembled and are continuing to assemble, data from small–mesh surveys in order to help understand the ecological dynamics of this abrupt change in the ecosystem.

Area of Coverage

The study area includes the continental shelf (0 – 200 m.) and upper slope (201 – 400 m.) from 144^0 W. longitude (in the vicinity of Kayak Island) westward to 168^0 W. longitude (vicinity of

Unalaska Island, eastern Aleutians). This area is characterized as having a relatively broad shelf which is punctuated with numerous islands, separated by deep gullies and large inlets, sounds, and fjords. Most of the data was collected in trawlable locations associated with the numerous gullys and bays that are associated with this bathymetry.

The area of coverage for the entire historical data set was divided into regions based on three guiding principles. First, areas within geographic proximity were included as groups taking into account the sampling coverage through the time series. If gaps in sampling were evident in geographic plots of the data then these were frequently used as rational for dividing the area. Second, general knowledge of the biological regimes in each area were also used as guides when defining areas for analysis. Third, oceanographic domains were used when knowledge of these domains was known. Based on the above principles the entire area covered was divided into 6 regions (Figure 1) for analysis of time series data. A description of each of the sub–areas follows.

1. Prince William Sound — Includes area west from Kayak Island to the vicinity of Cape Puget and includes all offshore sampling on the adjacent shelf area. A prominent gully intersects the shelf running from the head of Prince William Sound between Montague and Hinchinbrook Islands. A large reef area, Wessels Reef is located between Hinchinbrook and Middleton Islands. Bottom sediments in the area include soft mud, firm mud, mud with boulders, gravel and rock. Because large portions of the survey area are covered with rocky substrate, much of the area is unsuitable for sampling by trawls.

2. Kenai — Includes the region along the outer Kenai coast from the vicinity of Port Graham north and east along the coast to vicinity of Cape Puget. This area is influenced by Alaska CoastalCurrent (Reed and Shumacher, 1986). This area is also characterized by rocky areas which hinder trawl sampling in some areas.

3. Lower Cook Inlet — Includes areas north of Cape Douglas north of the a line drawn beneath the Barren Islands and intersecting with the coast near Chugach Passage. This area includes all waters of Kachemak and Kamishak Bays. This area has extremely limited flow of northern Gulf water into lower Cook Inlet (Hood and Zimmerman, 1986).

4. Kodiak — Includes all of the bays along the eastern side of the Kodiak Island group to south of the Barren Islands. This area is characterized by wind driven oceanic regime and under the direct influence of the Alaska Stream (Favorite et al., 1976).

5. Shelikof— The Shelikof region includes all waters north of Castle Cape and a line drawn to Chirikof Island and thence a line drawn to the southern tip of Tugidak Island in Trinity Island group. The region includes the bays along the western side of Kodiak Island including Alitak, Uganik, and Uyak Bays. The region also includes the bays from Chignik northeast along the Alaska Peninsula to Cape Douglas. The major oceanic feature in this area is the extreme tidal flow out of Cook Inlet and the strong winds that blow up and down the strait.

6. Shumagin — The Shumagin region encompasses the area from Unimak Island in the eastern Aleutians along the south side of theAlaska Peninsula in a northeasterly direction to Castle Cape. The area includes major embayments and straits associated with the Shumagin Island, Pavlof Island, and Sanak Island groups. The area includes Pavlof Bay the site of the longest continually conducted trawl survey in the entire Gulf of Alaska. The area also includes bays associated with Unalaska Island.

Time Series Description

The earliest sampling by small mesh gear in the Gulf of Alaska probably dates to the 1891 when the steamer RV Albatross conducted a cruise on the general biology of the Gulf of Alaska (Harriman Expedition, 1910). Small mesh studies directed at defining commercial quantities of shrimp were initiated in 1950 by the Bureau of Commercial Fisheries, the shelf region from Ketchikan to Unalaska Island was sampled in the period 1950–1957 (Ronholt, 1963). The series continues with the systematic collection of shrimp surveys that started in the GOA in 1970. In response to information needed to manage the rapidly expanding shrimp fishery both NMFS and ADF&G adopted survey methodology that was similar (Anderson and Gaffney, 1977).

Since 1971 both agencies have used the same high opening sampling gear and similar sampling methodology. Figure 2 shows the total number of tows in the data sets for each agency.

METHODS

Gear

Small–meshed sampling gears used during the studies are summarized below in Table 1. Basically, all small mesh gear was deemed to fit in this category if it was used for shrimp surveys. Also included for analysis were hauls conducted by the International Pacific Halibut Commission (IPHC) when small mesh liners were added to their standard sampling gear. Almost all of the small mesh tows of ADF&G and NMFS since 1971 have been conducted with the same sampling gear the 61' high–opening shrimp trawl. This gear as described by Wathne, 1977 is designed to sample the water column from .4 to 5 meters above the sea floor and has an opening of approximately 10 m wide.

Catch and Sample Handling

The surveys were designed to sample shrimp (biomass) abundance, however other benthic and pelagic species were quantified by weight and, in later years, by numbers as well. Seasonally, during the survey months dense aggregations of pandalid shrimp form in relatively deep water prior to mating and spawning (Anderson 1991). Earlier surveys had shown that shrimp concentrate in depths greater than 70 m (Ronholt 1963, Anderson, 1991). As a consequence, all survey tows were restricted to depths greater than 55 m in years after 1970 in order to adequately target primarily on shrimp.

Stations were sampled during daylight using a 50 to 32 mm mesh trawls. Tow duration was approximately 30 minutes; average tow length for the forty years (NMFS database) being 2.1783 km with a standard deviation of 0.463. Index of biomass estimates are conservative for the small species because small animals are not fully vulnerable to capture (Anderson, 1991)

Survey catches were sorted by species and all species were weighed separately. Occasionally catches were so large that sub–sampling of the catch was employed after the method described by Hughes, (1976). Subsamples were counted to obtain the average weight of individuals. All shrimp, juvenile fish (mostly pleuronectidae) were combined, weighed, and subsampled for species composition. The subsampled species groups were then counted and weighed using an triple–beam scale to the nearest gram. The extrapolated weights of each species were added to those of the adults of the same species.

Level of Species Sort

In the early years 1953 – 1962 only primary commercial species were enumerated, usually the top four or five species in a catch were recorded. Gradually as the surveys were designed to provide more useful information to a broader user group, catch sort and information collected was improved. Since 1970 everything in survey catches has been sorted, identified to the lowest possible taxon, weighed, and enumerated.

Data Structure

Two general data tables are used in the small–mesh sampling database. The haul table structure is given in table 2. Generally the haul table contains details on the location, time, depth, temperature, and gear type employed for a given sampling. The catch table structure is given in table 3. The catch record contains a species code usually identified to the lowest taxon possible, the total weight of the species caught and the number of individuals of the subject species.

Data Limitations

Fishes and invertebrates observed during these small–mesh surveys and the relative importance of species and species groups within the areas surveyed is largely a function of the sampling gear deployed. Trawls, as most sampling apparatus, employed to sample marine biota, are selective. Sizes and even species of fish captured are influenced by the mesh size used, particularly that in the end of the net or cod end. Species within the size range which theoretically would be retained if engulfed by the trawl, may differ substantially in their ability to escape through the mouth of the trawl or avoid capture altogether. The selective features of trawls thus alter the observed species composition and size frequencies which occur in the swept sampling area. The degree to which the "apparent" distribution and abundance differ from the actual is unknown. Therefore it is important to note thatsubsequent discussion in this report will deal with distribution and relative abundance obtained with the small mesh sampling gears used during the time period. The estimates presented and trends observed are representative only for those species, and sizes of species which are vulnerable to the trawl (Alverson et al., 1964).

Some of the earlier collected data does not have good position information represented in the on–line data sets, however original working charts and copies of them are available. If further funding is available these on–line data will be upgraded for future use by other investigators and will also increase the accuracy of historic catch–per–unit of effort values for important species in the time line analysis.

RESULTS

Species Occurrence and Composition

In general, preliminary results from the analysis of the entire trawl survey data set showed a change, beginning in the late 1970's, from catches being dominated by shrimps to a swift and abrupt change to higher fish proportions in catches. Coincident with changes observed in the composition of survey catches dramatic declines in the commercial fisheries for shrimp and later crab also indicated drastically smaller landings and closures of these fisheries. Just as quickly, fisheries for pollock and cod were beginning to increase in importance and catch levels. These changes witnessed during the past two decades show no sign of reverting tothe crustacean dominated fishery regime.

In all, over 411 species and specie groups were identified in survey samples from 1953 to 1994 in small–mesh trawl survey sampling. Ranking these species by total catch weight in the data base gives the relation of species occurrence in the data set (Table 4). Not surprisingly, several shrimp species are well represented in the top rankings. In addition to several shrimp species many other important forage species are represented in the top 20 entries on the rank order list. Among those that are of principle interest in this study are; capelin, sandfish, pollock, eulachon, cod, and possibly jellyfish (Scyphoza).

The focus of this study is directed towards the relative abundance and distribution of the five species mentioned above and a group of flatfish species. Many of the principle study species are true forage species such as capelin, sandfish, and eulachon. Many others serve a dual role acting as forage when juveniles and then becoming predators as they grow. Examples of this later group are cod, pollock, and flatfish. One of the declining species that has been studied is the longsnout prickleback which may be an important forage species only during its juvenile phase. Other species, including jellyfish, are probably indicators of productivity changes in the environment and their distribution and relative abundance will be studied as well.

Changes in Forage Species Abundance and Distribution

Capelin

Capelin are primarily planktivores with a relatively short life span. Their abundance is highly variable from year to year and is linked to zooplankton availability and to the feeding influence of their competitors or predators (Gerasimova, 1994). Capelin play a key role in the trophic interaction of species, transferring energy from primary production to higher level predators, including cod, marine mammals, and birds.

Data from shrimp cruises in the Gulf of Alaska starting in 1953 and continuing to the present showed no capelin present in catches prior to 1963. A possible reason for this observation may be explained by survey techniques which ignored "non–commercial" species in the early years when the emphasis was entirely directed toward commercial species. A review of what written material that still remains from these tows revealed that species were simply identified as "smelt" in the early data sets. We believe that many of these records most undoubtedly refer to capelin and eulachon since both of these species have high occurrences in the entire data set. Unfortunately we have no way of telling for sure, except that they are in the family Osmeridae. With the advent of MARMAP program in the early 1970's a more through approach to analyzing catch components in surveys was adopted. In the analysis of the data the year 1970 is useful as a baseline for comparison purposes due to this weakness in the data. Occurrences of capelin between 1963 and 1970 will be used in analyzing distributional patterns only.

Capelin showed two peaks in abundance since 1970 in the GOA Figure 3 (top). The first peak in abundance occurred in 1974 at little over 4 kg/km in survey catches. The second peak in relative abundance was in 1980 at 7.22 kg/km. In 1980 and 1981 the catch rates dropped to around 1 kg/km and has remained below a tenth of a kg/km since 1985. ADF&G data also clearly shows the peak value of 1980, mostly represented in the Kodiak region Figure 3 (bottom). The peaks in relative abundance observed in the mid 1970's and at the late 1970's and 1980 probably reflect strong cohorts or year classes of capelin during those times. Unfortunately data prior to 1970 frequently lacked specificity as discussed above so accurate trends in the data prior to 1970 cannot be assessed.

Mapping of relative densities of capelin showed defined areas of relative high abundance. The Shelikof region showed relative high catches in Kujulik, Alitak, and Olga Bays. Most catches of capelin were closely associated with bays with the exception of high catches offshore of Cape Ikolik at the southwest end of Kodiak Island Figure 4. Isolated offshore areas east of Kodiak Island showed some high catches, most of the high catches were associated with Ugak and Kazakof Bays (Figure 5; bottom). Only isolated catches of less than 50 kilograms were evident in the database from Prince William Sound, Kenai Coast, and Lower Cook Inlet regions (Figure 5 top). More detailed analysis of these areas of historical high relative abundance will be analyzed in the future.

Eulachon

Eulachon showed a peak in abundance in 1981 with an abrupt decline thereafter. Another subsequent peak in abundance at over 1 kg/km occurred in 1986. Since 1987 eulachon has remained at a low level of relative abundance in the data (Figure 6 top). Eulachon are known to be relatively abundant in areas adjacent to spawning rivers. Subsequent analysis will rely on mapping to better define areas of relative high abundance and abundance trends in those areas.

Longsnout Prickleback and Pacific Sandfish

Longsnout prickleback and the Pacific sandfish were two non–commercial species that showed decreased abundance in the 1980's. Longsnout prickleback abundance was variable showing a peak abundance in 1973 and a subsequent decline and increasing to a lesser peak in 1979 (Figure 6 middle). The abundance of longsnout pricklebacks has remained relatively low since 1984. Pacific sandfish peaked in abundance in 1980 and subsequently declined to relative low abundance since 1982 (Figure 6 bottom).

Juvenile and Adult Gadoids

Walleye pollock are pelagic throughout their life. Young–of–the–year occur in the upper 100 m and older juveniles are found down to 400 m. Adult fish are usually found in the upper 300 m in the water column. Pollock undergo diel vertical migration in thewater column, coming off bottom during darker periods of the day and settling down to near bottom depths during the brighter periods. Seasonal movements of fish also occur with movement offshore during the winter and returning inshore during the spring were they remain through the late summer and fall. Pollock are known for forming large pelagic spawning schools in the late winter and spring period. One of the most important areas for this mass spawning is the Shelikof Strait. Walleye pollock feed mostly on free–swimming pelagic animals. Juveniles and small adults feed on euphasids, copepods, amphipods, and isopods. Larger fish feed primarily on euphasids and pollock. Pollock are preyed on by pinnipeds, cetaceans, diving birds, and larger fishes.

Pacific cod are considered a demersal species along the continental shelf of the GOA from inshore to the upper slope. During the winter and spring cod concentrate in the gullys and canyons that cut across the shelf. Most spawning occurs in late winter to early spring at depths of 150 –200m. In summer they move to shallower depths of usually less than 100m. Pacific cod are a fast–growing and short–lived species attaining a maximum age of 10 to 13 years. Juveniles feed on benthic amphipods and worms, adult fish feed on crabs, shrimp, benthic and pelagic fishes. Pacific cod are preyed on by Pacific halibut and some cetaceans.

Pollock and Pacific cod abundance was highly variable but showed a trend to general overall higher relative abundance through the time series (Figure 7 top and middle). An unusually strong peak in cod abundance occurred in 1979. Recent data suggest an overall lower level of abundance averaging around 21 to 45 kg/km since1991, these values are much higher than those prior to 1975. Pollock exhibit several peaks in abundance 1973, 1977, 1979, 1983, 1989, and relatively high sustained abundance since 1991. The peak abundance in 1991 is the highest recorded in the data series at nearly 300 kg/km.

Flatfish Complex

The flatfish complex comprised of five pleuronectid species, arrowtooth flounder, flathead sole, yellowfin sole, rock sole, and Pacific halibut are all considered demersal species with varying depth ranges, but all are commonly found in the entire study area. Arrowtooth flounder and Pacific halibut are usually found over a broader depth range 100 – 500m than the other species. All spawn on or near the bottom with arrowtooth and Pacific halibut spawning during the winter and the other species spawning during the spring. The small–mouthed soles (rock and yellowfin) feed primarily on detrital–consuming invertebrates, polychaete worms, clams, amphipods, shrimp, snails, and brittlestars. Flathead sole are primarily benthic feeders but also feed on small nektonic animals such as shrimp, herring, and smelt. Arrowtooth feed primarily on nektonic prey. Halibut feed primarily on fishes, crabs, and other invertebrates.

A group of five pleuronectid species, arrowtooth flounder, flathead sole, yellowfin sole, rock sole, and Pacific halibut showed an almost continual increase in the data series from 1970(Figure 7 bottom). These trends are different than any of the other species groups studied. Questions yet to be answered revolve around the possibility of inshore migration of species and possible displacement or competition with other species groups.

Shrimp

Recent declines in shrimp abundance throughout the Gulf of Alaska have mirrored the decline of other species as well (Piatt and Anderson, 1995). Caredian shrimp of four major families; Pandalidae, Crangonidae, Hippolytidae, and Phasapheidiae occupy an important niche in the pelagic realm in Alaskan waters. There is a long history of commercial harvesting of several species in the Pandalidae family in the Bering Sea and Gulf of Alaska, no known harvests of members of the other families has occurred. Most of the available biological information in Alaskan waters relates to the commercially important shrimps in the family Pandalidae. With out exception Pandalid shrimps have declined in the entire central and western GOA. One species, the humpy shrimp, which was second in relative abundance to the northern pink shrimp has become nearly extinct since the late 1970's.

Commercially important pandalid shrimp first hatch as larvae in the spring (April) through early June. Shrimp larvae remain in near–surface waters until undergoing metamorphosis to the juvenile phase and settle into a semi–benthic existence. Pandalid shrimp are protandric hermaphrodites maturing first as males and thenundergoing a transformation to female depending on growth rate of the individual (Charnov and Anderson, 1989). Massive swarms of shrimp take part in diel migration up into near surface water at night to feed. During daylight shrimp are mostly near bottom. Females which bear eggs on attachments to the pleopods after spawning do not actively migrate up in the water column until after eggs hatch.

Shrimp are a major food item for important commercial fish species, birds and marine mammals. Albers and Anderson (1985) found that pandalid shrimp were a dominant food item by frequency of occurrence (63%) in Pacific cod diet in Pavlof Bay. Jewett (1978) and Hunter (1979) found significant amounts of shrimp in cod taken from offshore areas but not as high as that found in inshore populations. Shrimp are also important in the diet of almost all fishes where they co–occur with shrimp. Shrimp larvae and juveniles are preyed on by pink, sockeye and coho salmon, sand lance, walleye pollock, longfin smelt, surf smelt, juvenile great sculpin, starry flounder, and rock sole taken from near–shore samples (Blackburn et al., 1983). MacDonald and Peterson (1976) report shrimp in the diet of Beluga whales, Steller's sea lion, and harbor seal. Hatch et al. (1978) reported glacous–winged gulls, kittiwakes, and tufted puffins preyed on shrimp. Shrimp therefore are a major forage species that is an important source of food when available.

CONCLUSIONS ON SPECIES' CHANGES IN RELATIVE ABUNDANCE

During the late 1970's to early 1980's an abrupt reorganization of species groups occurred in the demersal ecosystem in the Gulf of Alaska. A crustacean dominated species complex abruptly declined while round and flatfishes uniformly have increased over a short span of time in the late 1970's and early 1980's (Piatt and Anderson, 1995). Commercially fished crustaceans both of shrimps and crabs have declined to very low levels and the fisheries have remained closed for many years (Blau, 1986; Anderson, 1991). Pollock and Pacific cod abundance is variable probably due to influxes of strong year–classes but in a general up trend. Strong year–classes of cod moved into inshore areas in the late 1970's where they had been absent before. This influx of predators is responsible for the initial decline of many species (Albers and Anderson, 1985). Five species of pleuronectids have been in a general up trend from beginning of the 1970's, increasing to the highest recorded level in 1994. In turn many non–commercial species such as capelin, eulachon, longsnout prickleback, and Pacific sandfish declined and have remained in relative low abundance similar to that experienced by the crustacean populations. These general trends may obscure the effects of distributional patterns that may have also changed during the time period. Future studies will concentrate on changes by mapping distribution patterns and define trends in isolated areas were persistent populations of forage species occur.

Seasonal Component

A review of the data reveals that the most consistent time series are usually those taken from the late–summer and fall periods. An example is the data from Kachemak Bay which showed much more variability in the spring or early summer than the fall or late–summer period (Fig 8). This is probably not a function of this one single location. It was found that late–summer/fall sampling period was beneficial for the sampling of in–shore bays in the western GOA (Anderson, 1991). The reason for this is not enterly clear however the fall period is the time of year when spawning aggregations of shrimp form prior to matting and spawning, it is also the period of maximum bottom temperature for these areas. It could be that a stable temperature regime as found during this time period also leads to stability in the fish populations as well. Future analysis will focus on this apparent relationship.

FUTURE DIRECTION OF RESEARCH AND ANALYSIS

1. Monitor critical forage species

Capelin

Monitor known spawning beaches for eggs and larvae. Much easier than sampling for the adults (Mangel and Smith, 1990). An indication of shoal spawning of capelin in the GOA is illuded to in this study, this deserves further investigation.

Predator stomach sampling, including birds, mammal and fishes. Continuation of hydroacoustic and trawl surveys in areas ofdemonstrated high historical abundance.

Eulachon

Monitor spawning rivers for abundance, probably concentrate on larval out–migration indexing.

Sandlance

Monitor spawning beaches after late–summer inshore migration.

Predator sampling conducted on selected species, index on frequency of occurrence. Trawl surveys inadequate but hydroaccoustic surveys may prove viable for estimating abundance of inshore migrating schools in late summer. Surface tow nets are also a possible sampling tool for inshore migrating schools and offshore migrating larval fish.

Shrimp

Monitor selected bays where shrimp densities were high during the crustacean regime era. Pay particular attention to recovery of near–extinct shrimp species.

2. Compile complete integrated database which combines all elements of each data set to provide a database for more complete analysis.

3. Creating a geographic information system (GIS) on forage species for the GOA that can be used by other researchers and serve as a repository for future data collection.

4. Spatial analysis of historic data to analyze for changes in distribution patterns over time and employing spatial analysis models in order to understand the dynamics of the changes that have occurred (once GIS database has been developed).

5. Prepare bibliography of forage species.

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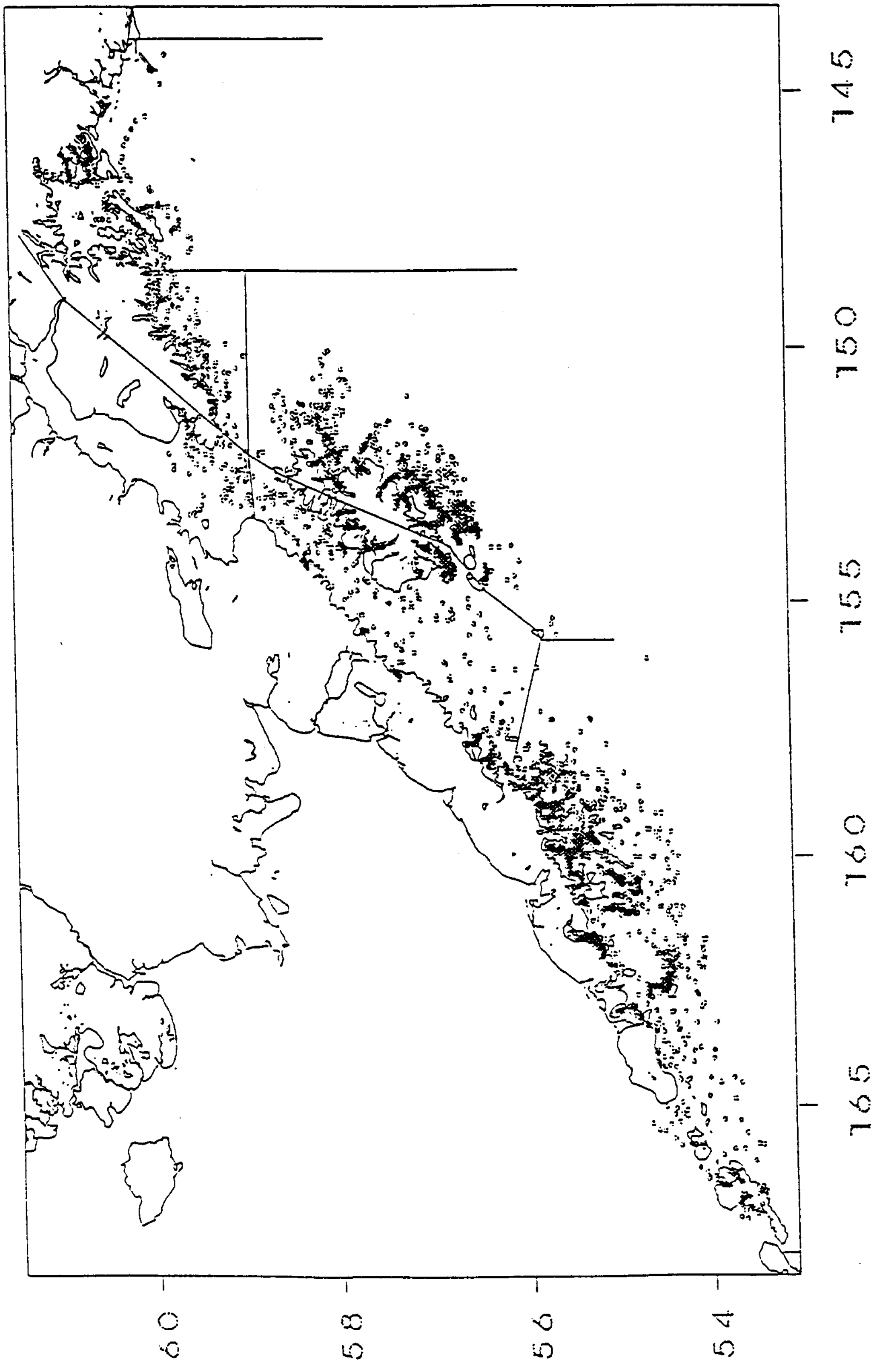
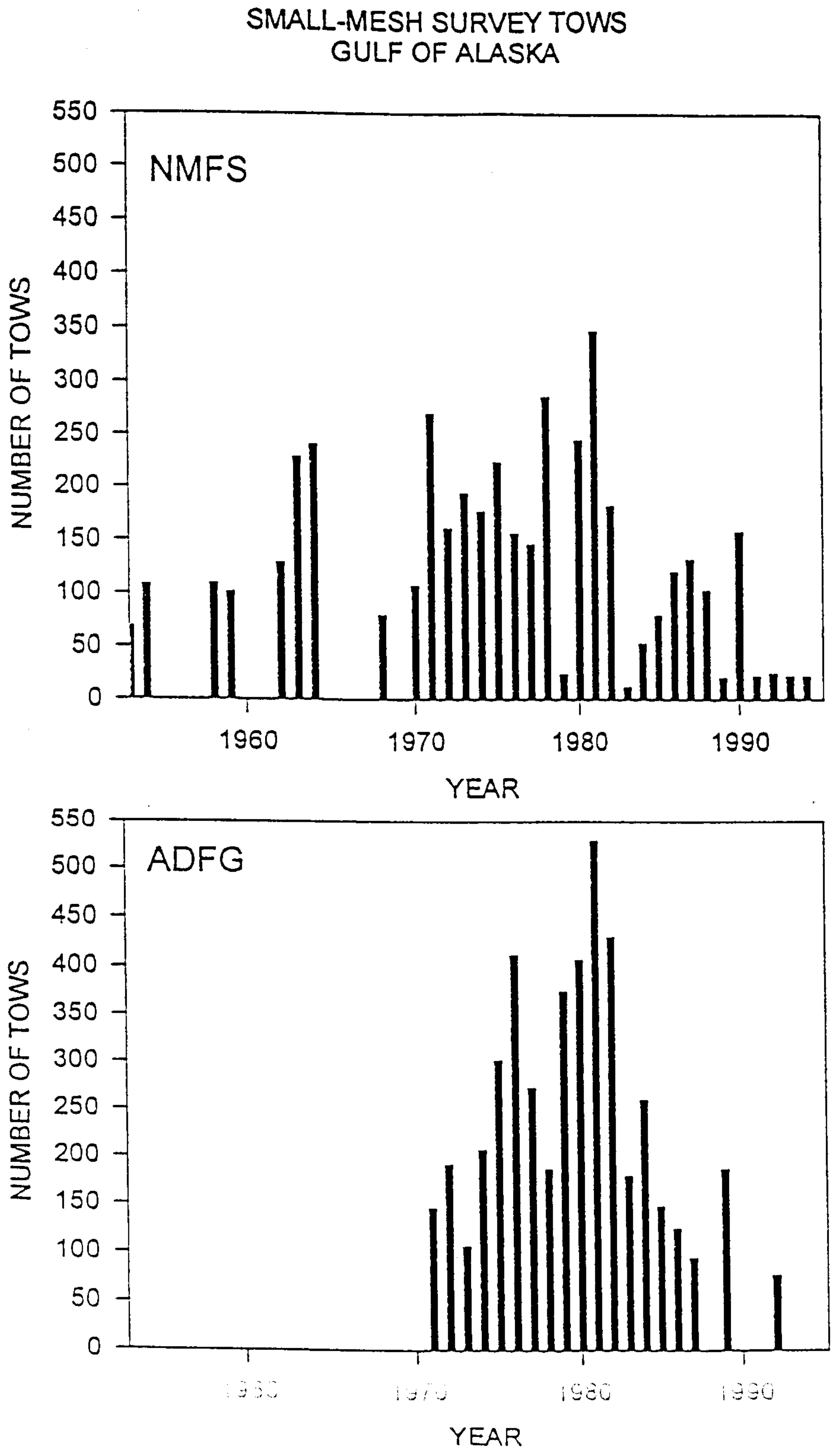
Appendix L-12

Figure 1. Distribution of small–mesh survey sampling 1953 to 1994 in the Gulf of Alaska with sub–area delineation.



Appendix L-13

Figure 2. Number of small–mesh survey tows by year currently in ADF&G and NMFS databases.



Appendix L-14

Figure 3. Capelin relative abundance in Gulf of Alaska small-mesh trawl samples expressed as kilograms caught per kilometer towed (NMFS database top). Capelin relative abundance for three regions (ADFG database bottom).

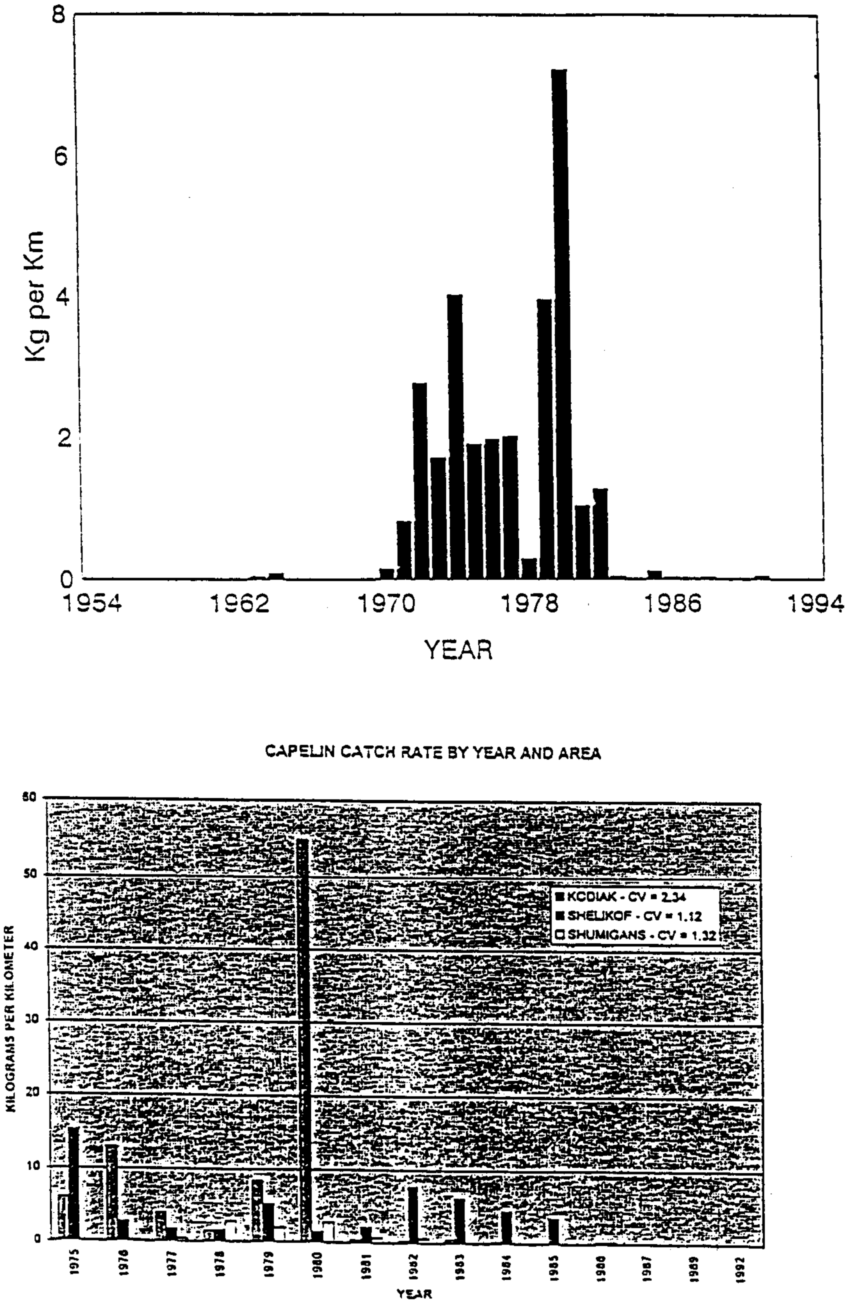
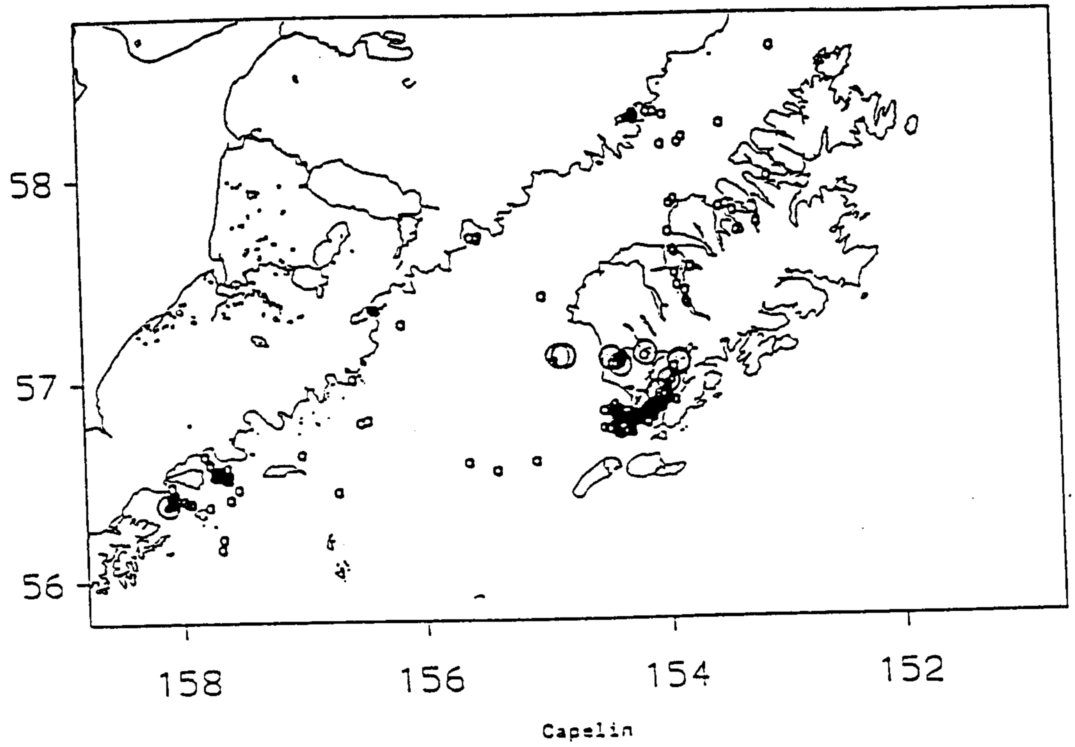
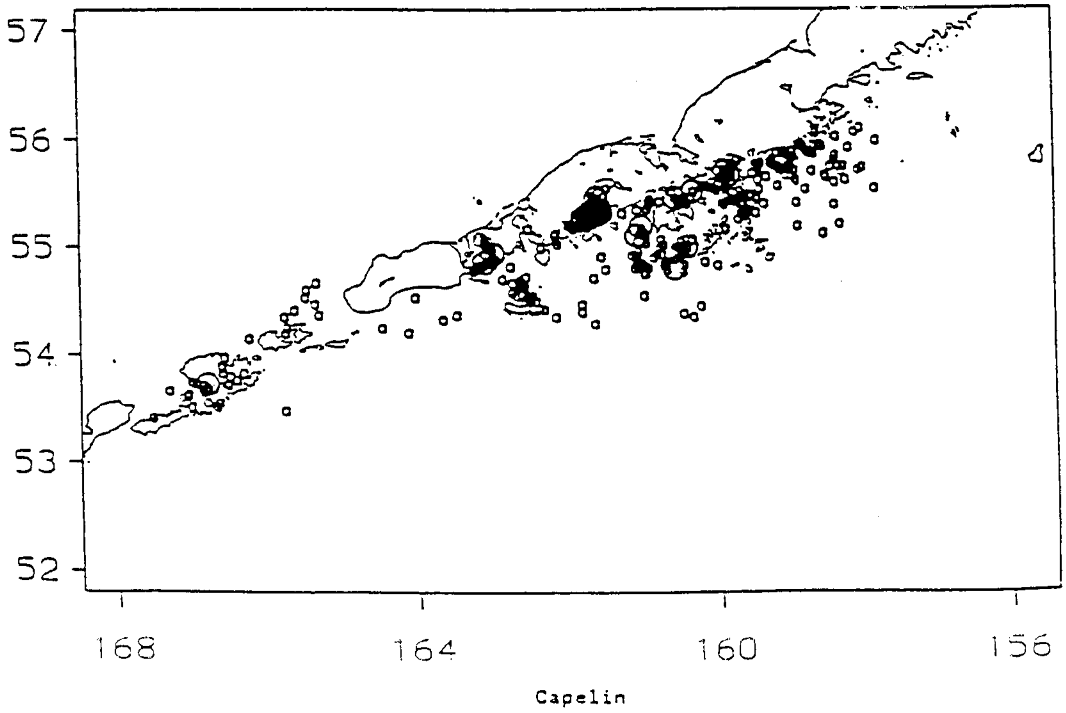


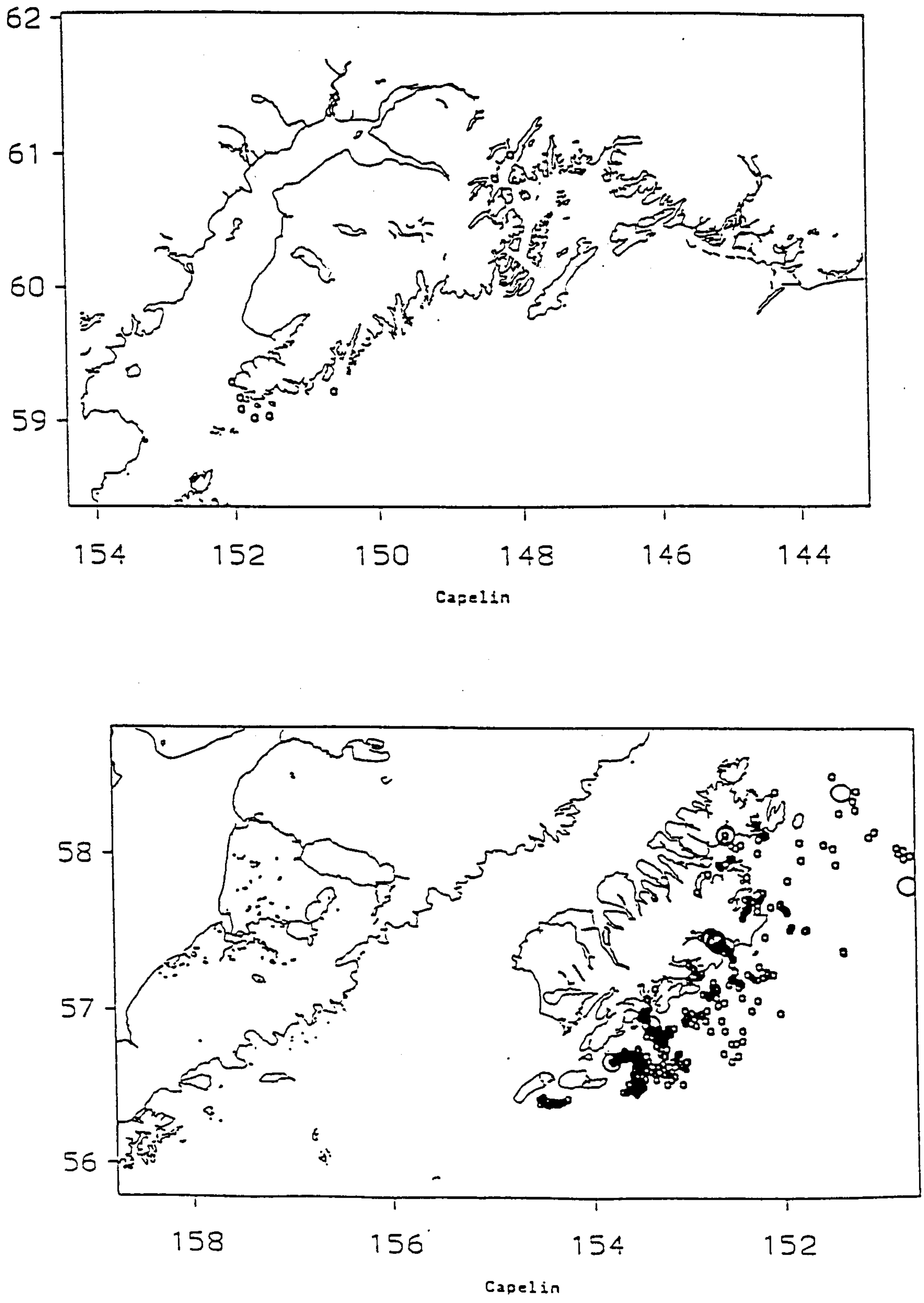
Figure 4. Maps of relative catch density of capelin in the Shelikof and Shumagin areas. Large circles represent catches greater than 50 kilograms; small circles less than 49 kilograms.





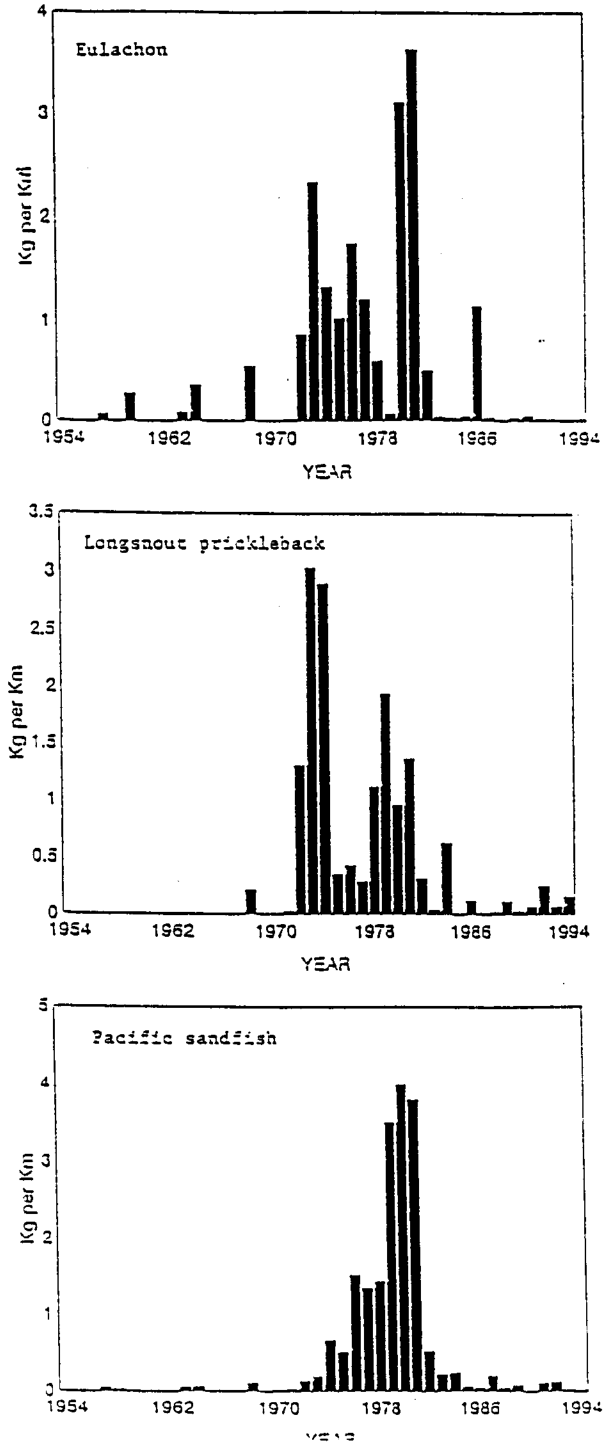
Appendix L-16

Figure 5. Maps of relative catch density of capelin in the Lower Cook, Kenai, and Prince William Sound (top) and Kodiak areas (bottom). Large circles represent catches greater than 50 kilograms; small circles less than 49 kilograms.



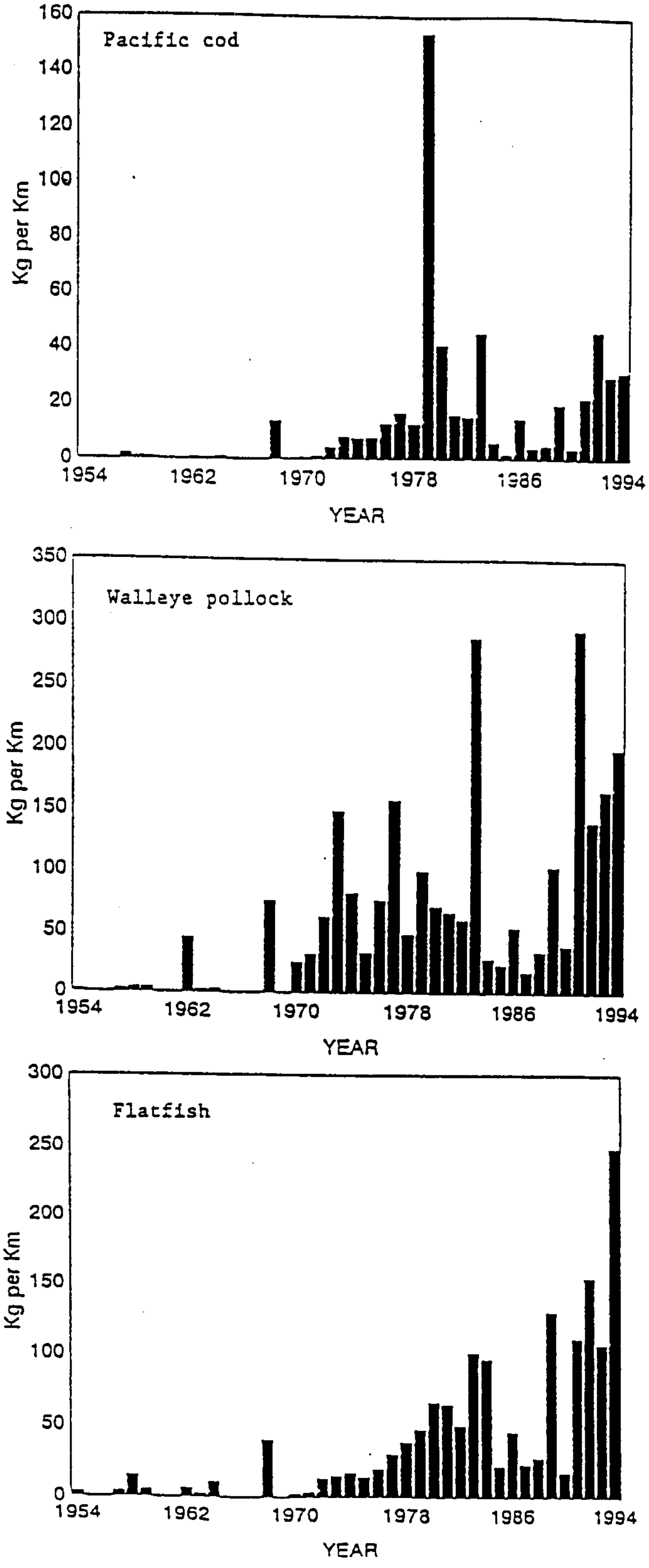
Appendix L-17

Figure 6.Relative abundance of eulachon (top), longsnout prickleback (middle), and Pacific sandfish (bottom).



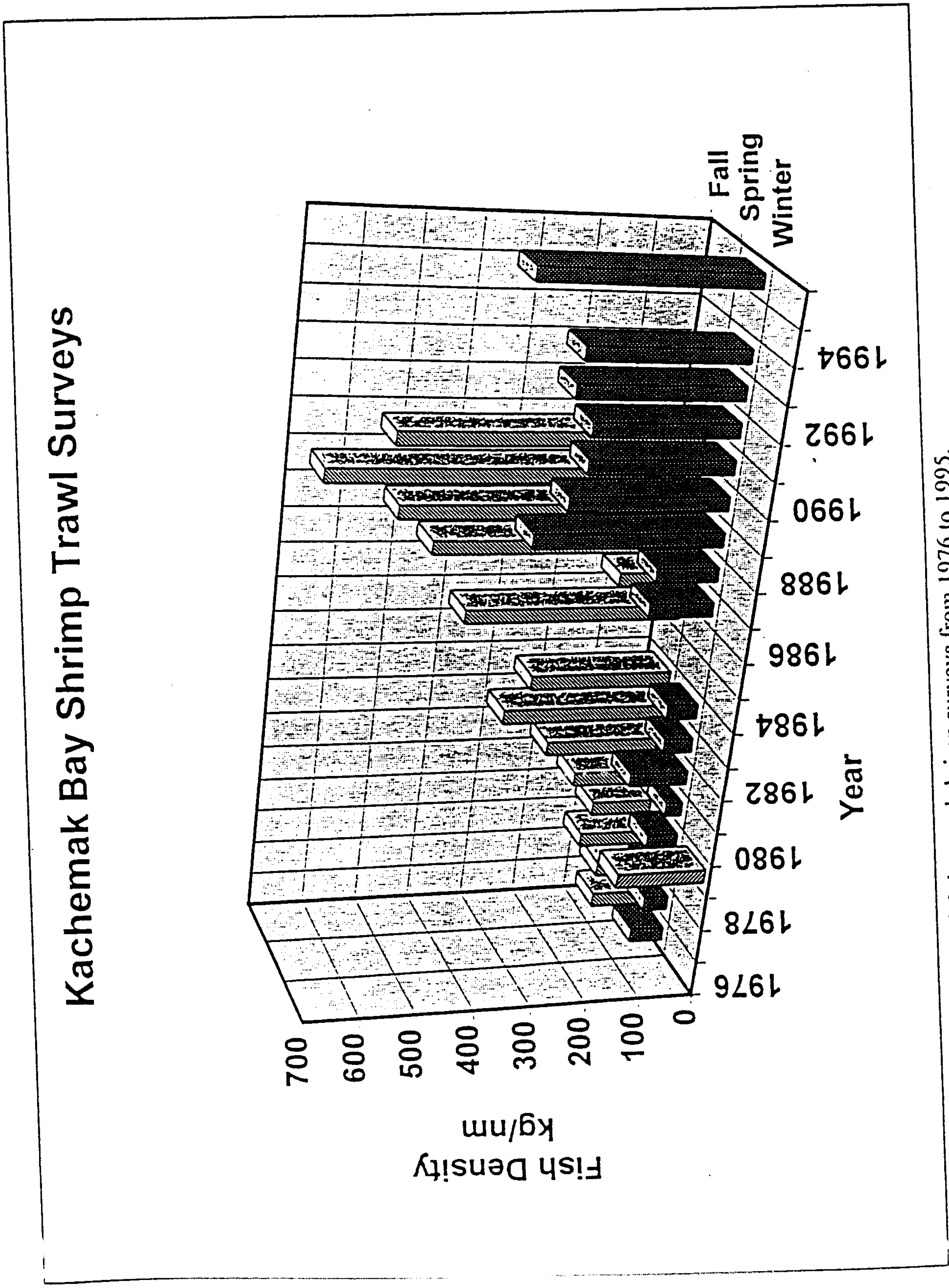
Appendix L-18

Figure 7. Relative abundance of Pacific cod (top), walleye pollock (middle), and a group of faltfish (bottom).



Appendix L-19

Figure 8. Fish catch (kg/km) in Cook Inlet trawl shrimp surveys from 1976 to 1995.



Fish catch (kg/nm) in Cook Inlet trawl shrimp surveys from 1976 to 1995.

Appendix L-20

Table 1. Cruises by vessel that includes most small-mesh survey sampling as of 11/13/95 in NMFS database.

VESSEL	CRUISE	STARTDATE	ENDDATE	SURVEY TYPE	GEAR CODES
1	8104	08/31/81	09/14/81	SHRMP PAV	508
1	8404	08/29/84	08/30/84	SHRMP PAV	508
1	8405	09/04/84	09/12/84	Y OF YR	508, 507, 509
2	5301	03/10/53	04/07/53	SHRMP YAKUT	610
2	5401	02/26/54	04/06/54	SHRMP PR.WM	610
2	5402	07/13/54	09/08/54	SHRMP PR.WM	610
2	5801	07/22/58	08/26/58	SHRMP KODK	506
2	5902	10/14/59	11/11/59	SHRMP KENAI	506
2	7205	05/10/72	05/31/72	SHRMP KODK	516
2	8203	08/14/82	08/21/82	SHRMP KOD-PAV	508
2	8605	08/28/86	09/01/86	SHRMP PAV	508
2	8606	09/03/86	10/08/86	Y OF YR	508, 507, 305
3	8001	06/16/80	08/06/80	IPHC	751
3	8101	06/11/81	07/30/81	IPHC	751
4	7103	06/09/71	07/20/71	SHRMP KODK	514
4	7302	05/23/73	06/14/73	SHRMP KODK	508
9	6306	07/13/63	08/01/63	ROCK	761
14	7102	04/17/71	05/24/71	SHRMP KODK	516
14	7203	08/25/72	09/28/72	SHRMP SHUM	508
14	7305	08/29/73	10/23/73	SHRMP SHUM	508
14	7401	04/15/74	05/22/74	SHRMP KODK	508
14	7403	09/01/74	10/27/74	SHRMP SHUM	508
14	7501	04/01/75	05/22/75	SHRMP KODK	508
14	7503	09/07/75	10/31/75	SHRMP SHUM	508
14	7603	09/08/76	10/28/76	SHRMP SHUM	508
14	7704	08/21/77	09/23/77	SHRMP SHUM	508
14	7803	08/25/78	10/16/78	SHRMP SHUM/AL	508
14	7903	09/01/79	09/07/79	SHRMP PAV/AL	508
14	8003	08/12/80	09/16/80	SHRMP PAV/AL	508
15	7003	08/30/70	10/10/70	SHRMP KODK	510
21	9009	09/07/90	09/22/90	Y OF YR	507, 302
24	8201	06/11/82	07/17/82	IPHC	751
27	7801	06/18/78	07/06/78	SHRIMP/PLK	508
33	6202	08/21/62	10/02/62	SHRMP PR.WM	506, 512
33	6302	07/12/63	09/10/63	SHRMP PR.WM	506
34	6802	07/03/68	09/26/68	SHRMP KODK	506, 510, 605
37	8102	08/30/81	09/23/81	ADFG SHRMP	508
37	8302	08/11/83	08/12/83	SHRMP PAV	508
37	8502	08/12/85	08/15/85	SHRMP PAV	508
37	8503	08/21/85	09/09/85	Y OF YR	508
37	8702	08/05/87	08/08/87	SHRMP PAV	508
37	8703	08/13/87	09/19/87	Y OF YR	508
37	8802	08/10/88	08/15/88	SHRMP PAV	508
37	8803	08/18/88	09/10/88	Y OF YR	508
37	8902	08/18/89	08/21/89	SHRMP PAV	508
37	9002	08/09/90	08/16/90	SHRMP PAV/KOD	508
37	9102	08/19/91	08/21/91	SHRMP PAV	508

Table 1 Cont.

VESSEL	CRUISE	STARTDATE	ENDDATE	SURVEY TYPE	GEAR CODES
38	6402	08/13/64	09/04/64	SHRMP KODK	506
38	6402	06/16/64	09/15/64	SHRMP KODK	506, 512
41	8001	09/09/80	09/23/80	ADFG SHRMP	508
41	8101	09/03/81	10/03/81	ADFG SHRMP	508
42	8001	08/23/80	09/16/80	ADFG SHRMP	508
43	8001	08/23/80	09/05/80	ADFG SHRMP	508
43	8201	08/24/82	09/23/82	ADFG SHRMP	508
87	9202	08/09/92	08/13/92	SHRMP PAV	508
88	9302	08/04/93	08/06/93	SHRMP PAV	508
89	9402	08/04/94	08/06/94	SHRMP PAV	508
88	9502	08/05/95	08/09/95	SHRMP PAV	508
620	5702	09/06/57	09/30/57	SHRMP SHUM	506
620	7801	06/23/78	08/17/78	IPHC	751

GEAR CODES:

305 --Marinovitch mid-water; 32 mm mesh.
506 --Gulf Shrimp Trawl; 38 mm mesh.
507 --High-opening Shrimp Trawl; 32 mm mesh.
508 --High-opening Shrimp Trawl; 32 mm mesh.
509 --High-opening Shrimp Trawl; 32 mm mesh.
510 --Kodiak Shrimp Trawl; 32 mm mesh with 19 mm mesh liner
512 --Gulf Semi-balloon Shrimp Trawl; 38 - 41 mm mesh.
514 --Kodiak Shrimp Trawl; 32 mm mesh with 19 mm mesh liner.
516 --Nordby Shrimp Trawl; 32 mm mesh.
610 --Beam Trawl; 32 mm mesh.
751 --INPHC Saml1-mesh Trawl; 32 mm mesh.
761 --Semi-balloon Shrimp Trawl; 38 mm mesh with 13 mm mesh liner.

Table 2. Structure for haul table in NMFS and ADF&G small-mesh database.

NMFS Field	Field Name	Type	Width	Decimals	Definition
1	CRUVESHAL	Numeric	12		Identification
2	THEREGION	Character	3		Region Code
3	VESSEL	Numeric	4		Vessel Code
4	CRUISE	Numeric	4		Cruise Number
5	HAUL	Numeric	4		Haul Number
6	HAULTYPE	Numeric	4		Haul Type Code
7	PERFORMANC	Character	2		Performance Code
8	STARTDATE	Date	8		Date of Haul
9	STARTHOUR	Numeric	4		Time of Haul
10	DURATION	Numeric	7	3	Duration Time
11	DISTANCE	Numeric	8	4	Distance Kilometers
12	NETWIDTH	Numeric	7	3	Net Width Meters
13	NETMEASURD	Character	2		Measurement Code
14	NETHEIGHT	Numeric	7	3	Net Height Meters
15	STRATUM	Numeric	4		Stratum Code
16	STARTLAT	Numeric	10	6	Starting Latitude
17	ENDLAT	Numeric	10	6	Ending Latitude
18	STARTLON	Numeric	11	6	Starting Longitude
19	ENDLON	Numeric	11	6	Ending Longitude
20	STATIONID	Character	10		Identification
21	GEARDEPTH	Numeric	6		Gear Depth Meters
22	BOTTOMDEPT	Numeric	6		Bottom Depth Meters
23	BOTTOMTYPE	Character	3		Bottom Type Code
24	SURFTEMP	Numeric	5	1	Surface ^{0}C
25	GEARTEMP	Numeric	5	1	Gear ^{0}C
26	WIRELENGTH	Numeric	7		Trawl Warp Meters
27	GEAR	Character	4		Gear Code
28	ACCESSORIE	Character	3		Gear Accessory Code
29	SUBSAMPLE	Character	2		Subsample Code

ADFG No.	Column Name	Attributes	Definition
1	Cruise	INTEGER, Index:MULTI-COLUMN	Cruise Number
2	Haul	INTEGER, Index:MULTI-COLUMN	Haul Number
3	Region	INTEGER	Region Code
4	Area	INTEGER	Area Code
5	Stratum	INTEGER	Stratum Code
6	Station	TEXT 4	Station Code
7	Vessel	TEXT 2	Vessel Code
8	Dateup	DATE	Date
9	LatDeg	INTEGER	Start Latitude
10	LatMin	REAL	"
11	LongDeg	INTEGER	Start Longitude
12	LongMin	REAL	"

13	TowHeading	INTEGER	Heading Degrees

Table 2. Structure for haul table in NMFS and ADF&G small-mesh database. CONT.

ADFG Cont.

No.	Column Name	Attributes	Definition
14	StartHaul	TIME	Start Time
15	EndHaul	TIME	End Time
16	Minutes	INTEGER	Duration Time
17	Distance	REAL	Distance Naut. Mi.
18	Loranx	INTEGER	Loran Position
19	Lorany	INTEGER	"
20	DepthMax	INTEGER	Maximum Depth Fm
21	DepthMin	INTEGER	Minimum Depth Fm
22	Weather	TEXT 3	Weather Code
23	Scope	INTEGER	Trawl Warp Fathoms
24	Perform	INTEGER	Performance Code
25	DepthAvg	INTEGER	Average Depth Fthms
26	Temperature	REAL	Gear Temperature ?C
27	Latitude	REAL	End Latitude
28	Longitude	REAL	End Longitude
29	The Area	TEXT 4	Area Code

Table 3. Structure of catch table in NMFS and ADF&G small-mesh database.

NMFS Field	Field Name	Type	Width	Decimals	Definition
1	CRUVESHAL	Numeric	12		Numeric ID
2	THEREGION	Character	3		Region Seperator
3	VESSEL	Numeric	4		Vessel Code
4	CRUISE	Numeric	4		Cruise Number
5	HAUL	Numeric	4		Haul Number
6	SPECIES	Numeric	10		Species Code
7	WEIGHT	Numeric	12	4	Weight Kg
8	NUMBERS	Numeric	7		Number Caught
9	SUBSAMPLE	Numeric	2		Sub-sample Code

ADFG No.	Column Name	Attributes	Definition
1	Cruise	INTEGER	Cruise Number
2	haul	INTEGER	Haul Number
3	region	INTEGER	Region Code (Different than NMFS)
4	area	INTEGER	Area Designator
5	spcode	INTEGER	Species Code (Same as NMFS)
6	catchlbs	INTEGER	Weight Pounds
7	lbseach	INTEGER	Number Caught

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Table 4. Rank order by weight of species and species groups caught in NMFS small-mesh surveys 1953 to 1994 in the Gulf of Alaska (Partial listing).

Species Name	Total Weight
Pandalus borealis	579290.6243
Theragra chalcogramma	461348.0636
Hippoglossoides elassodon	127052.4604
Gadus macrocephalus	93530.7165
Scyphozoa (class)	89143.0956
Pandalus goniurus	84706.3639
Atheresthes stomias	54169.9554
Pandalopsis dispar	52019.9269
Pleuronectes asper (prev. Limanda aspera)	45522.9413
Chionoecetes bairdi	20388.2346
Pandalus hypsinotus	19428.4267
Paralithodes camtschatica	18234.4558
Hippoglossus stenolepis	14911.9423
Hemilepidotus jordani	12287.4737
Pleuronectes bilineatus (prev. Lepidopsetta bilineata)	11816.2032
Mallotus villosus	11301.6434
Myoxocephalus sp.	9363.9947
Thaleichthys pacificus	8785.2017
Lycodes brevipes	8717.7221
Trichodon trichodon	7750.9781
Anoplopoma fimbria	7735.5310
Clupea pallasi (=Clupea harengus pallasi)	6205.9402
Lumpenella longirostris	5376.1010
Starfish unident.	5028.5994
Microgadus proximus	4954.5920
Myoxocephalus polyacanthocephalus	4816.4318
Ophiuroid unident.	4451.8761
Cottidae	3805.1354
Chionoecetes tanneri	3242.5600
Crangonidae (family)	3241.7790
Platichthys stellatus	3027.6931
Zoarcidae	2905.3840
Sebastes alutus	2875.0132
Chionoecetes sp.	2813.5810
Shrimp unident.	2352.5960
Dasycottus setiger	2166.7533
Cancer magister	2137.0568
Rajidae unident.	1967.5116
Psettichthys melanostictus	1944.2313
Asterias amurensis	1851.8155
Myoxocephalus jaok	1807.6141
Isopsetta isolepis (=Pleuronectes isolepis)	1737.5801
Pleuronectes quadrituberculatus	1597.1843
Porifera	1588.5310
Argis dentata	1456.5558

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Lumpenus sagitta	1430.0163
Pandalus jordani	1396.2030