FINAL REPORT

TO THE

OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM (OCSEAP)

Contract: 01-5-022-2538
Research Unit: 341
Reporting Period:
November 1977 to April 1978
Number of Pages: 123

THE WINTER FEEDING ECOLOGY AND TROPHIC RELATIONSHIPS OF MARINE BIRDS IN KACHEMAK BAY, ALASKA

by

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Reporting partially on the final results of research conducted under OCSEAP Research Unit 341, "Population Dynamics and Trophic Relationships of Marine Birds in the Gulf of Alaska," Calvin J. Lensink, Patrick J. Gould, and Gerald A. Sanger, Principal Investigators.

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March 1981

ABSTRACT

The winter feeding ecology of oldsquaw, white-winged scoters, common murres and marbled murrelets was studied on Kachemak Bay, Alaska, from November 1977 through April 1978. The birds together ate a minimum of 79 prey species. The sea ducks ate mostly benthic bivalves and gastropods, with fish and crustaceans sometimes important, while the alcids ate mostly pelagic and demersal crustaceans and fish.

Oldsquaw were extreme generalists, eating at least 60 prey species. The most important were sand lance, and the bivalves Spisula polynyma and Mytilus edulis. Scoters were generalists on molluscs, mostly bivalves. They ate at least 22 species; the most important were the bivalves Protothaca staminea and Mytilus, and the snail Margarites pupillus. Both sea ducks generally foraged in water less than 20 m, the oldsquaw over substrates of sand and mud, and the scoters over bottoms of shell debris and cobbles.

Murres ate at least 11 species of mid-water and demersal prey, mostly the crustaceans Neomysis rayii (mysid) and pink shrimp. Murrelets ate at least 8 prey species, primarily fish; capelin was the most important, followed by sand lance, the euphausiid Thysanoessa raschii, and mysids. Both alcids generally foraged in water deeper than 20 m over rocky bottoms, but the murrelets occurred relatively closer to shore. —

Highly significant differences in average prey length were observed between oldsquaw and scoters, and between murres and murrelets.

The birds studied appear to have minimal impact on commercially important species of fish and shellfish.

The base of the food web in Kachemak Bay depends on the production and availability of organic detritus, which apparently originates largely from winter die-off of extensive kelp beds. However, little is known about ecological processes between kelp production, and production and availability of the birds' filter- and deposit-feeding prey.

Birds wintering in Kachemak Bay appear to be at high risk from both acute and chronic oil spills. Most of the wintering community of birds are either waterfowl or alcids, the two major groups of birds most susceptible to oiling. Pollution that interferes substantially with the production of organic detritus, particularly from the extensive beds of kelp, could have more serious long-term consequences to the birds than direct oiling. In general, any potential threats to the bird community from petroleum activities needs to be evaluated in terms of the pattern of ocean currents. Accidents which may occur on the south side of the outer Kachemak Bay, and around the southern primeter of the Kenai Peninsula would threaten the birds and their ecosystem more seriously than ones on the north side of the bay, which are "downstream" from most of Kachemak Bay.

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INTRODUCTION

Kachemak Bay, located at the southern end of Cook Inlet in southcentral Alaska, has long been recognized for its high biological productivity, important commercial fisheries, and recreational uses. The marine birds in Kachemak Bay recently received attention when Erikson (1977) studied their populations throughout 1976 as part of broadly based environmental studies of lower Cook Inlet by the Alaska Department of Fish and Game (Trasky, Flagg, and Burbank 1977). In winter, over 90% of the marine birds found in lower Cook Inlet were in Kachemak Bay. Erikson believed this was because Kachemak Bay remained essentially ice-free in winter, and that food was abundant in intertidal and nearshore subtidal waters.

Despite Erikson's (1977) study, the food habits and trophic relationships of this community of wintering birds remained essentially unknown. This was recognized as a major gap in the knowledge of lower Cook Inlet at the first "synthesis meeting" of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in November 1976. This study of the winter food habits and trophic relationships of birds in Kachemak Bay was subsequently added as a part of OCSEAP Research Unit 341 (Population Dynamics and Trophic Relationships of Marine Birds in the Gulf of Alaska).

Field studies were initiated in November 1977, and continued at monthly intervals through April 1978. The primary objectives of the study were: (1) to determine the kinds, amounts and trophic levels of prey used by the main species of marine birds wintering on the bay; and (2) to relate these findings to the physical and biological environment of the bay, particularly as related to potential petroleum development.

The species we studied and collected were limited to those present in the areas we could reach consistently. These were the oldsquaw (*Clangula hyemalis*), white-winged scoter (*Melanitta deglandi*), and common murre (*Uria aalge*). Erikson (1977) listed these species as abundant in lower Cook Inlet in winter. We discovered the location of marbled murrelets (*Brachyramphus marmoratum*) wintering in the bay in January and collected samples of this species from then until April. Erikson considered marbled murrelets common residents in lower Cook Inlet. No other species was consistently present in the areas we worked, but we collected small samples of surf scoters (*M. perspicillata*), black scoters (*M. nigra*), and pigeon guillemots (*Cepphus columba*). Glaucous-winged gulls (*Larus glaucescens*) and mew gulls (*L. canus*) were abundant near Homer Spit, but their proximity to human activities prevented our collecting them.

CURRENT STATE OF KNOWLEDGE

Ainley and Sanger (1979) reviewed the food habits of marine birds in the eastern subarctic North Pacific Ocean and coastal waters from literature published through spring 1975. However, there has been little effort to define and analyze the trophic relationships *per se* among marine birds. Wiens and Scott (1975) and Wiens *et al.* (1979) studied the feeding energetics of marine birds, but these and prior studies have stopped short of examining the interrelationships of energetics, food webs and prey trophic levels among ecological communities of marine birds and their prey. These topics are at the heart of understanding trophic relationships among animals, and much additional work is needed in this area.

Table 1 lists the general prey categories previously reported for the seven-bird species considered here. The three scoters prey mainly on bivalves and gastropods. In addition, benthic fish and fish eggs and larvae are minor dietary items of white-winged scoters; fish eggs, larvae, and plant matter are minor items to surf scoters; and, black scoters occasionally eat plant matter and benthic crustaceans. Oldsquaw prey mainly on benthic and emersal crustaceans and they also eat a variety of bivalves, gastropods, and benthic fishes. Common murres eat mostly mid-water fishes and benthic fishes, and mid-water crustaceans are less important in their diet. Benthic fishes are the major prey of pigeon guillemots, but they also eat cephalopods and benthic crustaceans. Mid-water fishes and crustaceans are reported as major prey of marbled murrelets.

STUDIES IN KACHEMAK BAY

Crow (1978) studied the foods of marine ducks shot by hunters in the China Poot Bay area of Kachemak Bay during two fall months in 1978. He did not indicate collection sites, but the birds were presumably taken close to shore over relatively shallow water. The mussel *Mytilus edulis* comprised the highest estimated volume of prey for scoters and other bivalves (possibly *Macoma* or *Tellina*) were less important. Marine algae and flower parts of beach rye (*Elymus mollis*) were minor prey items in white-winged scoters, as were algae and unidentified fish bones in surf scoters, and gastropods and sponge tissue in black scoters.

Knowledge of the distribution, abundance and species composition of the wintering marine bird community on Kachemak Bay is important to understanding their trophic relationships. During Erikson's (1977) study, numbers of sea ducks increased from Cook Inlet into Kachemak Bay. Numbers of gulls increased dramatically along the north shoreline of the outer bay near Bluff Point, and large numbers were seen feeding on cannery waste at the end of Homer Spit. In the same study, a pelagic survey on March 17, 1976 across the mouth of the inner bay revealed sizeable populations of oldsquaw, common murres, pigeon guillemots, and lesser numbers of marbled murrelets.

Table 1. General Categories of Prey Reported for Selected Species of Marine Birds Along the Pacific Coast of North America. X = major dietary item; o = minor item; . = incidental item. Adapted from Ainley and Sanger 1979

	General Type of Prey							
	Fish			Mollusca		Crustacea		Plants
Bird Species	Midwater	Benthic	Eggs/Larvae	Cephalopod	Clams/Snails	Midwater	Benthic	
Oldsquaw *Clangula hyemalis*		o			o	o	X	
White-winged Scoter *Melanitta deglandi*		o	o		X			
Surf Scoter *M. perspicillata*			o		X			o
Black Scoter *M. nigra*					X		o	o
Common Murre *Uria aalge*	X	o				o		
Pigeon Guillemot *Cepphus columba*		X		o			o	
Marbled Murrelet *Brachyramphus marmoratus*	X		o			o		

On March 30, 1976, a similar survey from the end of Homer Spit due westward for ca. 22 km into the outer bay encountered an enormous flock of white-winged scoters, which Erikson estimated at 10,000 birds; he believed that these birds spent the entire winter in Kachemak Bay. He saw fewer common murres, pigeon guillemots, and marbled murrelets. There were large numbers of white-winged scoters along the 20-fathom isobath between Yukon Island and Seldovia Bay in February 1977 (unpublished USFWS data).

Sea ducks collected for food studies in spring 1976 in Kachemak Bay (David Erikson, unpublished data) showed that oldsquaw preyed mostly on the clam Nucula tenuis and ate some Macoma balthica in the northern part of the inner bay. Surf and black scoters ate mainly Macoma balthica in the same area. White-winged scoters had a more diverse diet, but had mainly eaten the clam Nuculana fossa. All three species of scoters on the south side of the bay between Halibut Cove and China Poot Bay had preyed heavily on the mussel Mytilus edulis.

OTHER PERTINENT STUDIES

Stott and Olson (1973) studied the populations and food habits of seven species of marine ducks on the New Hampshire Coast in winter. Oldsquaw had the most generalized diet, consisting mainly of bivalves, gastropods, sand shrimp, and isopod crustaceans. The three scoters selectively used areas of sandy substrate and had quite similar food habits, preying principally on bivalves. All sea ducks were generally concentrated near the mouths of estuaries. A major conclusion of the study was that "...food availability, coupled with the physical structure of the substratum in the different coastal habitats, is apparently a major determinant in the way that coastal water fowl selectively use habitat types."

The feeding ecology of oldsquaw and black scoters was studied along the coast of south Sweden in winter (Nilsson 1972). The bivalves Mytilus edulis and Macoma balthica dominated in 156 oldsquaw stomachs. Other species of bivalves, polychaetes, mysids, gammarid amphipods, plant matter, and occasionally flatfish were also present, but gastropods were conspicuously absent. Most oldsquaw foraged to depths of 22 m, over stoney and gravelly substrates with concentrations of Mytilus, or over sandy bottoms rich with Macoma. Mytilus and Macoma also dominated in 14 black scoter stomachs. Scoters seen during boat surveys were usually in water of 0-15 m, but ocasionally to 20 m.

Similar results were obtained for wintering oldsquaw collected along the coast of Denmark (Madsen 1954). By percent frequency of occurrence, bivalves accounted for 47% of the prey, gastropods 13%, crustaceans 28%, fishes 7%, polychaetes 3%, and echinoderms 2%. The most important genera of prey were the bivalves Cardium and Mytilus, the amphipod Gammarus, and isopod Idothea. Madsen (1954) observed that oldsquaw foraged mainly at sea at night, but in daytime they foraged nearer the coast. Black scoters foraged in depths of 20-30 m, and the frequency of occurrence of major prey were: Bivalves, 95% (mainly Mytilus and Cardium); gastropods, 16%; crustacea, 11%; polychaetes, 13%; echinoderms, 4%; and vegetable matter, trace. Madsen concluded that the birds he studied had eaten the same broad categories of prey reported by other authors. He believed that the maximum prey size was "fairly fixed" for each bird species, but the minimum sizes varied with the availability and abundance of smaller prey. The birds ate larger sizes of soft-bodied prey such as fishes and soft-shelled crustacea than hard-shelled kinds.

Common Murres prey principally on mid-water fishes up to seven inches (178 mm) (Tuck 1960, and papers he cites). Capelin (Malotus villosus) are of particular importance off Newfoundland in winter. In summer in the eastern Bering Sea (Ogi and Tsujita 1973) and in the Sea of Okhotsk (Ogi and Tsujita 1977), mid-water schooling fishes, primarily walleye pollock (Theragra chalcogramma) dominated the stomach contents of murres. Squid and euphausiids were less important, although the latter accounted for 15% by weight of food eaten by murres in the southeastern Bering Sea. There appears to be little information on the feeding habits of common murres in protected waters such as Kachemak Bay.

Sealy's (1975) study of the feeding ecology of marbled and ancient murrelets in British Columbia during the breeding season is one of the few with data on prey lengths. He noted that the marbled murrelets consistently foraged within 500 m of shore, in areas sheltered from prevailing winds and in water depths less than 30 m. Four marbled murrelets collected in winter near Vancouver Island (Munro & Clemens 1931) contained remains of shiner perch (Embiotocidae), and mysids.

STUDY AREA

Trasky et al. (1977) provide extensive information on the geography, climate, oceanographic environment, fisheries, and other living resources of Kachemak Bay. Descriptions below are from this report, unless cited otherwise.

PHYSIOGRAPHY AND GEOGRAPHIC SETTING

Kachemak Bay is a major geographic feature of the Kenai Peninsula and Cook Inlet (Figure 1). The bay is 38 km wide at its entrance, defined as a line from Anchor Point on the north to Point Pogibshi on the south; and it is approximately 62 km long. The extreme upper 6 km are mud flats which are exposed most of the time. Away from shore, water depths are relatively shallow throughout the bay, mostly ranging from about 35 to 90 m (20-50 fm). Maximum depths, occurring just offshore between Yukon and Gull Islands, range from about 110 to 165 m (60-90 fm). At about the midway point of the north shore, Homer Spit projects for about 7 km into the bay. This Spit divides the bay into physically and biologically distinct sub-areas termed the "inner" and the "outer" bays.

Kachemak Bay is bordered on the north by rolling hills up to about 460 m and the northern shoreline is unbroken by inlets. The rugged Kenai Mountains border the south side of the bay and rise to elevations of 1,200-1,500 m (4,000-5,000 ft.) within 9 km of shore. The southern shoreline, in marked contrast to the northern one, has several islands, fjords and shallow bays. Extensive shoals lie adjacent to the north shore. For example, the 5 fm contour is about 3-4 km off the north shore of the inner bay, and from Homer Spit to a point opposite Bear Cove, about 25-40% of the inner bay is comprised of water less than 5 fm at mean lower low water (NOAA Nautical Chart 16645). An area of about 36 km^2 at the extreme head of the bay upstream of Chugalak Island is comprised entirely of mud flats or water of less than a fathom.

Areas shallower than 5 fm near Homer and Homer Spit in the outer bay are more subject to tidal currents than the inner bay and the type of substrate is markedly different. The bottom of the outer bay has been classified into various substrate types (Figure 2, after Driskell and Lees 1977). Boulders and cobbles predominate in depths less than 10 fm along the north shore. From here to the 20 fm line, an area which comprised a major foraging habitat for benthic feeding birds, the substrate is shell debris, muddy sand, or rippled sand. In the inner bay, an important foraging area for oldsquaw, mud flats with scattered boulders (NOAA Nautical Chart #16645) occur immediately adjacent to the north shore. Clays originating from the glacial streams at the head of the bay and from erosion of bluffs extend from here to the 10 fm line. Presumably, scattered boulders also

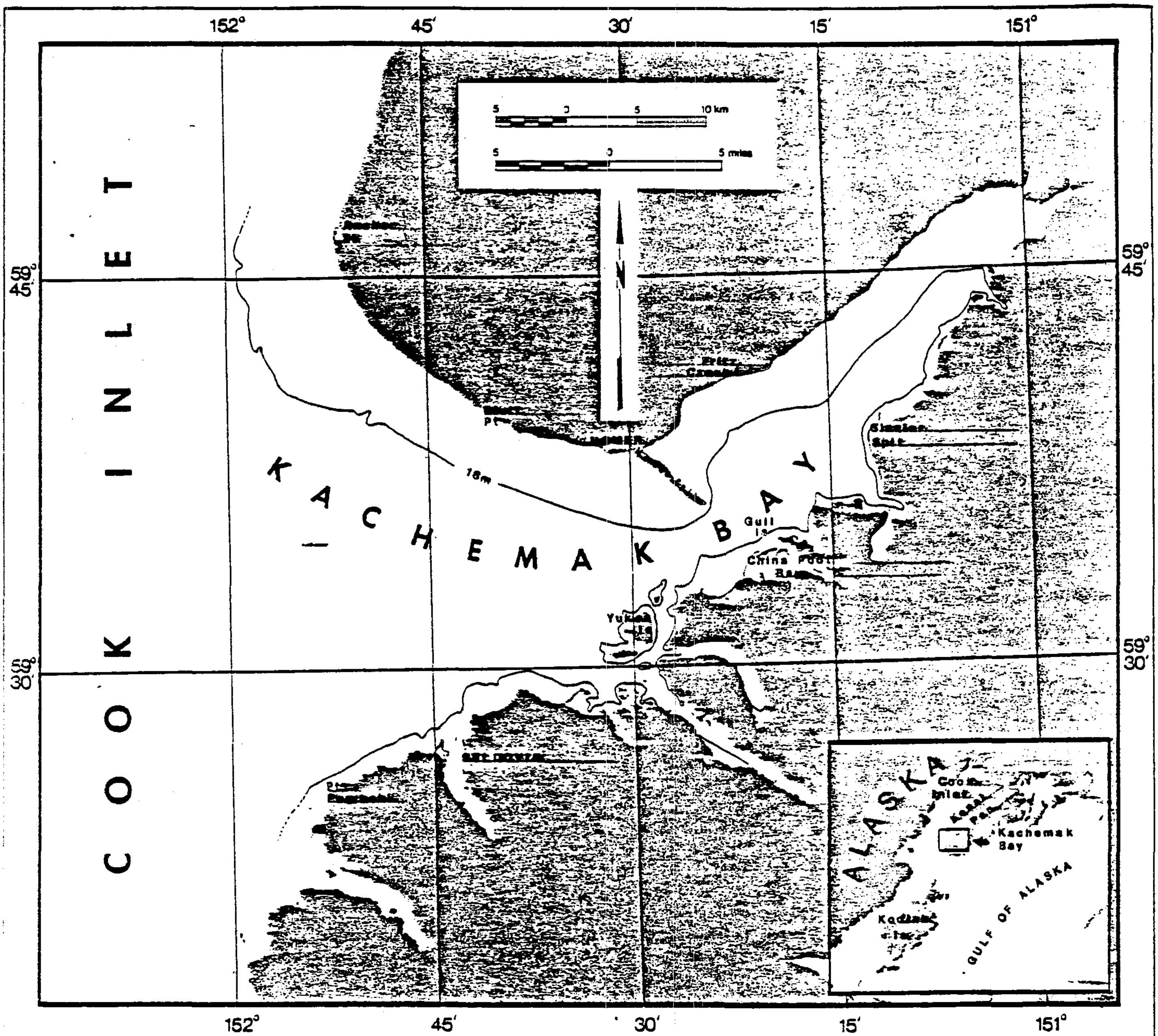

Figure 1. Kachemak Bay, Alaska , indicating features mentioned in text.

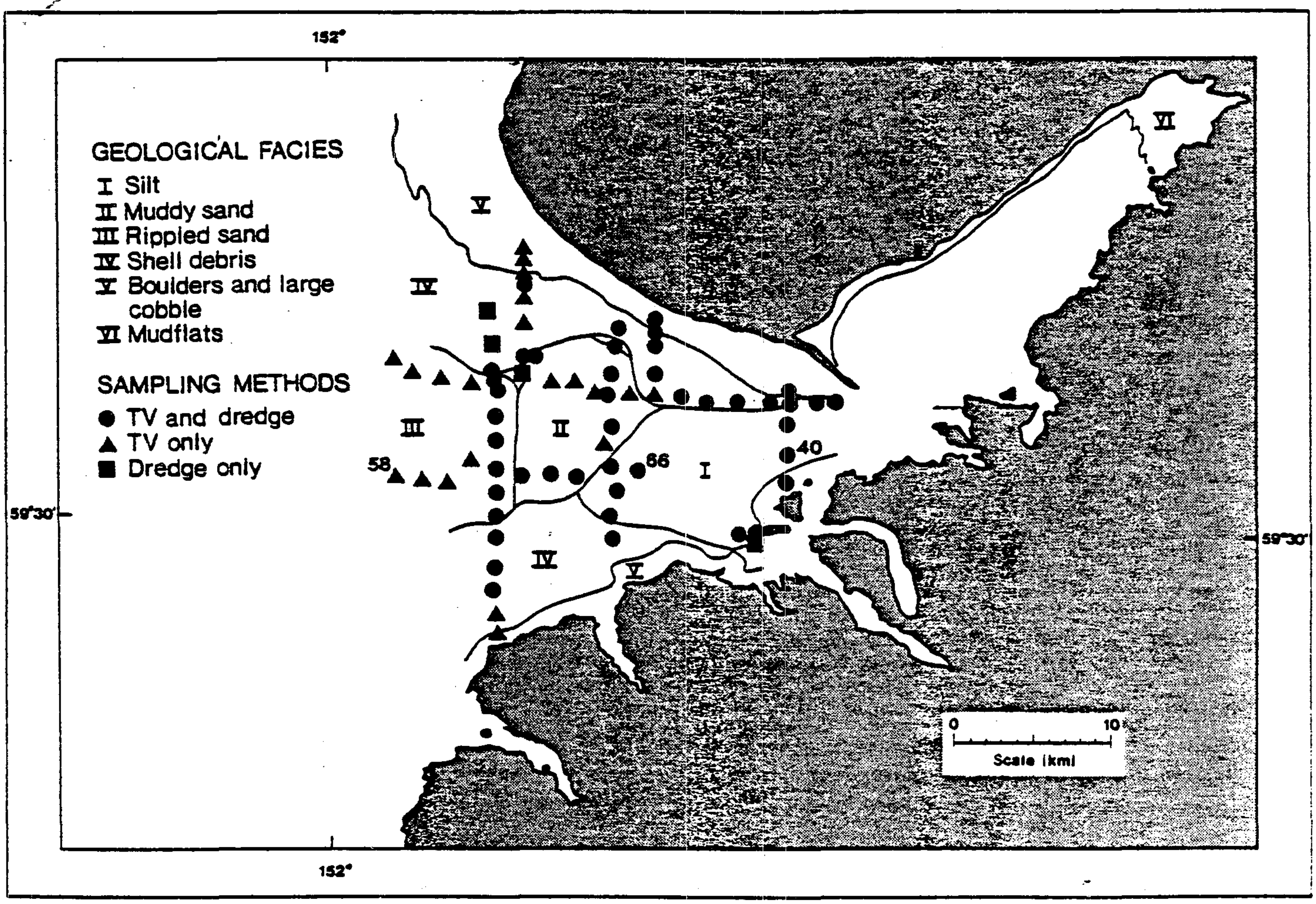

Figure 2. Types and locations of bottom substrates in Kachemak Bay. After Driskell and Lees 1977, and SAI 1979.

occur in adjacent subtidal depths. These boulders contain communities of mussels (Mytilus edulis) and other biota, thus constituting rocky micro habitats amid the mud and sand bottom (Less 1978).

OCEANOGRAPHY AND THE MARINE ENVIRONMENT

Climate and Weather

Climatically, Kachemak Bay is transitional between the maritime Gulf of Alaska and the continental climate of interior Alaska. Cool summers, mild winters, and frequent storms characterize the area. Precipitation averages 71 cm (28 in.) per year, including 257 cm (101 in.) of snow. Air temperatures in winter generally range from -8.3 to 5.6°C (17 to 42°F), with occasional lows below -18°C (0°F). During this study, temperatures ranged from -13°C in December to 4°C in April.

Local topography exerts a strong influence on wind direction (Hayes, Brown and Michel 1977) and prevailing north and northeast winds parallel the northeast-southwest axis of the bay. Wind speeds at Homer average 5.7 knots in winter, with extremes up to 50 knots and occasionally as high as 75 to 100 knots.

Physical Oceanography

Information on water circulation and general features of physical oceanography are summarized from Burbank (1977) and Trasky et al. (1977), unless noted otherwise. Most water in Kachemak Bay is normally intruded from the Gulf of Alaska via Kennedy Entrance. A variety of evidence suggests that this water originates with coastal upwelling northwest of Elizabeth Island located just south of southernmost Kenai Peninsula. The general scheme of surface and subsurface circulation in outer Kachemak Bay in summer (Figure 3) indicates two adjacent, counter-rotating gyres on the south side of the bay and a net northwest current out of the bay, parallel to the north shore between Homer Spit and Anchor Point. It is uncertain how accurately Figure 3 reflects winter conditions; variations in the observed pattern are frequent, even in summer.

The inner bay is a positive estuary in summer when river runoff and precipitation exceed evaporation. The surface circulation (Figure 3) is characterized by two adjacent, counter-clockwise gyres over the southern, deep water part of the bay, and a southwest, longshore current over the shallow northern part of the bay.

There is little direct evidence, but relatively saline water from below 30 m is probably entrained into the inner bay from deeper than 30 m, coinciding with a net outward flow of low salinity water at the surface. The inner bay is well-mixed, with salinities ranging from near zero at the

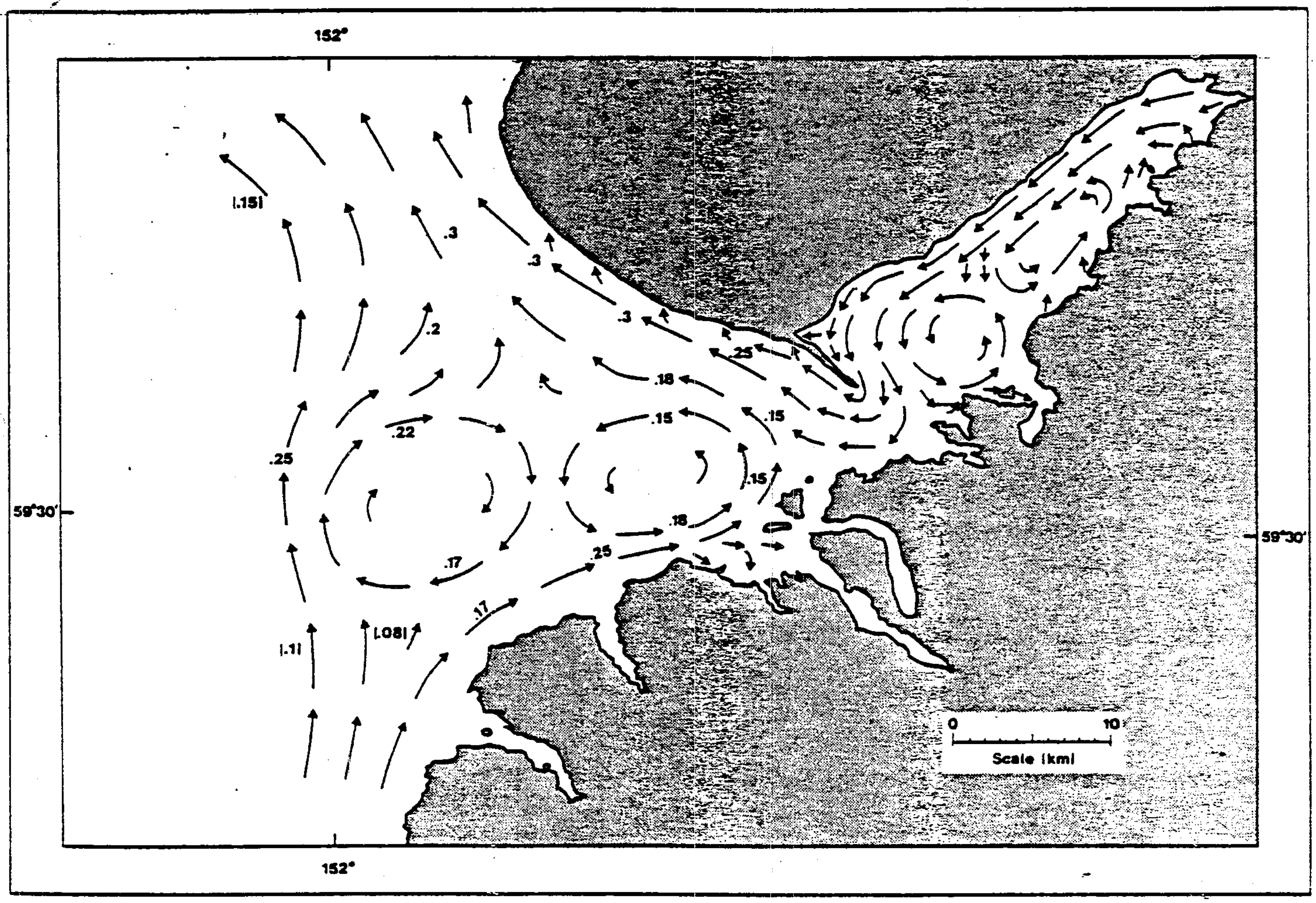

Figure 3. Surface circulation in Kachemak Bay in spring and summer, with typical net surface current velocities in knots. After Burbank 1977 and SAI 1979.

head of the bay near river mouths, to as high as 32.5°/oo (parts per thousand) at the entrance to the inner bay (Bright, Durham and Knudsen 1960, as cited by Burbank 1977). However, typical salinity values for summer 1973 were 29-30°/oo even in the more saline outer bay (Shumacher, Sillcox, Dreves & Muench 1978). Circulation patterns directly influenced the transport of mineral sediments and organic detritus. Sedimentation affects substrate type and thus, the nature of benthic animal communities, and organic detritus is believed to form the base of the ecosystem in Kachemak Bay (Lees et al. 1980).

There is little oceanographic information for Kachemak Bay in winter. In early March 1977, temperatures were 6°C and salinities were about 32°/oo in Kennedy Entrance from the surface to the bottom, indicating a well-mixed water column (Shumacher et al. 1978). Given the current pattern noted above, temperatures and salinities were likely similar in outer Kachemak Bay. During this study, surface water temperatures generally ranged from 4 to 5°C.

In severe winters, ice builds up considerably in the inner bay behind Homer Spit. Most ice probably forms from freshwater runoff at the head of the Bay and is carried by ebbing tides and the prevailing northeast wind to the Spit. During this study, moderate amounts of pan and brash ice were encountered in Homer Harbor and adjacent areas of the inner bay during each month from December to March. In particularly severe winters, fast ice has extended up to three miles off the north shore of the outer bay, but such ice was not seen during this study. Ice scouring of the bottom in intertidal and shallow subtidal depths can adversely affect the benthos (Lees et al. 1980), thus directly influencing the distribution and abundance of the birds' prey.

Primary Productivity

The classical view of primary production in the sea emphasizes the role of phytoplankton in the water column (e.g., Sieburth and Jensen 1970; Strickland 1970; Steele 1974). Larrance and Chester (1979) believe that zooplankton grazing on the phytoplankton and the subsequent production and sinking of fecal pellets was the main source of organic detritus reaching the floor of outer Kachemak Bay. Phytoplankton productivity in the water column was consistently high from May to August 1978. The significance of phytoplankton production during the remaining two-thirds of the year from September to April remain unknown, but it is probably insignificant in mid-winter. The existence of phytoplankton production within and beneath the ice (cf. McRoy and Goering 1974) has not been observed (nor suspected) in Kachemak Bay, because of the ice's freshwater origin, instability, and relatively short duration.

The importance of phytoplankton production should not be minimized, but organic detritus from other sources may play a major role in driving coastal marine ecosystems (Tenore 1977; Sieburth and Jensen 1970; Strickland 1970; Mills 1975). This may be particularly true for Kachemak Bay. Lees et al. (1980) contend that laminarian and fucoid kelps around the southern end of the Kenai Peninsula and in Kachemak Bay are the major source of this detritus. Other sources of the total load of organic detritus in the bay are of terrestrial origin via streams, from salt marshes bordering the bay (Crow 1978), and from peat sloughing directly into the bay from the bluffs along the north shore (M.P. Wennekens, personal communication). While the relative importance of phytoplankton productivity and organic detritus from its various sources remains quite unclear, it seems likely that the seasonal die-off and abrasion of kelp during winter storms could be a major source of detritus in Kachemak Bay, when productivity of phytoplankton is at its lowest.

Another unexplored source of productivity in Kachemak Bay could be water soluble organic fractions from kelp (Lees et al. 1980). Up to 40% of all production by kelp may result in such material (Sieburth and Jensen 1970). This material has been shown to be important in collating and precipitating detritus, and it may be used directly as an energy source by bacteria (Sieburth 1968).

Regardless of the origins of organic detritus in Kachemak Bay, the important point concerning the winter feeding ecology of marine birds is that most of the birds' prey species are deposit or filter-feeders (Lees et al. 1980; Feder and Paul 1979). As such, they are able to use organic detritus and its bacterial coating and associated microfauna (Tenore 1977) for food, so the birds' food supply is closely linked to the existence and production of organic detritus.

Distribution of Pelagic Fauna

Given the dynamic nature of the movements and numbers of pelagic fauna and the incomplete picture of their status in Kachemak Bay in winter, it is difficult to relate distribution or abundance of birds to that of their pelagic prey. However, general ideas of distribution and abundance of some organisms are available (Blackburn 1978; Haynes 1977; Barr 1970; and information from these and other sources as summarized by SAI 1979).

Birds ate a number of fish species (see below) but only three, Capelin (*Mallotus villosus*), walleye pollock (*Theragra chalcogramma*), and Pacific sand lance (*Ammodytes hexapterus*), were important to one or more bird species. There is little data available for these species in winter, but it seems likely that juvenile capelin (age classes I and II) occur from the surface to mid-depths, or perhaps even to the bottom. Although juvenile capelin stay near the surface above the thermocline in the western Atlantic in summer (Jangaard 1974), winter temperatures are likely uniform from the surface to the bottom in Kachemak Bay, and capelin may be distributed throughout the water column.

Even less is known about the winter habits of pollock and sand lance. Presumably pollock occur mainly at mid-water and demersal depths (Smith 1979) and sand lance are found mainly in, on, or near the bottom (Meyer et al. 1979). Sand lance were very important to oldsquaw collected in the shallow inner bay and, with the distinctive benthic character of the rest of the prey of oldsquaw, it seems quite possible the birds captured sand lance while they were buried in the bottom sediment (Meyer et al. 1979). Salmonids were not recorded in the diets of any birds, most likely because they are not abundant in the bay until late May (Blackburn 1978).

In the southern, deep portion of the outer bay in January 1967, pink shrimp (Pandalus borealis) were found from the surface to the bottom at night, but mainly concentrated at the 20-30 m level. During daylight hours they remained below 50 m (Barr 1970). Shrimp are thus available to the birds throughout the water column at some time in their diurnal cycle.

There is very little information on the distribution of the birds' benthic prey. This circumstance is discussed subsequently.

METHODS

FIELD METHODS

We collected birds for stomach samples and observed their distribution and feeding behavior during monthly field trips of three to five days, from November 1977 to April 1978 (Table 2). We worked in three general areas of the bay, largely determined by the prevailing weather and by the birds' distribution in areas safely reached from Homer Harbor in the 6.7 m (22 ft.) work boat. We collected sea ducks in two areas within a few kilometers of shore: 1. Between Homer Spit and Anchor Point in the outer bay; and 2. Between Homer Spit and Fritz Creek in the inner bay (Figures 4 and 5). In addition, we had available two white-winged scoters that had been collected off Seldovia Bay in February 1977. Most murres and murrelets were collected in a third area on the south side of the inner bay between Gull Island and Glacier Spit (Figure 6 and 7). In addition, we collected murrelets in China Poot Bay in January.

We patrolled one of the three areas until adequate concentrations of a desired species were seen. The behavior of birds to be collected was observed briefly before we attempted to obtain samples of at least five birds. Due to the constant threat of storms and the short winter daylight, we worked in a given area as quickly as possible and moved on to another area to seek the other desired species. The stomachs of all specimens were injected with 10% buffered formalin to arrest digestion (van Koersveld 1950). Specimens were then frozen until laboratory processing. Field data recorded for individual specimens included the location, date and time of collection.

LABORATORY METHODS

Frozen specimens were stored in a laboratory freezer until processing, which was usually completed within two weeks. For initial processing, specimens were thawed and we recored standard ornithological measurements and a "fat index," a qualitative evaluation of the amount of body fat (Table 3). We determined the sex and age of the specimen, removed the upper digestive tract (esophagus, proventriculus, and gizzard), and stored it in 50% isopropanol until analyzing the stomach contents.

To analyze the stomach contents, we carefully opened the digestive tract with fine pointed scissors and removed any non-food items such as rocks. The stomach contents were drained of excess moisture, weighed to the nearest 0.1 g, and their volume measured to the nearest ml by water displacement. We then counted and identified the prey items to the lowest possible taxon, and visually estimated the volume of each kind of prey as a percent of the total. The greatest length of whole specimens were measured

Table 2. Dates and numbers of birds collected in Kachemak Bay, Alaska, in winter for feeding ecology studies.

Number of Birds Collected

Species	1977			1978				
	Feb. 22	Nov. 9-13	Dec. 6-10	Jan. 9-12	Feb. 8-12	Mar. 6-9	Apr. 3-5	TOTALS
Oldsquaw		5	5	5	5	6	2	28
White-winged scoter	2	1	2	14	10 [c]	5 [a]	5	39
Black scoter		1					1	2
Surf scoter			1			1	2 [b]	4
Common murre			6	9	5 [b]	6 [c]	5	31
Pigeon guillemot				1		1	1	3
Marbled murrelet				6	5 [c]	5 [d]	5	21
Totals	2	7	14	35	25	24	21	128

a no prey volume data on 1 bird
b 2 empty stomachs
c 1 empty stomach
d No prey volume on 2 birds

Table 3. Criteria for determining the fat index of marine birds, modified after scheme designed for use on freshwater waterfowl (U. S. Fish & Wildlife Service, Northern Prairie Wildlife Research Center, Jamestown, ND).

Fat Index	Visibility of Feather Papillae on Breast	Presence of Fat on			
		Viscera and Neck	Skin	Humerus and Femur Region	Bifurcation of Clavicles
1	Very Evident	Very little	None	Little fascia and grey-orange fat	None
2	Still visible	Some	Some	Slight streak along femur	Slight streak along trachaea anterior to
3	Visible in dorsal half of belly tracts only	Moderate	Partially covered	Present	Present
4	Not visible through skin	Consolidated masses	Completely covered	Moderate	Moderate
5	Not visible through skin	Consolidated masses	3-6mm thick extending over lower belly	Heavy	Heavy

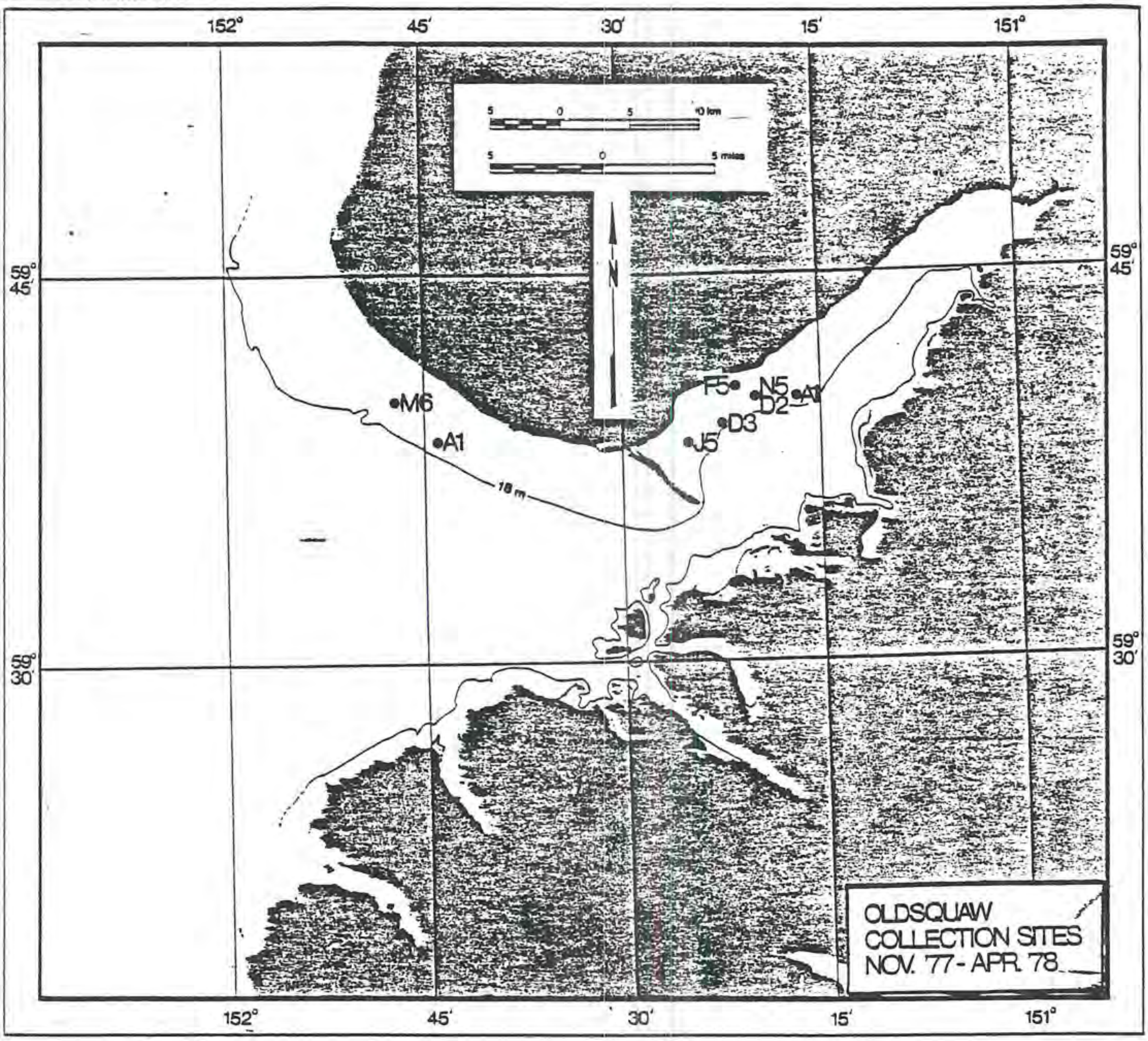

Figure 4. Collection sites of oldsquaw ducks. Letters and numbers indicate month and number of birds collected.

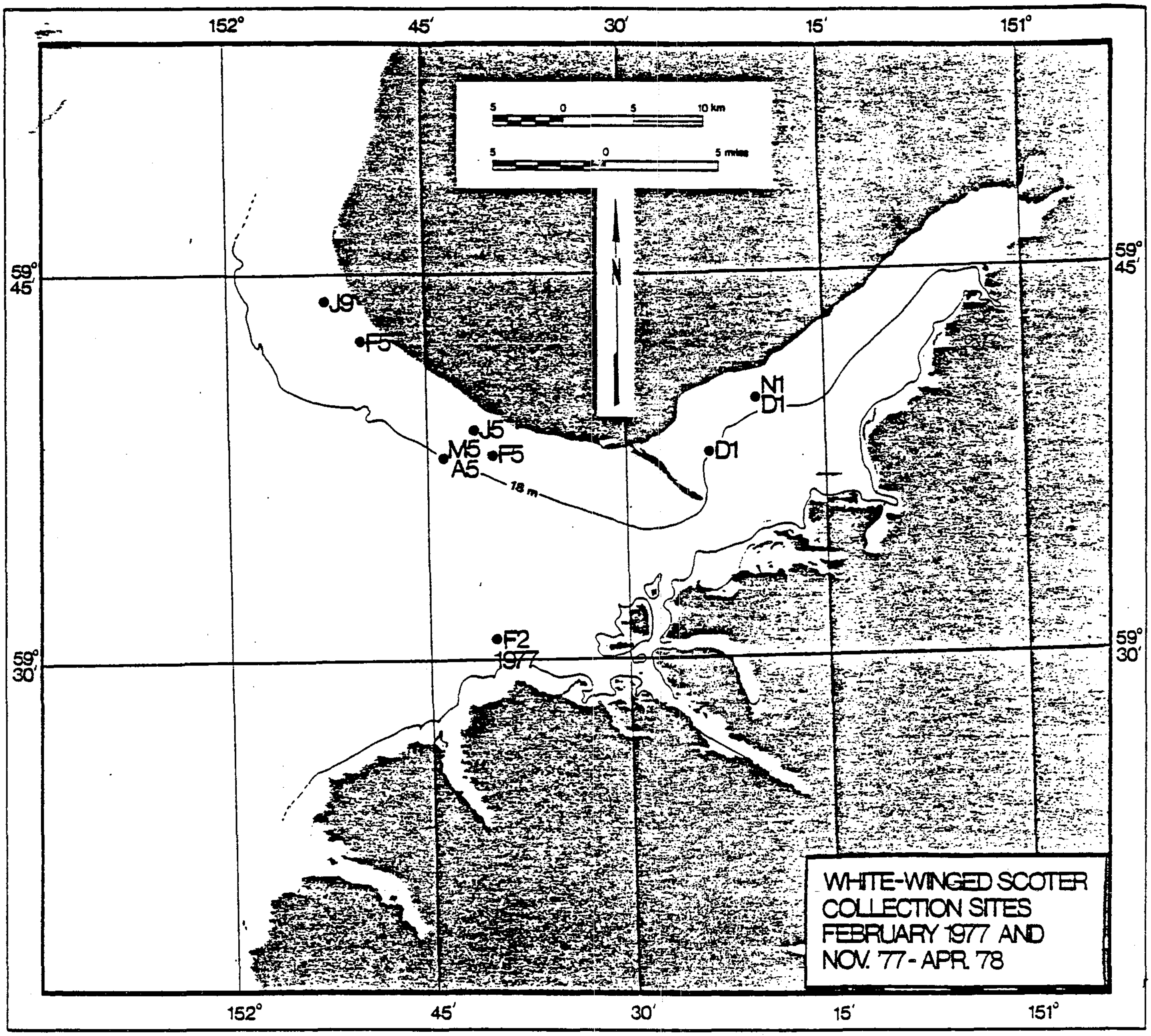

Figure 5. Collection sites of white-winged scoters. Letters and numbers indicate month and number of birds collected.

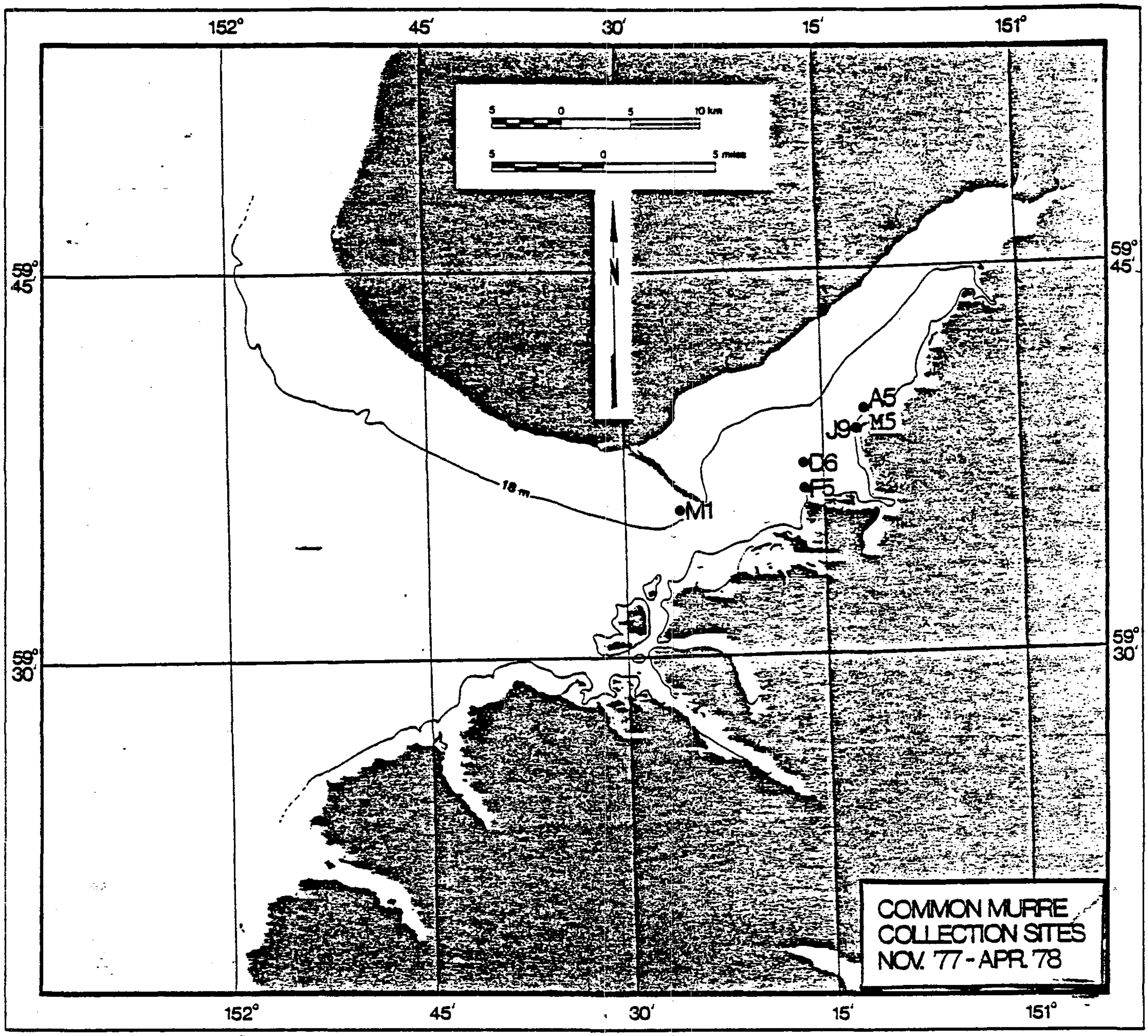

Figure 6. Collection sites of common murres. Letters and numbers indicate month and number of birds collected.

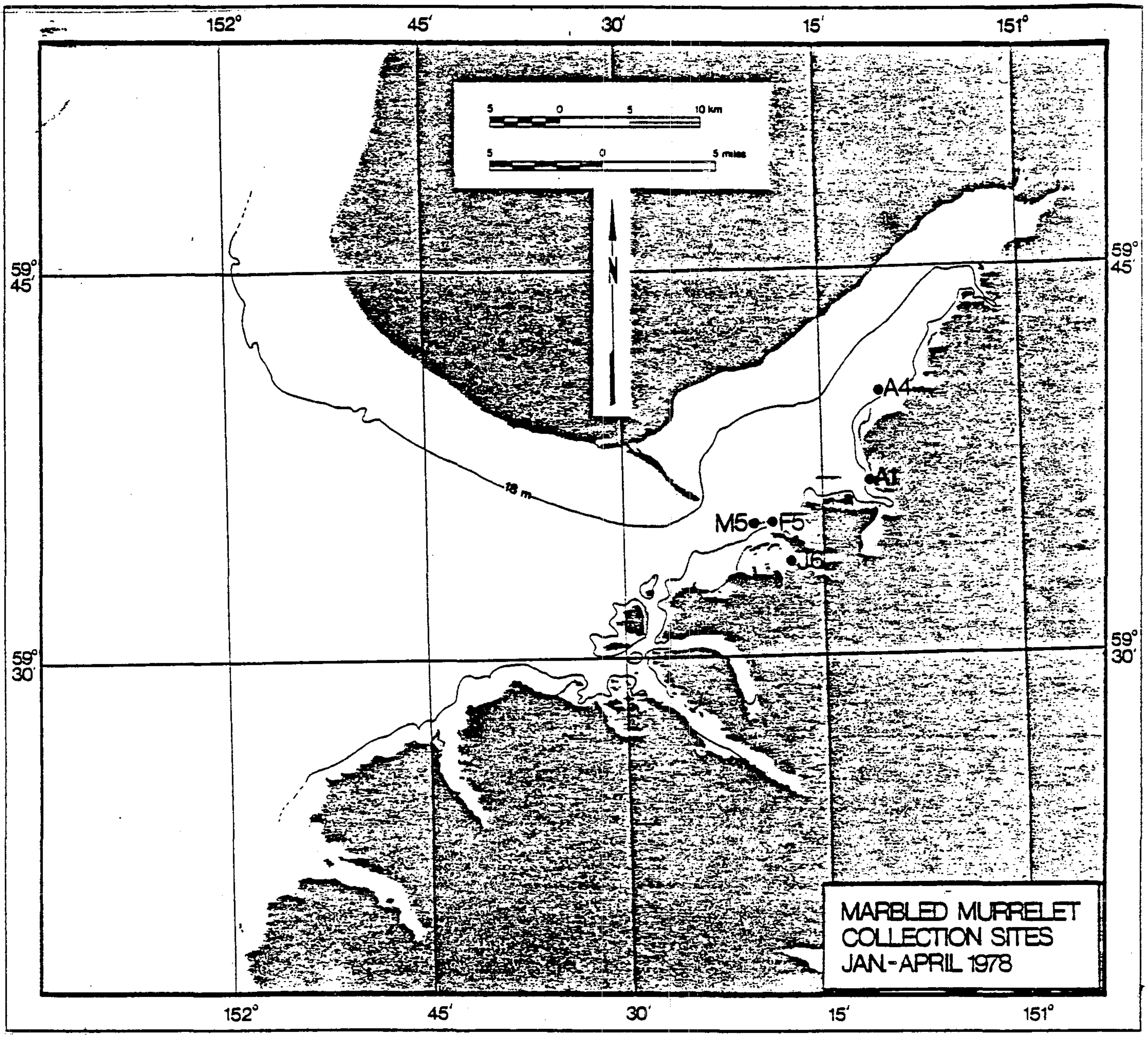

Figure 7. Collection sites of marbled murrelets. Letters and numbers indicate month and number of birds collected.

to the nearest mm, or in the case of fish otoliths (Frost and Lowry, in press) and fish vertebral columns and parasphenoid bones (Sanger et al. 1978), to the nearest 0.1 mm. We verified our prey identifications by consultation with taxonomic specialists (see Acknowledgments) and maintained a collection of voucher specimens for comparison with subsequent collections.

DATA ANALYSES, INTERPRETATION, AND PRESENTATION

This report analyzes the feeding ecology of the birds by examining their food habits, their feeding behavior, and their geographic distribution in relation to feeding habitats. We analyzed trophic relationships per se among the birds and their prey by comparing the relative importance of each prey among the birds and the sizes of the prey when known.

The term "feeding habitat" is defined as the location a bird captures its prey in terms of water depth, and in proximity to the sea surface, the sea bed, and for bottom-feeding birds, by the type of substrate. At times, it may be possible to use oceanographic features to describe feeding habitats, but this seems unlikely in Kachemak Bay in winter when the water column is probably well mixed.

A certain amount of speculation is needed to categorize the feeding habitat(s) of each bird species. However, by comparing the substrate types beneath the birds' collection sites (Driskell and Lees 1977) with what is already known about a bird's feeding behavior and the normal habitats of the prey in their stomachs, such speculation is credible. We collected birds only if they were sitting on the water, and have assumed that they captured their prey in the immediate vicinity. We often saw oldsquaw, common murres, marbled murrelets, and pigeon guillemots diving and presumably feeding before we collected them.

Three basic parameters were used to describe prey taxa in the stomach samples: The aggregate percent volume (cf. Martin, Gensch and Brown 1946; and Swanson et al. 1974); the aggregate percent numbers; and the percent frequency of occurrence. To calculate the aggregate percent volume of a prey taxa, we summed its measured volumes from all stomachs with food and then expressed this total as a proportion of the combined volumes of all prey. Aggregate percent numbers were calculated similarly. We also calculated these parameters for related groups of taxa (total fish, total crustaceans, total shrimp, etc.) to enable us to evaluate the importance of taxonomically related groups of prey. The percent frequency of occurrence is the percent of a sample of stomachs with any prey in which a particular prey taxa was found.

Pinkas, Oliphant and Iverson (1971) discussed the shortcomings of using any of these values alone to depict the importance of prey to a predator. In brief, differential digestion rates of hard and soft-bodied prey may distort their original relative volumes; percent numbers can make an abundant small prey seem more important than sparse larger ones, and percent frequency of occurrence ignores numbers and volume.

To overcome these shortcomings, Pinkas et al. (1971) combined these three values into an Index of Relative Importance (IRI), which we use here. The IRI is defined as:

IRI = %FO (%V + %N), where

%FO = percent frequency of occurrence of a prey taxa or group of taxa in a sample of n birds

%V = percent aggregate volume of a prey taxa, or group of taxa in the combined volume of all taxa in the stomachs of the sample of n birds

%N = aggregate percent numbers of a prey taxa or group of taxa in the combined numbers of all taxa in the stomachs of the sample of n birds.

Depending on the size of the three input parameters and by rounding them to the nearest 0.1%, IRI values can theoretically range from a low of 0.02 i.e., [0.1% (0.1% + 0.1%)] to a high of 20,000, i.e., [100% (100% + 100%)]. Although all of the IRI values and their input parameters appear in appendix tables, we simplified the graphical presentation of the monthly IRI data by assigning "importance levels" of each prey taxa to each bird species. These are based on exponential increments of the IRI values, as follows:

Prey Importance Level	Range of IRI Values
+ ("trace")	1 - 9
1	10 - 99
2	100 - 999
3	1,000 - 9,999
4	10,000 - and up

RESULTS - SPECIES ACCOUNTS

OLDSQUAW

Collection Sites and Sample Sizes

We collected 28 oldsquaw during the study (Table 2), including five each month from November through February in the inner bay, six in March in the outer bay, and one each in the inner and outer bays in April (Figure 4). We collected all specimens within a few kilometers of the north shore of the bay in water less than 18 m. All birds had food in their stomachs, although one taken in April contained only unidentifiable remains.

Food Habits

With a minimum total of 60 prey species (appendix Table 1), oldsquaw had by far the most diverse diet among the four primary bird species studied. The minimum numbers of prey species per month were: November, 22; December, 18; January, 11; February, 24; March, 23; and April, 2. The minimum grand total of 60 species includes at least eight species of gammarid amphipods, which are treated as a group here.

Oldsquaw ate a diverse array of higher taxa as well as prey species. These included: one foraminifera; 9 polychaetes; 14 gastropods; 12 bivalves; 19 crustaceans (including one each, barnacle, mysid, cumacean, and isopod; at least eight gammarid amphipods, three shrimps, and two crabs); one ectoproct, three echinoderms (including two brittle stars one sea urchin); and two fish. IRI values (appendix Table 1), indicate that the most important higher taxa were: bivalves, 2,838; crustaceans, 1,435; fish, 1,168; gastropods, 374; and polychaetes, 321.

Despite the plethora of prey species in the overall diet of the oldsquaw, the Pacific sand lance was considerably more important than any other, based on overall IRI values (appendix Table 1). The next most important taxa overall were the bivalves *Spisula polynyma*, *Mytilus edulis*, *Nucula tenuis*, *Glycymeris subobsoleta*, *Nuculana fossa*, and the snail *Oenopota*. However, except for the sand lance and perhaps *Spisula* and *Mytilus*, it is difficult to say if these species were truly more important than many of the others. The species composition in the diet changed radically from month to month, and many taxonomic groups like crustaceans were collectively more important than some of the individual species of molluscs.

Prey Lengths. The lengths of the 1,150 measurable prey pooled from all of the oldsquaw stomachs ranged from 1 mm *Lacuna* snails, and *Macoma* and *Mytiulus* bivalves, to sand lance of 115 mm; 95% of the prey were less than 10 mm,

Table 4. Total lengths, in 10 mm increments, of all measurable prey from 28 oldsquaw collected in Kachemak Bay in winter

Prey Species	No. of Prey in Length Increments (mm) 0-9	10-19	20-29	30-39	80-89	90-99	100-109	110-119	Total
POLYCHAETA/FORAMINIFERA									
Foraminifera	1								1
Pectinaria sp.		2							2
GASTROPODA									
Admete couthouyi	2	1							3
Aglaja diomedeum	2								2
Alvinia compacta	11								11
Cerithiopsis sp.	1								1
Lacuna variegata	13								13
Mitrella tuberosa	19	3							22
Natica clausa	4								4
Odostomia sp.	6								6
Oenopota sp.	19								19
Onchidoris bilamellata		1							1
Turridae	2								2
BIVALVIA									
Glycymeris subobsoleta	80								80
Macoma sp.	200	6							206
Mya sp.	4								4
Mytilus edulis	503								503
Nucula tenuis	41								41
Nuculana c.f. *fossa*	35	2							37
Orobitella sp.	1								1
Protothaca staminea	19								19
Saxidomus gigantea	1								1
Spisula polynyma	107								107
CRUSTACEA									
Gammarid Amphipods	13	7	3	2					25

Table 4 (continued)

Prey Species	No. of Prey in Length Increments (mm) 0-9	10-19	20-29	30-39	80-89	90-99	100-109	110-119	Total
Cancer oregonensis	1	8							9
Crangon septemspinosa			1						1
Cumacea	2								2
Gnorimosphaeroma oregonensis	1								1
Hyas lyratus	3	1							4
Mysids		1							1
Spirontocaris spina			1						1
ENCHINODERMATA									
Echinoidea				1					1
Ophiuroidea	3	1							4
FISH									
Ammodytes hexapterus					5	4	2	4	15
TOTALS	1094	33	5	3	5	4	2	4	1150
Percent of Total	95.1	2.9	0.4	0.3	0.5	0.3	0.2	0.3	

and only 2% were over 19 mm (Table 4). The mean length of all measurable prey was 6.8 mm (S.E. = 0.33) (Table 5). Most of the measurable prey were gastropods (n = 84) and bivalves (n = 99).

Data on the length frequencies of the prey are plotted by 2- mm increments for the invertebrates (Figures 8 through 11) and by 10- mm increments for sand lance (Figure 11). The gastropod Mitrella tuberosa ranged from 1- to 12- mm (Figure 8), the large individuals being considerably larger than the ca. 6.4 mm (1/4 inch) size normally attained by the species (Abbott 1974). However, about 73% of the 84 measurable gastropods were less than 6 mm (Figure 8).

Similarly, most of the bivalves were less than 6 mm but the data for Macoma and Mytilus (Figure 9), and Nuculana (Figure 10) suggest the presence of at least a few older animals. If the age-length ratio of Nuculana fossa in Kachemak Bay is similar to Cook Inlet in general, those eaten by oldsquaw were mostly in year classes 0, 1, or 2, with a few 4's and 5's (Feder and Paul 1980). Similarly, Nucula tenuis clams eaten by oldsquaw were less than 10 mm (Table 4), and ranged up to age 7. By the same inference, Glycymeris subobsoleta, also less than 10 mm, were age 3 or less, while Spisula polynyma, 88% of them 2-4 mm (Figure 10), were all age class "0" (Feder and Paul loc cit.). Abbott (1974) notes 76 mm as the maximum length attained by Mytilus edulis, so those of less than 10 mm eaten by oldsquaw were clearly juveniles.

Most of the gammarid amphipods were less than 16 mm, but a few were 26 to 36 mm (Figure 11). The sand lance, probably mostly two-year old fish, ranged in length from about 80- to 115- mm and averaged about 98- mm (Figure 10).

Monthly Changes In Prey Importance. The small sample sizes and variation in collecting sites preclude statistical evaluation of monthly changes in the importance of individual prey species or groups, but general trends are indicated. Fish, mostly sand lance, were present in the oldsquaw diet each month except February and April (Figure 12). Crustaceans were consistently of moderate importance throughout the study (Figure 12), although no one species nor taxonomic group was of particular significance. Total shrimp and total crabs (Figure 12), and total gammarid amphipods (Figure 13) fluctuated in their importance in no apparent orderly fashion. The shrimp Spirontocaris (Figure 12), mysids (Figure 13), and echinoderms (brittle stars and sea urchins, Figure 12) occurred only in the diet of birds collected in the outer bay during March.

Table 5. Mean lengths of all measurable prey from marine birds collected in Kachemak Bay in winter.

Species	N Prey	Length of Prey, mm $\bar{X}$	S.E.	Min.	Max.
Oldsquaw	1,150	6.8	0.33	1	115
White-winged scoter	103	13.6	1.42	4	105
Surf Scoter	4	7.5	0.85	6	9
Common Murre	174	44.6	1.67	31	179
Pigeon Guillemot	15	28.3	2.94	17	66
Marbled Murrelet	138	26.3	2.02	4	135

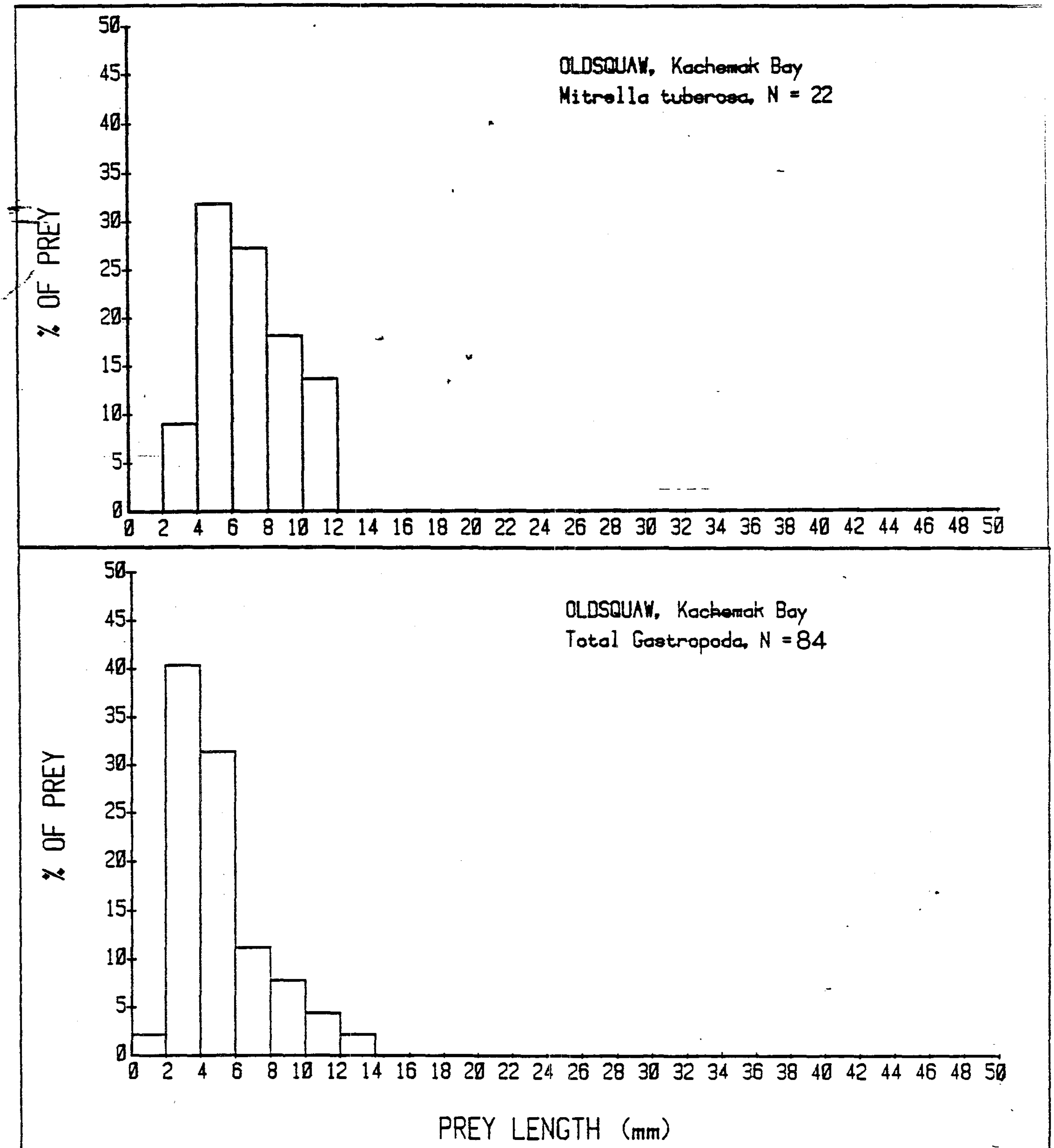

Figure 8. Length frequencies of the columbellid gastropod Mitrella tuberosa (top) and all gastropods (bottom) in the stomachs of oldsquaw from Kachemak Bay in winter.

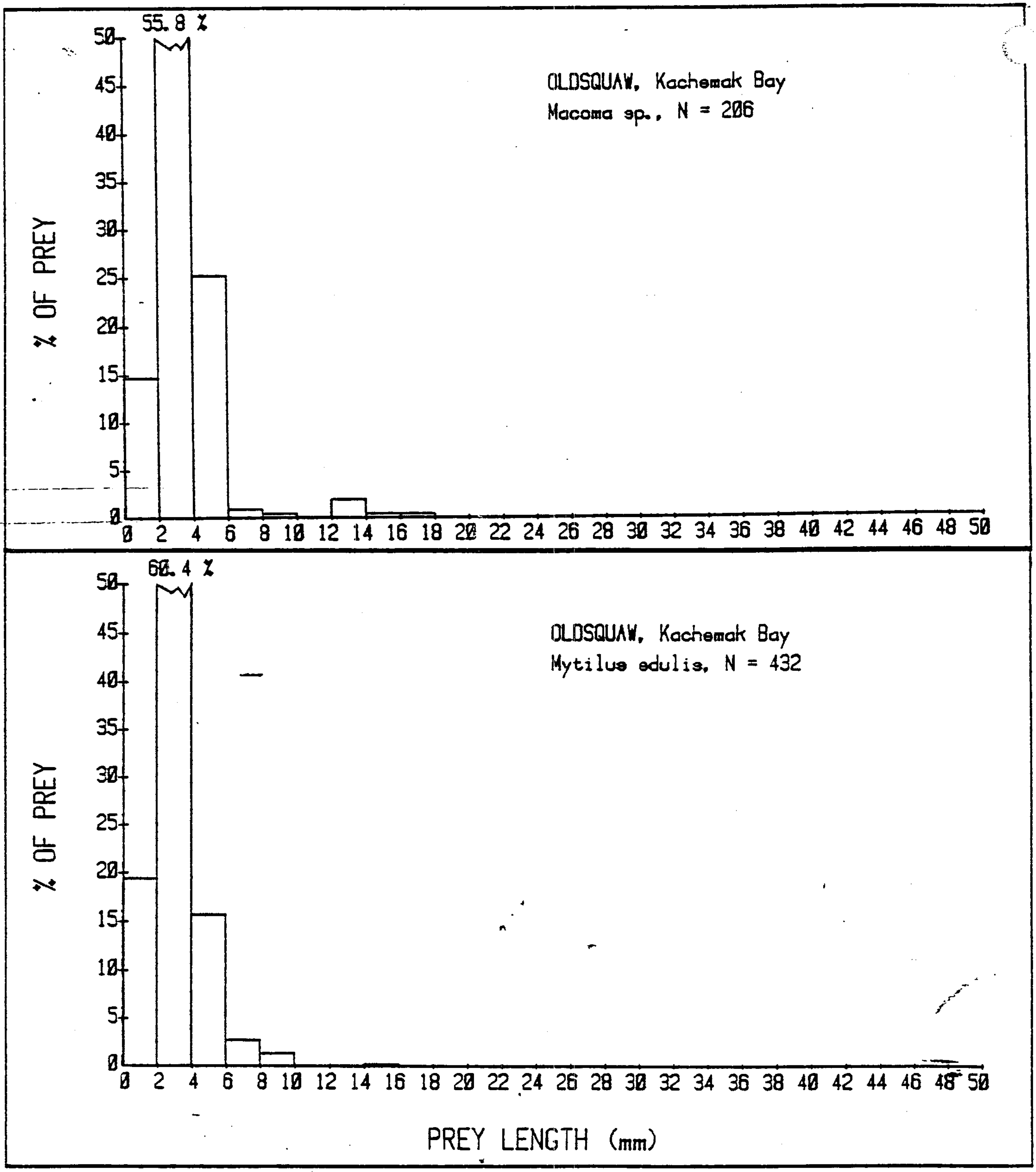

Figure 9. Length frequencies of the tellinid clam _Macoma_ sp. and the blue mussel _Mytilus edulis_, in the stomachs of oldsquaw from Kachemak Bay in winter.

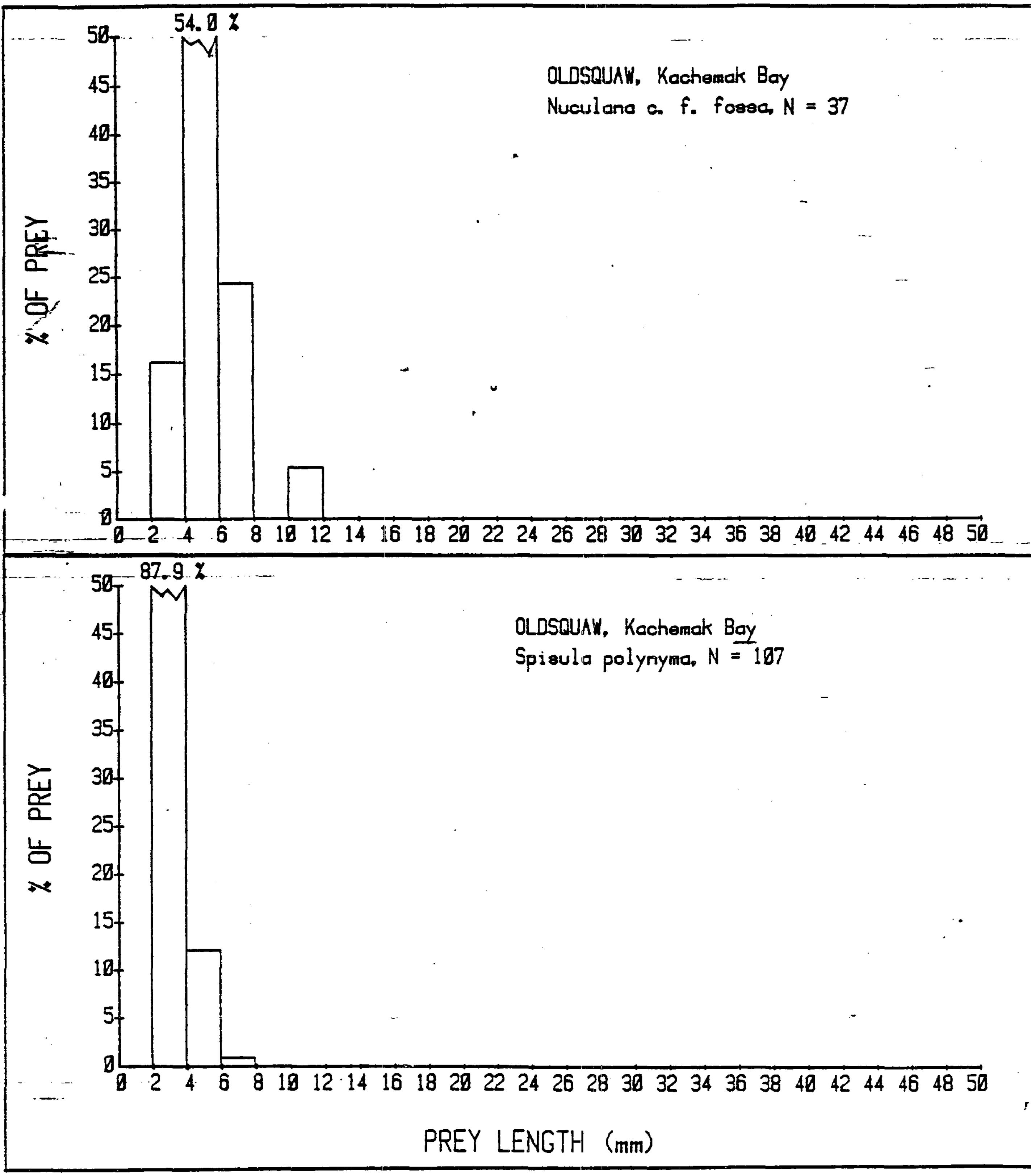

Figure 10. Length frequencies of the nuculanid clam Nuculana fossa and the mactrid clam Spisula polynyma in the stomachs of oldsquaw from Kachemak Bay in winter.

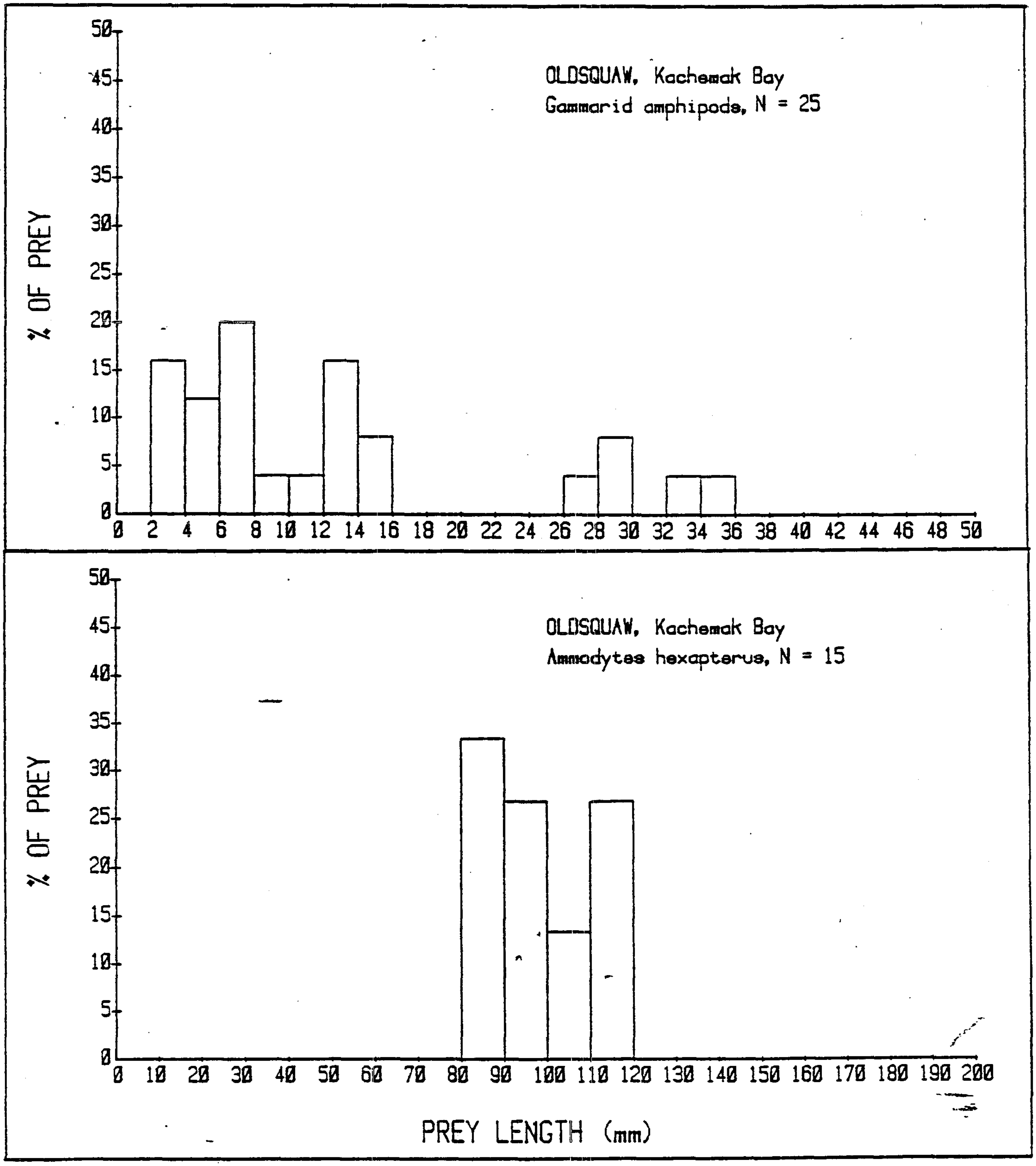

Figure 11. Length frequencies of gammarid amphipods (crustacea) and Pacific sand lance, *Ammodytes hexapterus*, in the stomachs of oldsquaw from Kachemak Bay in winter.

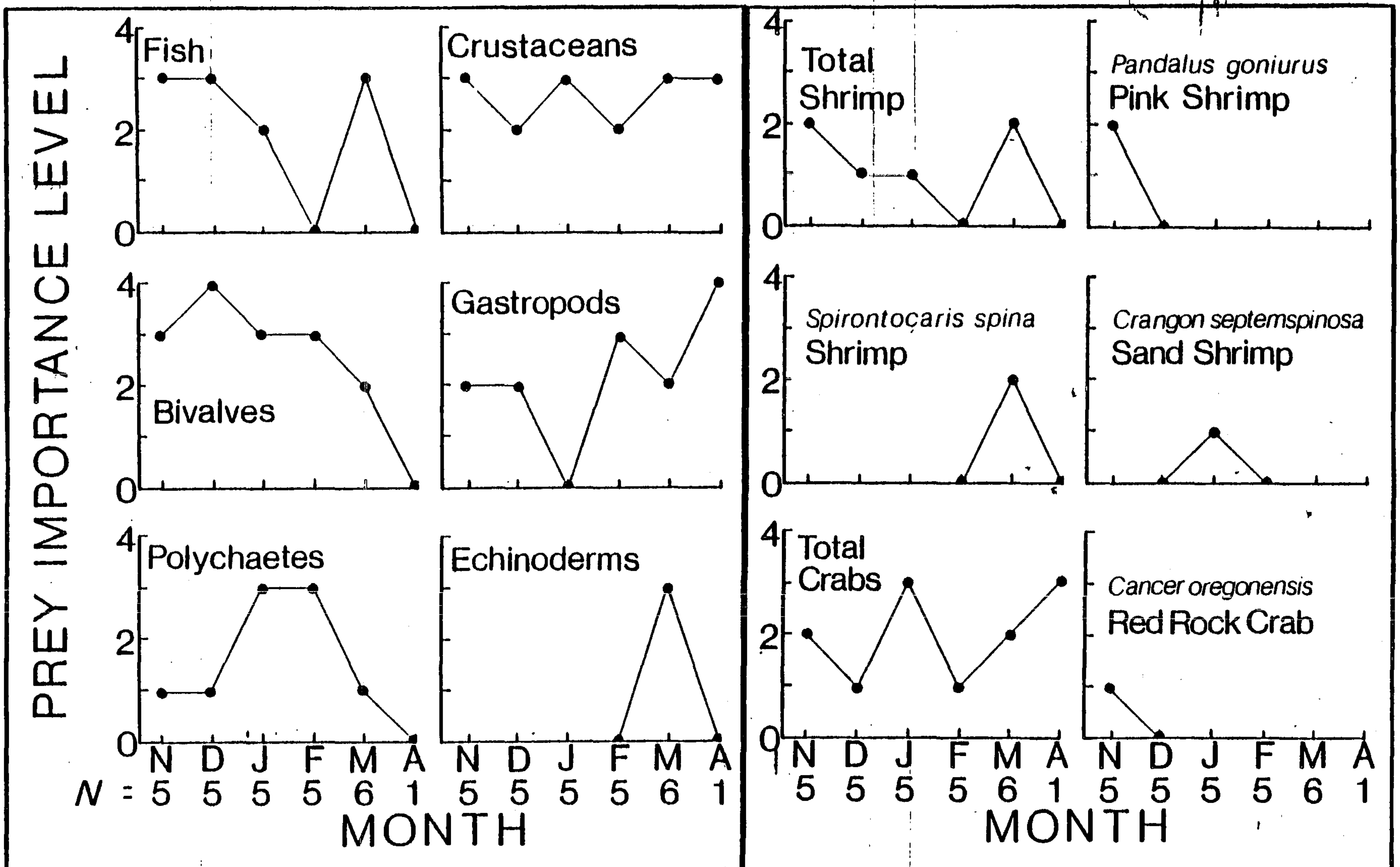

Figure 12. Monthly changes in the importance of major groups of prey (left panel) and crustaceans (right) in the diet of oldsquaw from Kachemak Bay in winter.

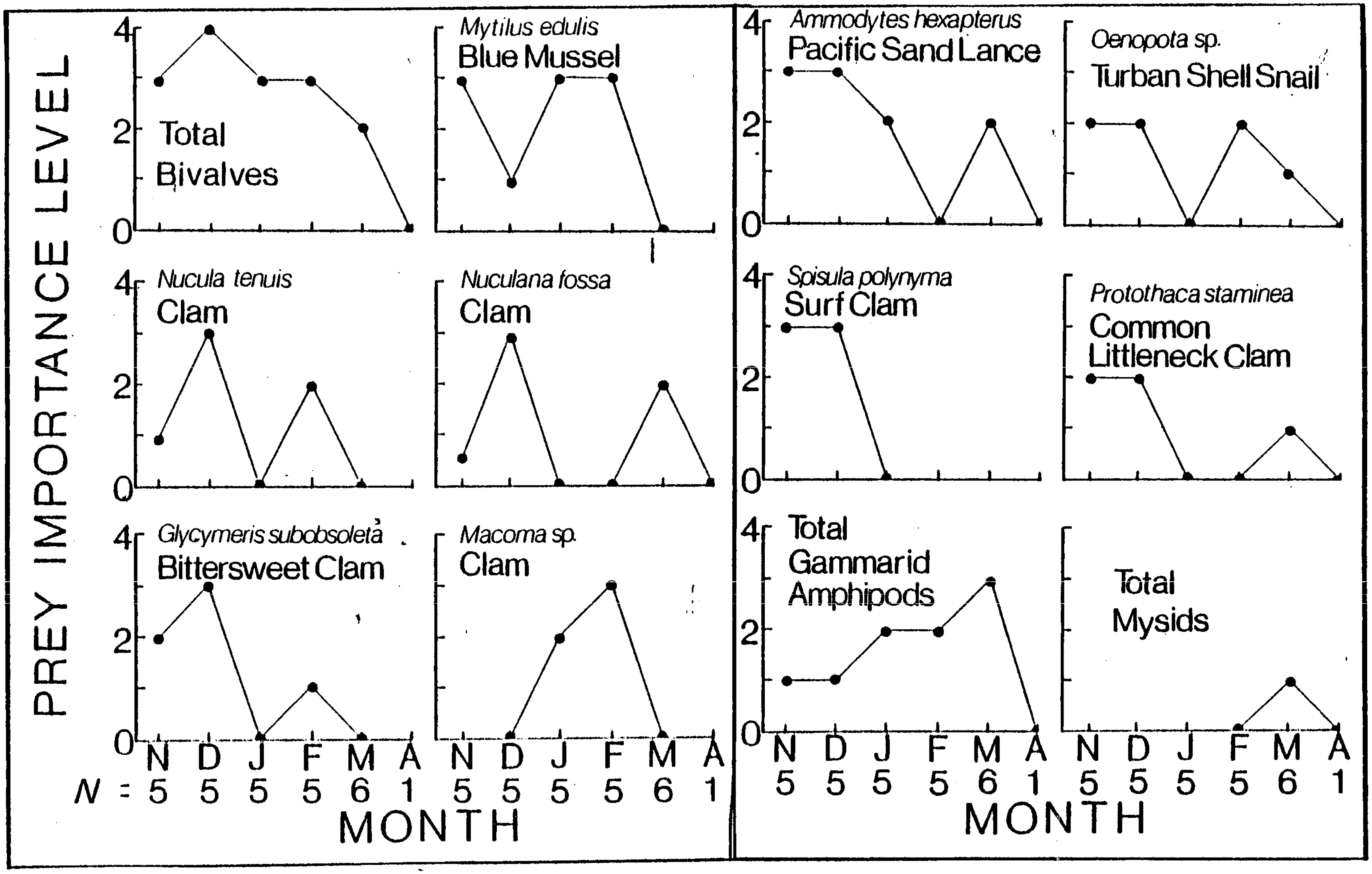

Figure 13. Monthly changes in the importance of bivalves (left panel) and miscellaneous prey (right) in the diet of oldsquaw from Kachemak Bay in winter.

Food Weight as Percent of Body Weight. The weight of food in stomachs as compared to the weight of individual birds ranged from a low of 0.2% in November and February, to a high of 3.0% for a bird in March (Table 6). The maximum value was the result of 20 g of food in a 674 g bird. Average monthly values were very low, ranging from 0.45% (S.E. = 0.15) in April, to 1.6% (S.E. = 0.32) in March, and with an overall average for the 28 specimens of 1.0% (S.E. = 0.19) (Table 6). Sixteen birds (57%) had values less than 1.0, and only four birds (14%) had values greater than 1.5. The oldsquaw, however, was the only species studied which had no empty stomachs.

Feeding Behavior and Feeding Habitats

The locations of the oldsquaw collection sites (Figure 4) and the known habitats of their prey indicate that oldsquaw fed benthically on both infauna and epibenthos (Figure 14). The oldsquaw were distributed mainly in the northern inner bay over mud/sand substrates, but they occasionally fed in shell debris and cobble habitats. With the exception of the sand lance and the various species of shrimp, the oldsquaws' prey are sessile, or only very weakly mobile. The birds' mode of capturing the sand lance may only be surmised, but it is possible that they captured these fish when they were buried in the sand (Meyer et al. 1979). Indeed, the preponderance of sessile animals in their diets may indicate a limited adaptation for capturing quickly moving fauna.

Net Body Weight and Fat Index

The net body weights of 15 male oldsquaw ranged from 753 g to 956 g and averaged 868 g; similar weights for 13 females ranged from 670 g to 888 g, and averaged 777 g (Table 7). An analysis of variance by the least squares method (1 and 16 degrees of freedom, $F = 14.56$) showed these means to be different at the 99% level of significance. A least squares analysis of variance also showed no significant differences in mean body weights among months.

The fat index (Table 8; Figure 15) ranged from one to five for individual birds. Monthly means ranged from a high of 4.2 (S.E. = 0.80) in November to a low of 2.5 (S.E. = 0.50) in April with decreasing monthly values throughout these months. A one-way anlaysis of variance suggested a 95% probability of significant difference among the monthly means at the 0.5 level ($F = 2.28$; $p = 0.80$). Figure 15 shows considerable overlap in standard errors for oldsquaw between November and December, and from January through April, with a break between December and January. This suggests that the birds were significantly fatter early in the winter than later.

Table 6. Food weight as a % of net body weight for marine birds collected in Kachemak Bay, November 1977 - April 1978.

Species	November n $\bar{X}$ S.E. min - max	December n $\bar{X}$ S.E. min - max	January n $\bar{X}$ S.E. min - max	February n $\bar{X}$ S.E. min - max	March n $\bar{X}$ S.E. min - max	April n $\bar{X}$ S.E. min - max	Total[a/] n $\bar{X}$ S.E. min - max
Oldsquaw	5 0.7 0.22 0.2-1.3	5 1.0 0.24 0.4-1.7	5 0.8 0.14 0.5-1.3	5 0.9 0.30 0.2-1.9	6 1.6 0.32 0.8-3.0	2 0.45 0.15 0.3-0.6	28 1.0 0.19 0.2-3.0
White-winged Scoter[a/]	1 2.5 -- - - -	2 2.6 -- 2.3-2.8	14 2.1 0.21 1.1-3.4	10 2.6 0.32 0.0 4.1	5 2.0 0.63 0.6-4.1	5 2.1 0.63 0.8-3.9	39 2.2 0.16 0.0-4.1
Black Scoter	1 0.6 -- - - -					1 0.0 -- - - -	2 0.3 -- - - -
Surf Scoter		1 0.5 -- - - -			1 0.8 -- - - -	2 0.2 -- - - -	4 0.4 0.14 0.0-0.8
Common Murre		6 1.6 0.39 0.4-2.9	9 1.0 0.21 0.1-2.1	5 0.1 0.09 0.0-0.5	6 0.8 0.22 0.0-1.5	5 1.0 0.32 0.1-1.8	31 1.0 0.14 0.0-2.9
Pigeon Guillemot			1 0.8 -- - - -		1 3.1 -- - - -	1 0.7 -- - - -	3 1.5 0.64 0.7-3.1
Marbled Murrelet			6 1.6 0.66 0.4 - 3.7	5 1.7 0.94 0.0-5.3	3 3.0 1.8 0.8-6.6	5 1.5 0.6 0.4-3.2	19 1.8 0.42 0.0-6.6

a/ Includes white-winged scoter data for Feb. 77:n=2(2.5 and 0.7), $\bar{X}$ = 1.6

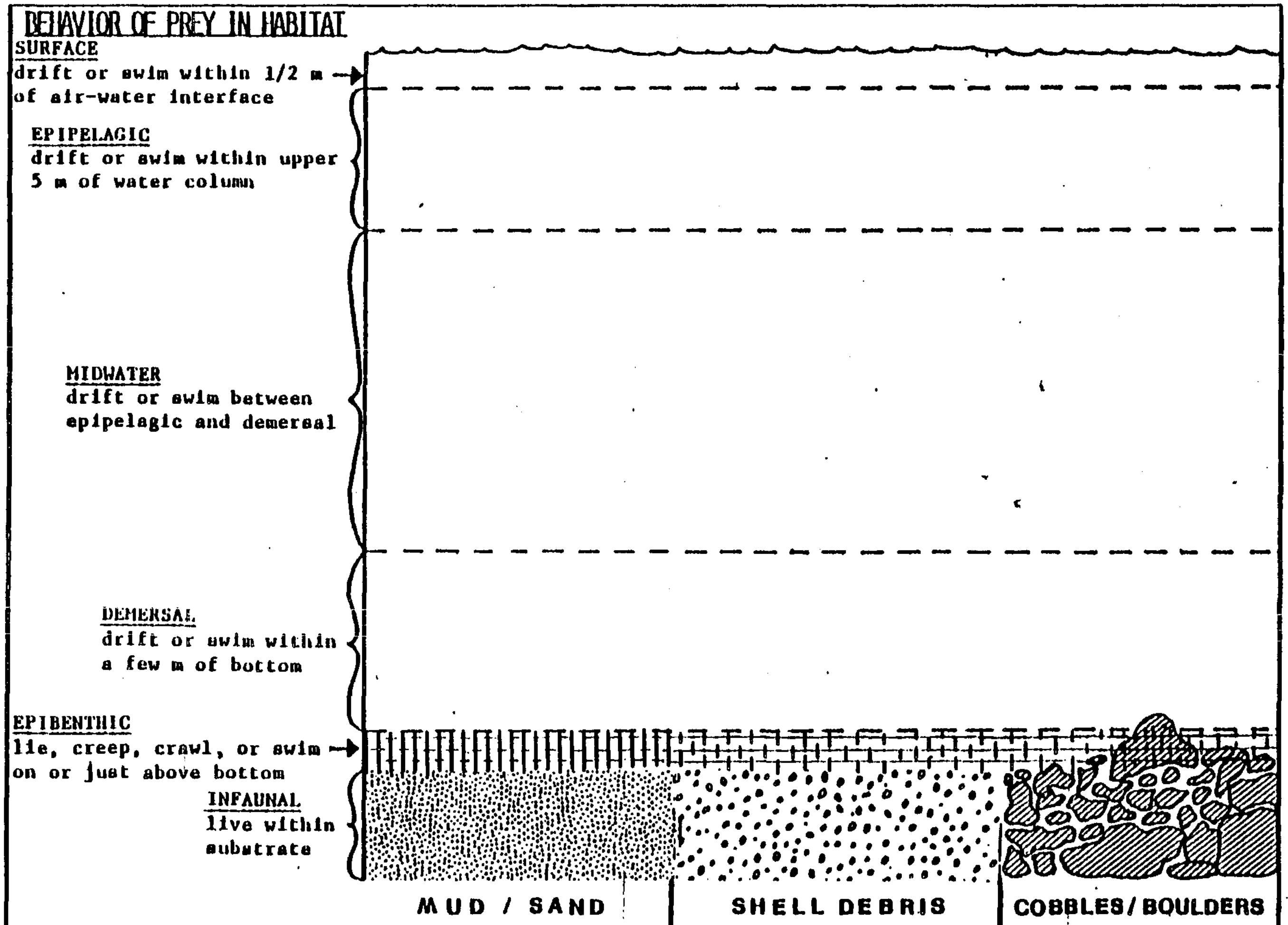

Figure 14. Schematic representation of the feeding habitats of sea ducks in Kachemak Bay in winter, in relationship to all subtidal feeding habitats. Oldsquaw = vertical lines; solid is primary habitat, dashed secondary. Scoters = horizontal lines; solid primary habitat, dashed secondary.

Table 7. Net body weights[a] of marine birds collected in Kachemak Bay, November 1977 - April 1978.

Species	Males				Females				Totals			
	n	$\overline{X}$	min	max	n	$\overline{X}$	min	max	n	$\overline{X}$	min	max
Oldsquaw	15	868	753	956	13	777	670	888	28	826	670	956
White-winged Scoter [a]	29	1,917	1,388	2,128	10	1,732	1,566	1,946	39	1,869	1,388	2,128
Black Scoter	2	1,184	1,118	1,249	-	---	---	---	2	1,184	1,118	1,249
Surf Scoter	3	1,152	1,038	1,223	1	1,053	---	---	4	1,127	1,038	1,223
Common Murre	20	1,111	914	1,253	6	1,119	950	1,214	26	1,113	914	1,253
Pigeon Guillemot	3	566	545	583	-	---	---	---	3	566	545	583
Marbled Murrelet	7	245	220	270	12	233	212	281	19	237	212	281

a/ All birds were in adult plumage, except for five (5) juvenile white-winged scoters collected in January; three males weighed 1,897, 1,936, and 1,966 g; two females weighed 1,704 and 1,762 g. White-winged data includes one each male and female collected February 1977.

Table 8. Fat indices[a/] of marine birds collected in Kachemak Bay, Alaska, November 1977 - April 1978

Species	November n $\overline{X}$ S.E. min - max	December n $\overline{X}$ S.E. min - max	January n $\overline{X}$ S.E. min - max	February n $\overline{X}$ S.E. min - max	March n $\overline{X}$ S.E. min - max	April n $\overline{X}$ S.E. min - max	Total n $\overline{X}$ S.E. min - max
Oldsquaw	5 4.2 0.80	5 3.8 0.37	5 3.0 --	5 2.8 0.21	6 2.7 0.21	2 2.5 0.50	28 3.2 0.20
	1-5	3-5	3	2-4	2-3	2-3	1-5
White-winged Scoter [a/]		2 3.0 --	14 3.1 0.13	10 2.6 0.13	5 2.8 0.37	5 2.0 --	38[a/] 2.8 0.11
		3	2-4	2-3	2-4	2	2-4
Black Scoter						1 2 --	1 2 --
						-	-
Surf Scoter		1 3 --			1 4 --	2 2.5 --	4 3.0 0.35
		-			-	2-3	2-4
Common Murre		6 4.0 0.26	9 3.2 0.22	5 3.2 0.20	5 2.6 0.24	5 2.8 0.37	30 3.2 0.15
		3-5	2-4	3-4	2-3	2-4	2-5
Pigeon Guillemot			1 3 --		1 2 --	1 2 --	3 2.3 0.27
			-		-	-	2-3
Marbled Murrelet			6 3.0 --	5 2.8 0.20	5 2.2 0.49	5 2.2 0.20	21 2.6 0.15
			3	2-3	1-4	2-3	1-4

a/ Includes white-winged scoter data for Feb. 77:n=2, both 4

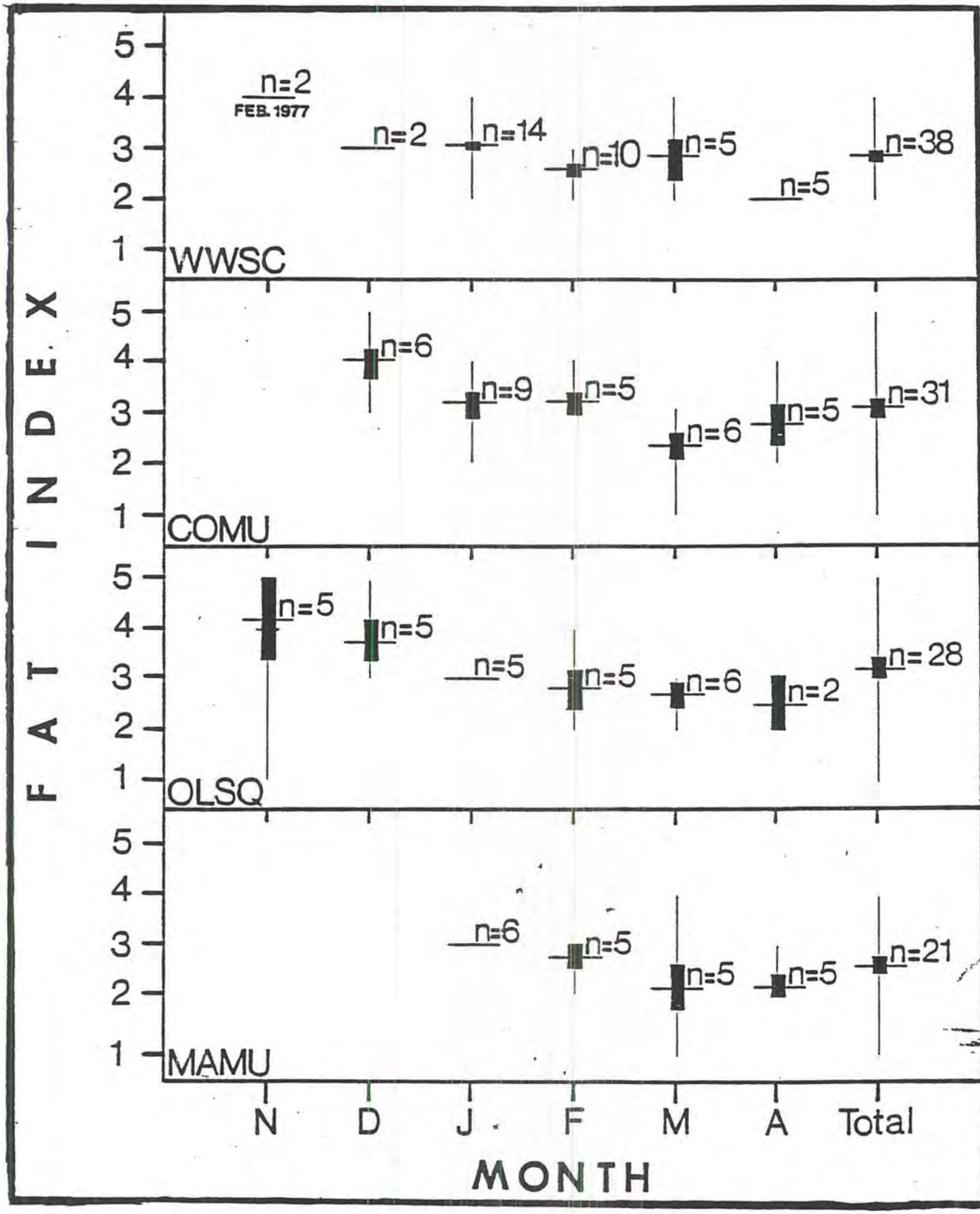

Figure 15. Monthly changes in the mean fat index of marine birds in Kachemak Bay in winter.

WHITE-WINGED SCOTER

Collection Sites and Sample Sizes

We collected 39 white-winged scoters (Table 2). In November and December specimens were collected in the shallow northern part of the inner bay, but during subsequent months we collected scoters only in the outer bay between Anchor and Bluff Points over water shallower than 18 m (Figure 5). Two birds collected in February 1977 were taken in about 40 m of water on the south side of the outer bay. The stomach of one specimen in February 1978 was empty, but the remaining 38 birds (97%) had food in their stomachs.

Food Habits

White-winged scoters had a fairly diverse diet, eating a minimum of 22 species of prey (appendix Table 2). There was one prey species in the birds collected in November and December, six species in the stomachs each month from February through April, and a high of 12 prey species in January.

Overall, bivalves (IRI=6,112) and gastropods (IRI=1,510) dominated the diet of the scoters, and polychaete worms (IRI=16), crustaceans (IRI=16), and echinoderms (IRI=6) were of relatively minor importance (appendix Table 2). The bivalves Mytilus edulis (IRI=1,158) and Protothaca staminea (IRI=1,996) were overwhelmingly the most important prey species. The puppet margarite snail, Margarites pupillus (IRI=151), was relatively important compared to the remaining prey, none of which had an IRI value higher than 60 (appendix Table 2).

Monthly Changes in Prey Importance. Bivalves, and in some habitats gastropods, were consistently important in the diet of the scoters (Figure 16). Other groups of prey were sporadic in their monthly occurrence. Mytilus was the only prey in the three birds collected in the shallow inner bay in November and December (Figure 16). However, the mussels were in an advanced state of digestion, indicating the possibility of their being eaten elsewhere. The littleneck clam, Protothaca staminea, was consistently the most important prey of scoters collected in the outer bay from January through April.

Two birds collected on the south side of the outer bay in February 1977 had eaten mostly clams, Astarte rollandi and glycymeris subobsoleta. One of these birds contained a single Kennerly's venus clam, Humilaria kennerlyi, plus sea urchin spines and fragments of barnacles. Differences in prey species compared to areas on the north side of the bay probably reflect different species in the two areas, rather than differences in prey selection.

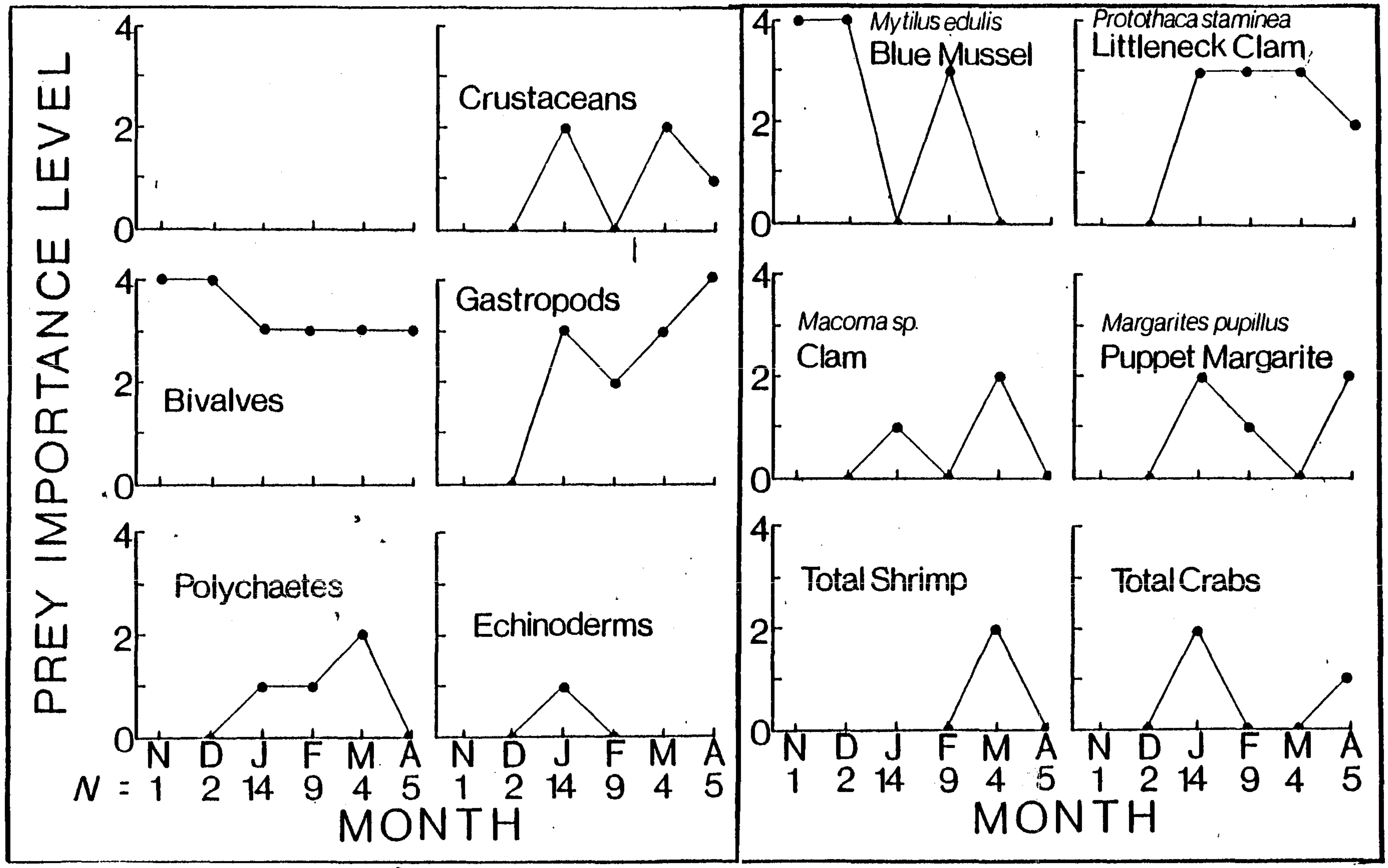

Figure 16. Monthly changes in the importance of major groups of prey (left), and shrimp, crabs, and molluscs (right) in the diet of white-winged scoters from Kachemak Bay in winter.

Prey Lengths. The lengths of the prey eaten by white-winged scoters ranged from common northern admete snails (Admete couthouyi) of 4 mm to a Nephtys polychaete worm of 105 mm (Table 9). The average length of 103 measurable prey pooled from all stomachs was 13.6 mm (S.E.=1.42) (Table 5). In contrast to the sub-10 mm size of the Mytilus eaten by the oldsquaw, the three measurable Mytilus in the white-wings were in the 50-70 mm range (Table 9). Some 90% of the measurable prey in the scoters were less than 20 mm, although the occasional presence of bivalves (Mytilus and Protothaca) and the snail Neptunea lyrata over 40 mm in the scoters shows that they are able to take advantage of larger prey.

Length frequencies of 28 Margarites pupillus snails pooled from the stomachs (Figure 17) indicate that those snails over 8 mm were adults within the maximum size range of 8 to 13 mm attained by the species (Abbott 1974). In contrast, the length frequencies of 37 Glycymeris clams (Figure 17) are smaller than maximum size (about 25 mm) for that species (Abbott 1974). According to Feder and Paul's (1980) data for Cook Inlet in general, G. subobsoleta eaten by scoters were 3 to 7 years old, with a median age of about 5.

Food Weight as a Percent of Body Weight. The weights of food in stomachs as compared to weights of individual birds ranged from zero (empty stomach) in February 1978, to a high of 4.0% for one bird each in February and March 1978 (Table 6). The latter bird, weighing 1,911 g, had 78 g of food in its stomach, the maximum observed in white-winged scoters. The average value for February 1977 was 1.6% (S.E.=0.9), and the average values from November through April were consistently in the 2.0% to 2.6% range. The overall mean for the 39 birds was 2.2% (S.E.=0.16). Only five birds (13%) had values less than 1.0%. This, considered with the fact that only one bird had an empty stomach, suggests that the birds were consistently able to find at least some food.

Feeding Behavior and Feeding Habitats

The locations of collection sites (Figure 5) and the known habits of their prey suggests that scoters fed exclusively in benthic habitats, usually in areas with shell debris and boulder/cobble substrates, but occasionally in sand/mud substrates (Figure 14). The distribution patterns of the birds observed by us and by Erikson (1977) indicate that white-winged scoters occur relatively infrequently in the shallow inner bay over sand/mud substrates. It thus seems possible that the scoters could have captured prey such as Macoma clams and Natica clausa snails, animals typical of sand/mud substrates (Keen and Coan 1974), in pockets of mud/sand amid the shell debris and cobbles typical of the shallow subtidal area of the northern outer bay (Driskell and Lees 1977).

The fairly wide range in prey sizes indicates that while scoters are able to selectively locate and sieze single large molluscs (to 105 mm),

Table 9. Total Lengths, in 10 mm Increments, of all Measurable Prey from 37 White-winged Scoters Collected in Kachemak Bay in Winter

Prey Species	No. of Prey in Length Increment (mm) 0-9	10-19	20-29	30-39	40-49	50-59	60-69	100-109	Totals
POLYCHAETA									
Nephtys sp.								1	1
GASTROPODS									
Admete couthouyi	3	10							13
Littorina sp.	1								1
Margarites pupillus	25	3							28
Natica clausa		1		1					2
Neptunea lyrata			1	1		1			3
Oenopota sp.	1								1
BIVALVIA									
Astarte rollandi	2	5							7
Glycymeris subobsoleta	10	27							37
Mya sp.		1							1
Mytilus edulis						1	2		3
Protothaca staminea		2	1		1				4
CRUSTACEA									
Cancer oregonensis	1								1
ECHINODERMATA									
Strongelocentrotus droebachiensis	1								1
TOTALS	43	50	2	2	1	2	2	1	103
Percent of Total	41.8	48.6	1.9	1.9	1.0	1.9	1.9	1.0	100.0

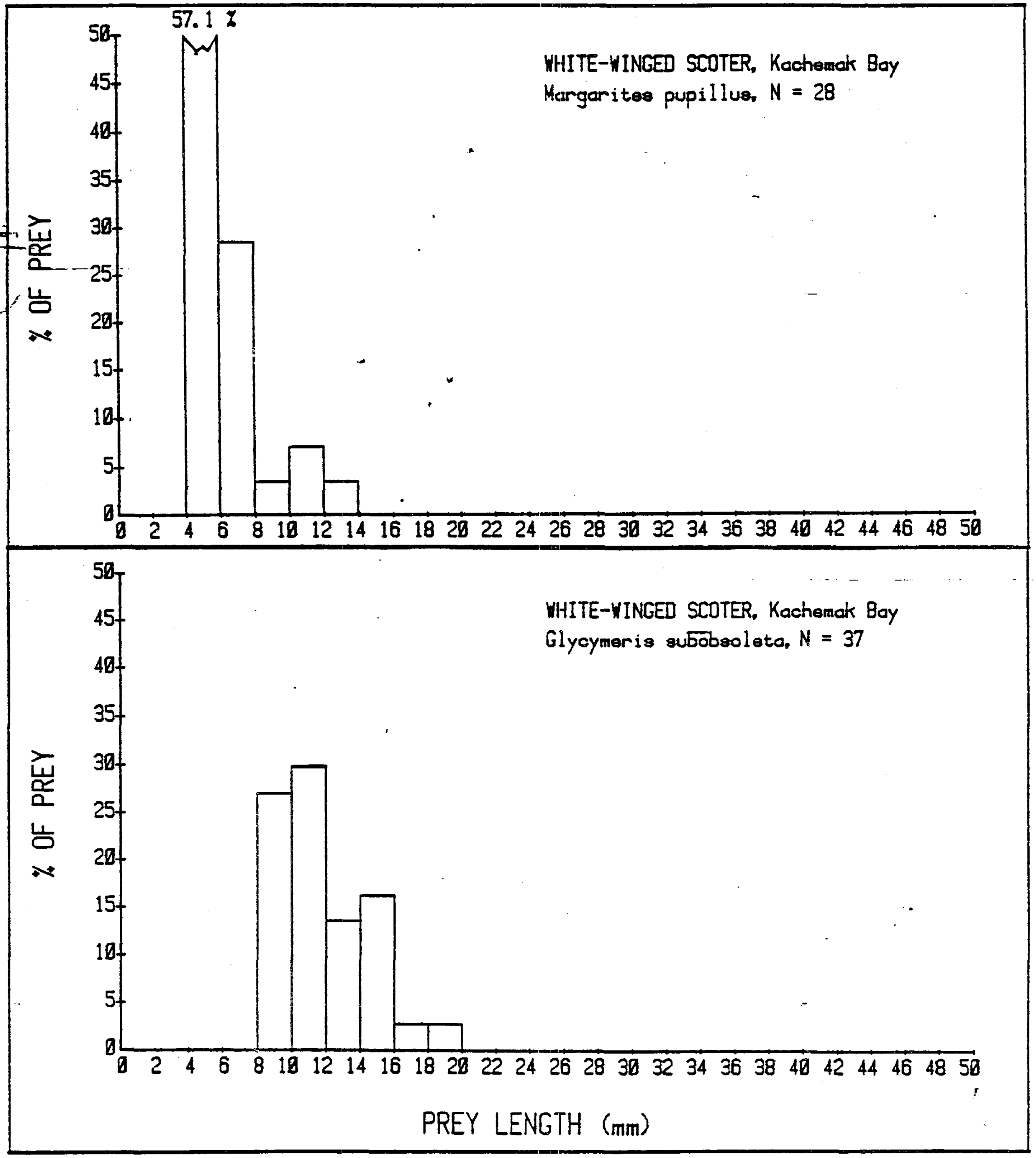

Figure 17. Length frequencies of the puppet margarite snail, *Margarites pupillus* and the clam *Glycymeris subobsoleta* in the stomachs of white-winged scoters from Kachemak Bay in winter.

they probably use a certain amount of indiscriminant seiving through the substrate to capture smaller prey. There is likely little or no light in the feeding habitats of the scoters during much of the winter, which suggests that the birds may use a sense other than sight to locate their food.

Net Body Weight and Fat Index

Pooled net body weights of 29 male white-winged scoters ranged from 1,388 g to 2,128 g, and averaged 1,917 g; similar weights of 10 females ranged from 1,566 g to 1,966 g, and averaged 1,732 g (Table 7). These averages were significantly different at the 99% level, as determined by a least squares anaslysis of variance (df=1 and 28; F=15.05). However, there were no significant differences in the monthly mean weights of adult birds (total n=34), nor of adults and juveniles combined (n=5, all collected in February), as determined by a least squares analysis of variance.

Fat indices for 38 individual birds ranged from highs of four in January and March 1978, and February 1977, to lows of two each month from January through April (Table 8; Figure 15). A one-way analysis of variance indicated large differences in fat index among the six monthly means at the .05 level of significance (F=5.97; p=0.0005). The results of a Duncan's multiple range test to determine which month(s) varied significantly from the other(s) are summarized below:

Month	N	Mean, ranked in descending order	Means connected by same letter are not statistically different
Feb 1977	2	4.00	A
Jan 1978	14	3.07	A B
Dec 1977	2	3.00	A B C
Mar 1978	5	2.80	B C
Feb 1978	10	2.60	C
Apr 1978	5	2.00	D

These results show that the fat index fluctuated, though decreased throughout winter and early spring, and culminated with a value for April that was significantly lower than any other month.

BLACK SCOTER

We collected one black scoter each in November and April on the north side of the inner bay (Table 2; Figure 18). Only the November bird contained food, consisting entirely of blue mussels, Mytilus edulis (appendix Table 3). The Mytilus weighed 6.8 g, or 0.6% of the body weight (1,118 g). The Mytilus were well digested, so the scoter possibly ate them elsewhere than the area of sand/mud substrate over which it was collected.

Both black scoter specimens were males. The bird collected in November had a net body weight of 1,118 g (Table 7), its stomach contents weighed 0.6% of the net body weight (Table 6), and the amount of body fat was undetermined (Table 8). The bird collected in April weighed 1,249 g (Table 7), its stomach was empty and it had a fat index of two.

SURF SCOTER

We collected one surf scoter in the outer bay in March, and in the inner bay, one in December and two in April (Table 2; Figure 18). Only the December and March specimens had food in their stomachs, one of the April bird's stomach was empty and the other had only unidentifiable remains.

The surf scoters ate a minimum of seven prey species (appendix Table 3). The December bird had two polychaetes, two clams and a shrimp, and the March bird had one gastropod, and a clam different from the above two. The polychaete Nephtys and unidentified bivalves were the most important prey. The bivalve Mytilus was conspicuously absent in the stomachs of the surf scoters.

The weight of the stomach contents ranged from '0' (empty) to 0.8% of net body weight, and averaged 0.4% (S.E.=0.14) (Table 6). The net body weight of three males ranged from 1,038 to 1,223 g, and a female collected in April weighed 1,053 g (Table 7). The fat index of the four birds ranged from two to four and averaged 3.0 (S.E.=0.35) (Table 8).

COMMON MURRE

Collection Sites and Sample Sizes

We collected five to nine common murres each month from December to April for a total of 31 specimens (Table 2). All specimens were taken in water deeper than 18 m on the south side of the inner bay, generally between Halibut cove and Glacier Spit (Figure 6). Twenty-eight birds (90%) had food in their stomachs.

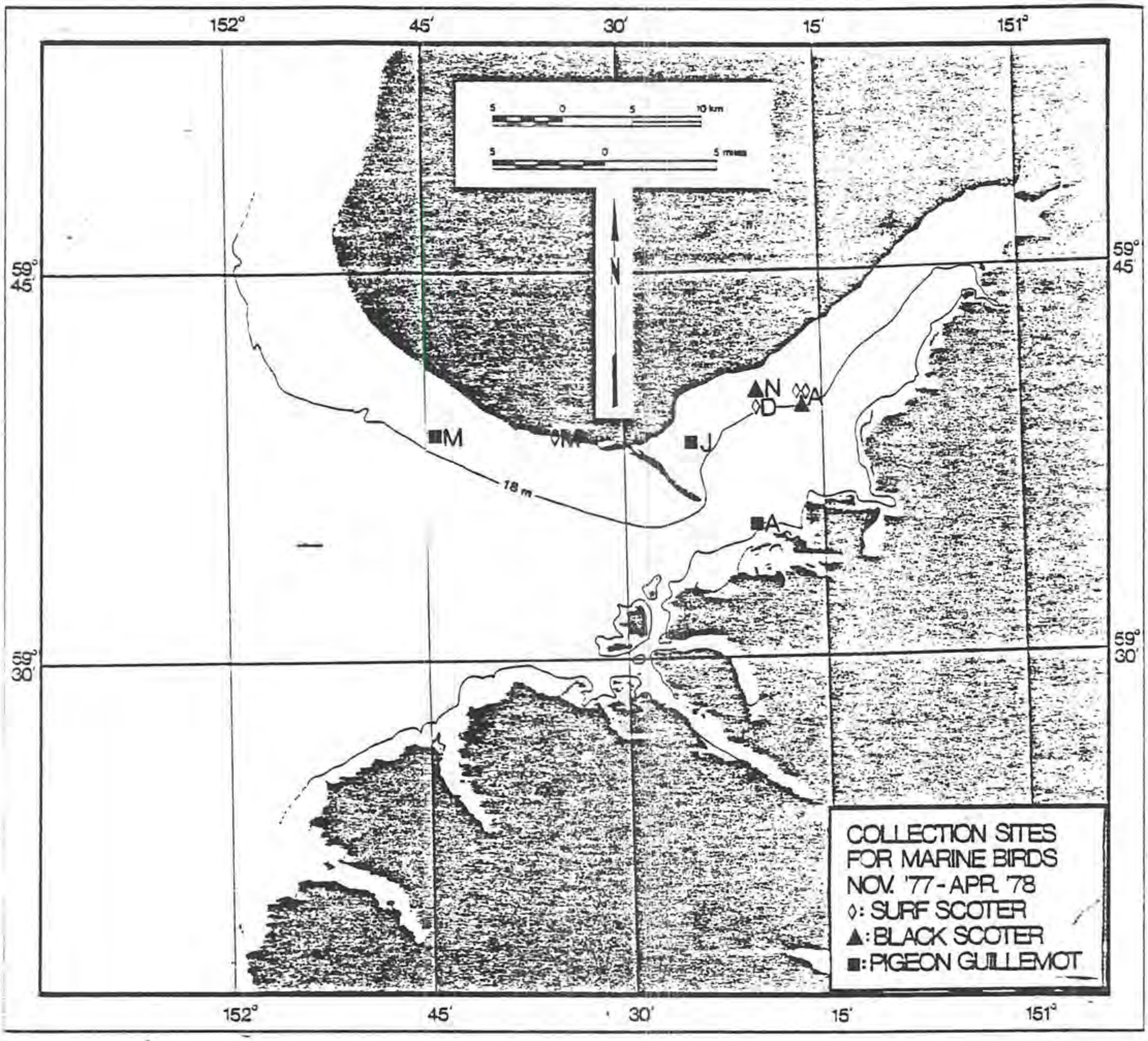

Figure 18. Collection sites of surf and black scoters, and pigeon guillemots. Letters indicate month of collection.

Food Habits

Crustaceans dominated the diet of the murres. Fish were relatively less important, and a trace of polychaetes was present in one bird. Five species of crustaceans contributed to an overall IRI of 6,944, while five species of fish accounted for an IRI of 417 (appendix Table 4). Overall, the murres are a minimum of 11 prey species, although the minimum number of prey in a given month fluctuated between three and five (Appendix Table 4), probably indicating varying differences in prey availability.

With a total IRI of 5,200, the most important prey species was the mysid shrimp, Neomysis rayii, followed in descending order of IRI values by: Pink shrimp (Pandalus borealis), 398; walleye pollock (Theragra chalcogramma), 117; capelin (Mallotus vilosus), 22; and Pacific herring (Clupea harengus), 20 (Appendix Table 4). Pandalid shrimp as a group (including P. borealis, P. goniuris, P. sp., and unidentifiably pandalids) were relatively important with an IRI of 1,049. Considering the predominantly piscivorous feeding habits of common murres elsewhere (Ainley and Sanger 1979) the preponderance of crustaceans in the diet of the Kachemak birds was unexpected.

Prey Lengths. The lengths of the measurable prey pooled from the murre stomachs ranged from Neomysis mysids of 31 mm to a walleye pollock of 179 mm, and the mean of all 174 prey was 44.6 mm (S.E.=1.67) (Table 10). Eighty-seven percent of the prey, all except one a crustacean, were less than 50 mm, while only 4% of the prey, all fish (one Lumpenus and the remainder pollock) were over 100 mm (Table 10).

Nine measurable pandalid shrimp ranged from 40 to 80 mm (mode about 55 mm). One-hundred-fifty-one Neomysis rayii accounted for 87% of the measurable prey. Their lengths (Figure 19) ranged from 31 to 52 mm, with a mode of about 39 mm.

Monthly Changes in Prey Importance. Crustaceans were consistently important to the murres (Figure 20). Neomysis was particularly important in December and January, but was not eaten thereafter when pandalid shrimp were important in the murres' diet. This relationship is particularly noticeable in the percent of the monthly aggregate volume comprised by these two kinds of crustaceans. Summarized from Appendix Table 4, these data may be compared:

Table 10. Total lengths, in 10 mm increments, of all measurable prey from 28 common murres collected in Kachemak Bay in winter.

Prey Species	No. of Prey in Length Increment (mm) 30-39	40-49	50-59	60-69	70-79	80-89	Totals
CRUSTACEA							
Neomysis rayii	98	52	1				151
Pandalus borealis			5	2	1		8
P. goniuris		1					1
Crangon franciscorum				1	1	1	3
FISH							
Mallotus villosus						1	1
Unid. Osmerid		1		2			3
Theragra chalcogramma a/							
Lumpenus maculatus b/							
TOTALS	98	54	6	5	2	2	167
Percent of Total	56.3	31.0	3.4	2.9	1.1	1.1	

a/ Six T. chalcogramma in length increments, as follows: 1,110-119; 1,120-129; 2,130-139; 1,150; 1,170-179.

b/ One L. maculatus in 100-109 increment

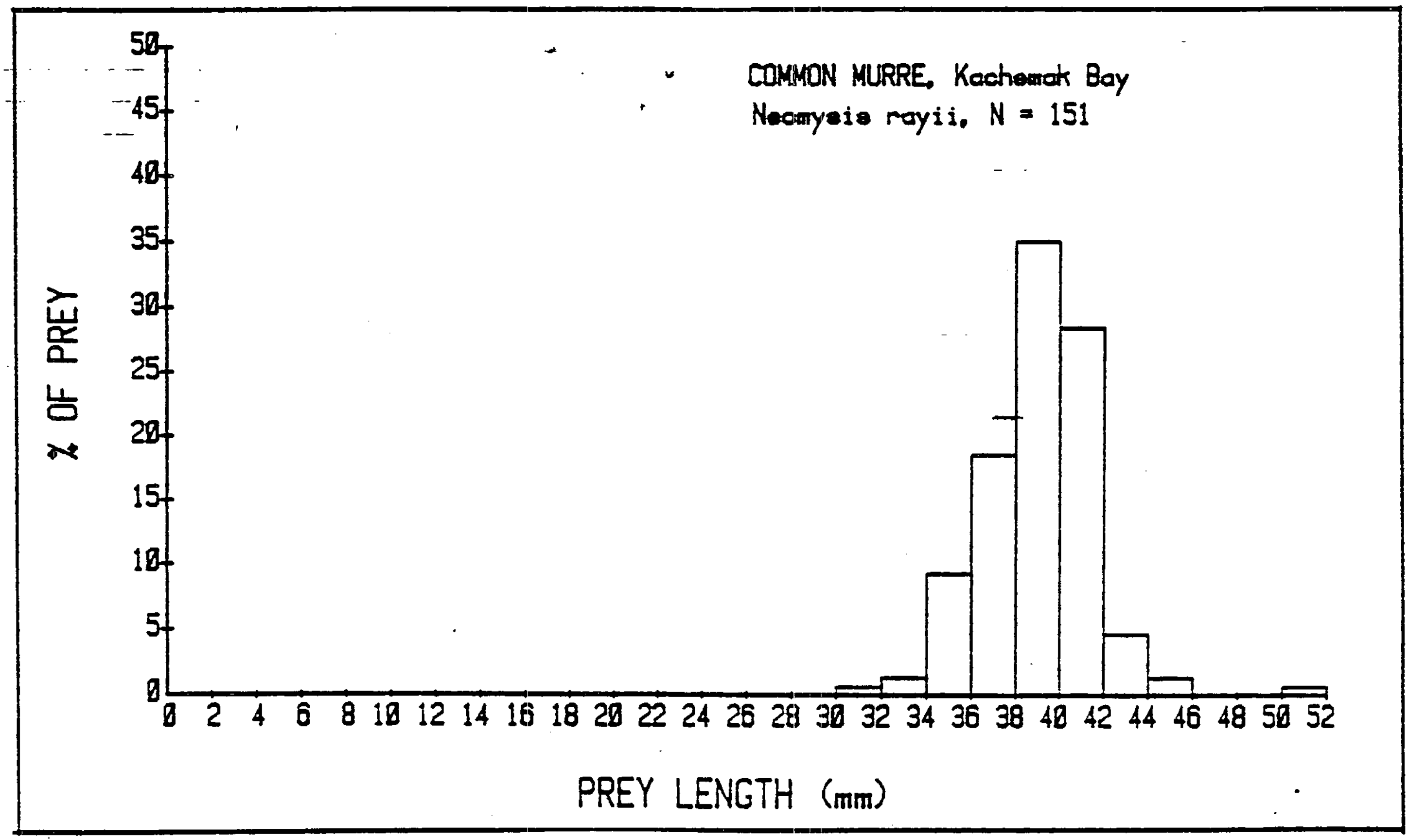

Figure 19. Length frequencies of the mysid crustacean Neomysis rayii in the stomachs of common murres from Kachemak Bay in winter.

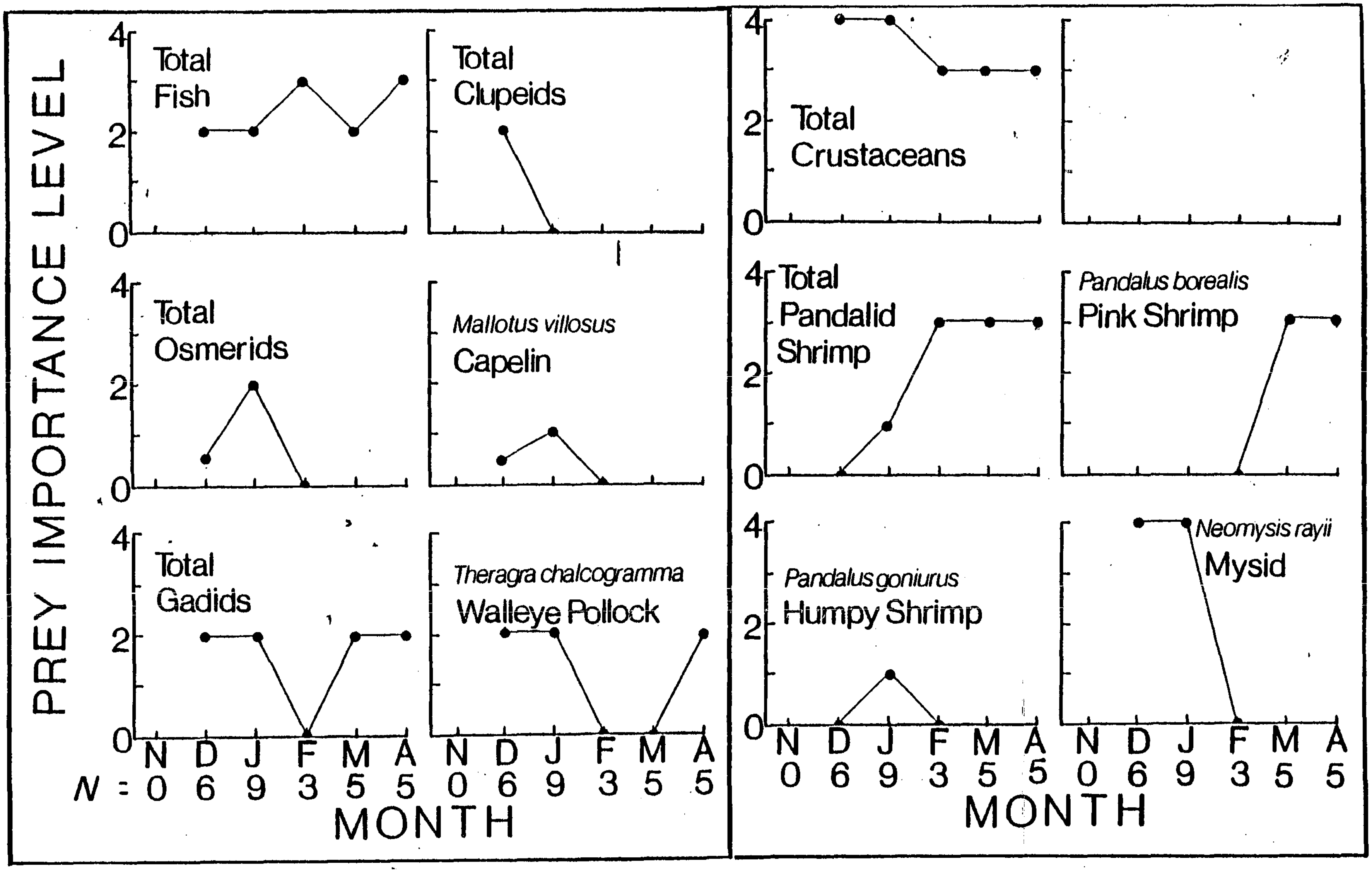

Figure 20. Monthly changes in the importance of fish (left) and crustaceans (right) in the diet of common murres from Kachemak Bay in winter.

Month	N Birds	Percent of Aggregate Volume	
		Neomysis rayii	Pandalid Shrimp
December	6	73.0	0
January	9	75.9	1.3
February	3	0	54.4
March	5	0	70.2
April	5	0	58.0

Despite the fact that the murres ate mysids only in December and January, they were still the most important prey overall. Although Neyomysis occurred in only 39% of the birds, they comprised 83% of the aggregate numbers of prey and 49% of their aggregate volume (Appendix Table 4).

Fish were also consistently present in the diet of the murres, but were generally less important than crustaceans (Figure 20). There was no pattern apparent in the monthly occurrence of any one species of fish. Total clupeids (including Pacific herring) occurred only in December, capelin only in December and January, and walleye pollock in December, January, and April.

Food Weight as a Percent of Body Weight. The weight of stomach contents ranged from "0" (empty stomach) for two birds in February and one in March, to a maximum of 2.9% of net body weight for a bird in December, and averaged 1.0% (n=31, S.E.=0.14) (Table 6). The maximum value was the result of 36 g of food in a bird of 1,224 g. Seventeen (55%) of the birds had values less than 1.0% of body weight and only four (13%) had values of 2.0% or greater.

Feeding Behavior and Feeding Habitats

Murres feed by pursuit diving (Ashmole 1971). The locations of their collection sites (Figure 6), and the known habits of their prey indicates that the birds probably fed over rock substrates at depths ranging from midway in the water column to or very near the bottom (Figure 21). The murres' principal prey, mysids and pandalid shrimp, typically occur at demersal or epibenthic depths, but the occasional occurrence of prey such as herring and capelin in their diet indicates that the murres probably fed part of the time at mid-depths in the water column.

Net Body Weight and Fat Index

Least squares analyses of variance showed no significant difference between mean weights of 20 male and six female murres and between mean monthly weights. Weights of individual birds ranged from 914 g to 1,253 g,

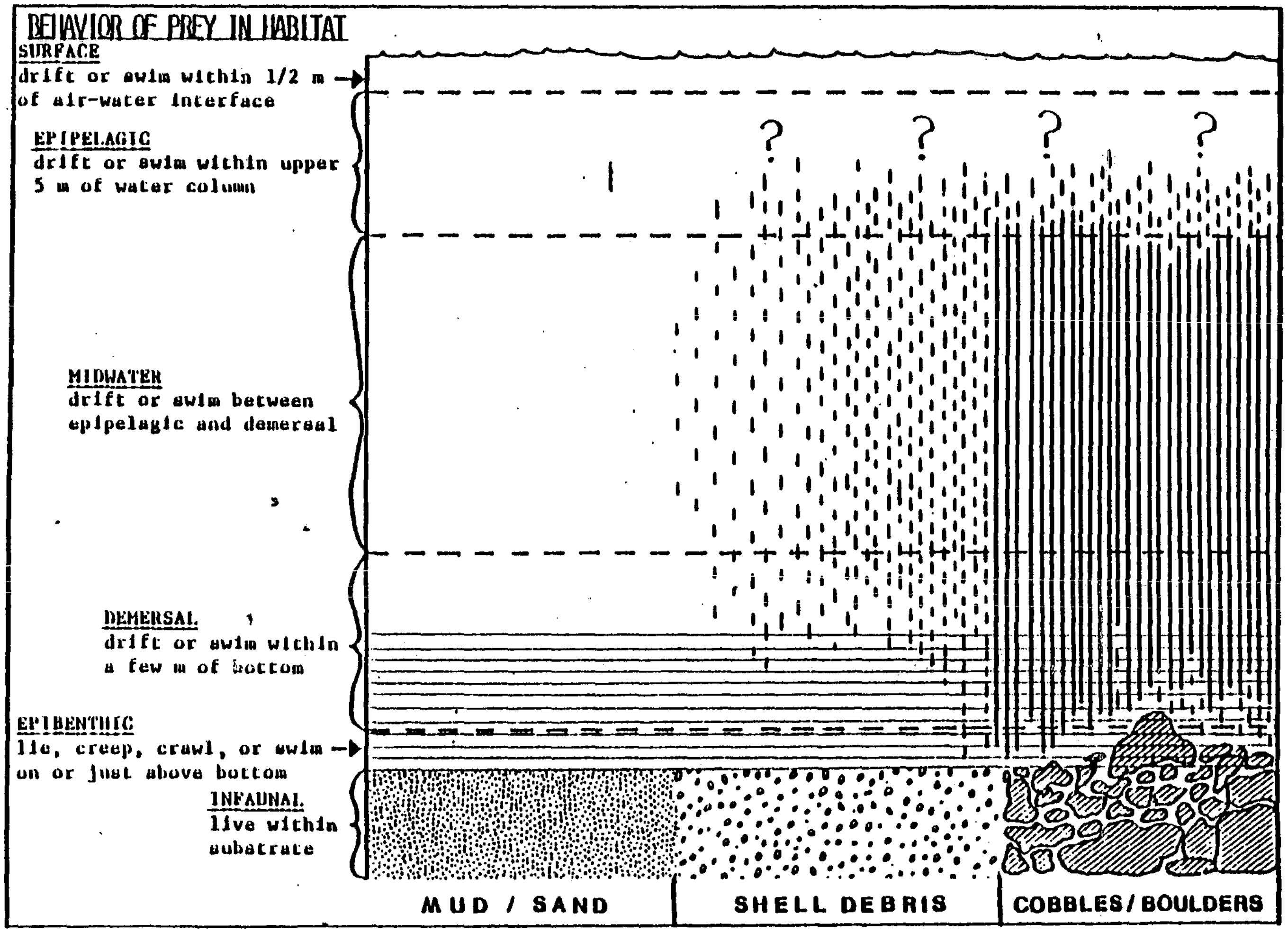

Figure 21. Schematic representation of the feeding habitats of alcids in Kachemak Bay in winter, in relationship to all subtidal feeding habitats. Common murres and marbled murrelets = vertical lines; solid are primary habitat, dashed secondary. Pigeon guillemot = horizontal lines.

and averaged 1,113 g for all 26 birds (Table 7).

The fat index (Table 8, Figure 15) ranged from two to five for individual birds, and averaged 3.1 (S.E.=0.15) for all birds. A one-way analysis of variance revealed significant differences between monthly means at the .05 level (F=4.68; p=0.0056). Inspection of the fat index data for the common murres suggests that fat indices declined from December through March.

PIGEON GUILLEMOT

We collected three pigeon guillemots--one on the north side of the inner bay in January, one on the north side of the outer bay in March, and one on the south side of the inner bay in April (Table 2; Figure 18). All three birds had food in their stomachs.

Food Habits

Together the guillemots ate a minimum of nine species of prey, including at least one polychaete, seven crustaceans, and at least one fish (Appendix Table 5). No one prey species occurred in more than one bird specimen, perhaps because each was collected in a different part of the bay. Unidentified fish and unidentified crabs were found in two of the birds. The shrimp together comprised 81% of the aggregate prey volume. The shrimp were dominated by *Pandulas goniuris*, which accounted for 50% (IRI=2,832) of the aggregate volume of all prey, and by *Crangon septemspinosa*, which comprised another 26% of the volume (IRI=1,693) (Appendix Table 5).

Although the limited sample size prevents speculation about the guillemot's preference of substrates for feeding, the kinds of prey suggests that they fed at demersal and epibenthic depths.

Weight of the stomach contents for the three birds was 0.7%, 0.8%, and 3.1% of the net body weight, and it averaged 1.5% (S.E.=0.64) (Table 6).

Prey Lengths. The lengths of 15 measurable prey pooled from the guillemots ranged from 17 to 66 mm, and averaged 28.3 mm (S.E.=2.94) (Tables 5 and 11). Seventy-three percent of the prey were less than 30 mm.

Body Measurements

Net body weights of the three birds, all males, were 545, 571 and 583 g, with an average of 566.2 g (S.E.=9.2) (Table 7). Fat indices (n=3) were either two or three, and averaged 2.3 (S.E.=0.27) (Table 8).

Table 11. Total Lengths, in 10 mm Increments, of all Measurable Prey from three Pigeon Guillemots Collected in Kachemak Bay in Winter

Prey Species	No of Prey in Length Increments (mm) 10-19	20-29	30-39	60-69	Totals
CRUSTACEA					
Mysids	1				1
Pandalus goniuris		6	2		8
Crangon septemspinosa		2		1	3
Sclerocrangon alata	1	1	1		3
TOTALS	2	9	3	1	15
Percent of Total	13.3	60.0	20.0	6.7	

MARBLED MURRELET

Collection Sites and Sample Sizes

We collected 21 marbled murrelets (Table 2), six of them in the shallow water of China Poot Bay in January and five each month thereafter in the inner bay in water deeper than 18 m (Figure 7). Twenty (95%) of the birds had food in their stomachs.

Food Habits

Marbled murrelets had the least diverse diet among the four primary species studied (Appendix Table 6). The numbers of prey items in the stomach samples ranged from at least six in February to two in Arpil, and the total number of prey species for the entire study period was at least eight. Total numbers of prey items are uncertain because gammarid amphipods were not identified to species.

Marbled murrelets ate only fish and crustaceans and, except for February, fish was the most important category of prey in their diet (Appendix Table 6). Capelin (IRI about 3,000) was by far the most important prey species. Sand lance, the euphausiid Thysanoessa raschii, and unidentifiable mysids were equally important, with IRI's of about 400. The mysids were unidentifiable, but they may have been juvenile Neomysis rayii, the species eaten by common murres. The low IRI's of walleye pollock, the euphausiids T. inermis and T. spinifera, and gammarid amphipods reflect their minor importance to the murrelets. Amphipods occurred in their diet only in February.

Prey Lengths. The lengths of the prey eaten by the murrelets ranged from 4 mm Thysanoessa euphausiids, to a 135 mm sand lance (Table 12), and the mean length of all prey (n=138) pooled from all stomachs was 26.3 mm (S.E.=2.02) (Table 5). About 66% of the prey, mostly crustacea, were 10- to 19-mm, and another 285, mostly fish, were between 20- and 59-mm (Table 12).

Length frequencies of capelin (Figure 22) and sand lance (Table 12) suggest the presence of 0- and 1-year classes, with the younger fish predominating. The euphausiids (Thysanoessa raschii) eaten by the murrelets ranged from 10 to 22 mm, with a mode of about 14 mm (Figure 23). The lengths of the mysids eaten by the murrlets (Figure 23) ranged from 10 to 40 mm, and may suggest the presence of at least two or three year classes.

Although the average length of all measurable prey of the murrelets was about 26 mm (Table 5), the modal length increment was 10 to 19. Prey in this length increment were mostly euphausiids, with some mysids and amphipods. The modal length increment of the measurable fish from the murrelets was about 40 to 49 mm. These lengths are similar to lengths of

Table 12. Total lengths, in 10 mm increments, of all measurable prey from 18 marbled murrelets collected in Kachemak Bay in winter.

Prey Species	No. of Prey in Length Increments (mm) 0-9	10-19	20-29	30-39	40-49	50-59	Totals
FISH							
Mallotus villosus a/			1	2	6	8	17
Ammodytes hexapterus b/				2	9		11
Unid. larvae		3					3
CRUSTACEA							
Gammarid Amphipods		6					6
Mysids		16	1	4			21
Thysanoessa inermis		1	1				2
T. raschii		42	2				44
T. spinifera			2				2
T. sp.	1	23					24
TOTALS	1	91	7	8	15	8	130
Percent of Totals	0.7	65.9	5.1	5.8	10.9	5.8	

a/ Plus six *M. villosus* in length increments as follows: 2,60-69; 1,70-79; 1,80-89; 1,90-99; 1,100-109.

b/ Plus two *A. hexapterus* in length increments as follows: 1,100-109; 1,130-139.

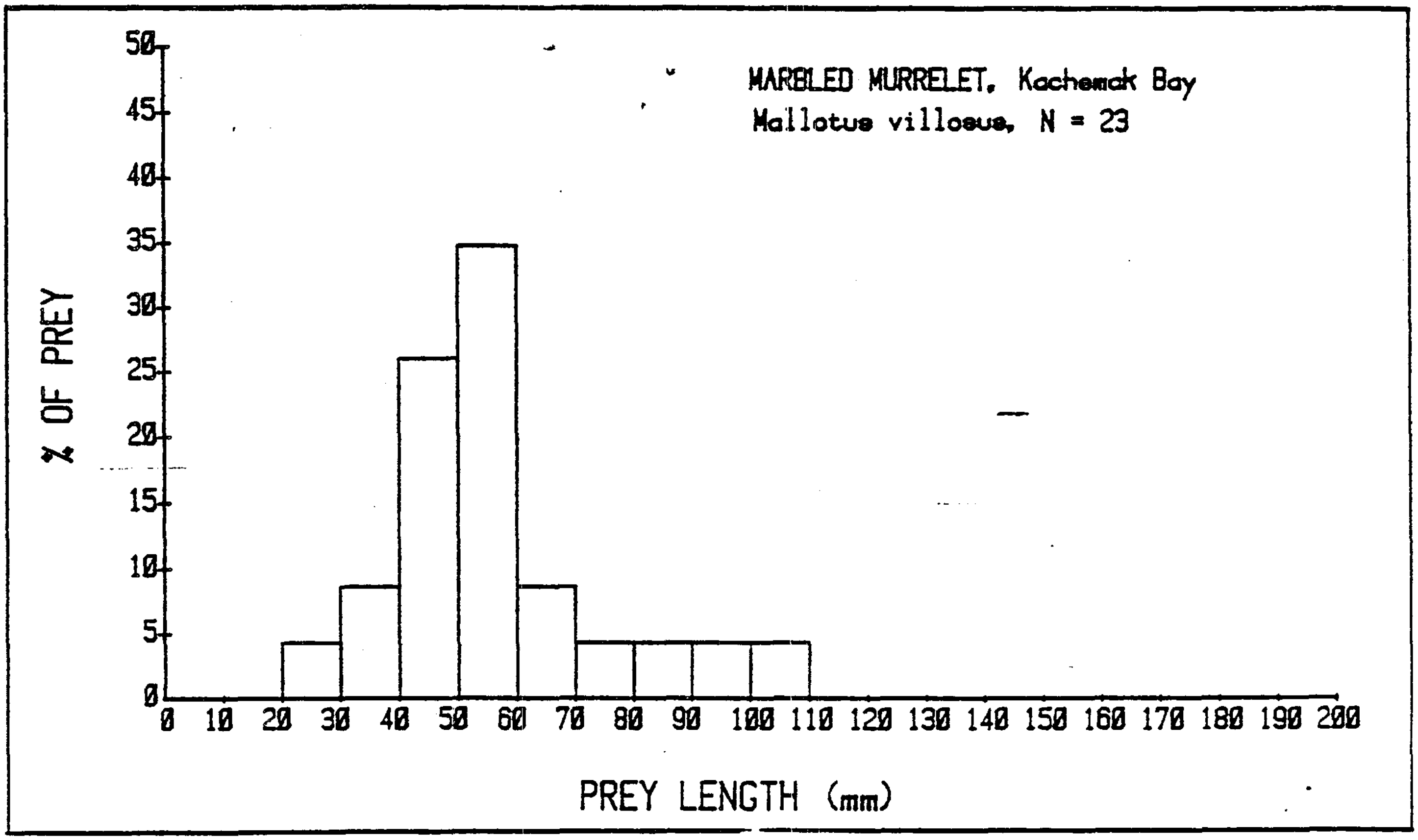

Figure 22. Length frequencies of capelin, Mallotus villosus, in the stomachs of marbled murrelets from Kachemak Bay in winter.

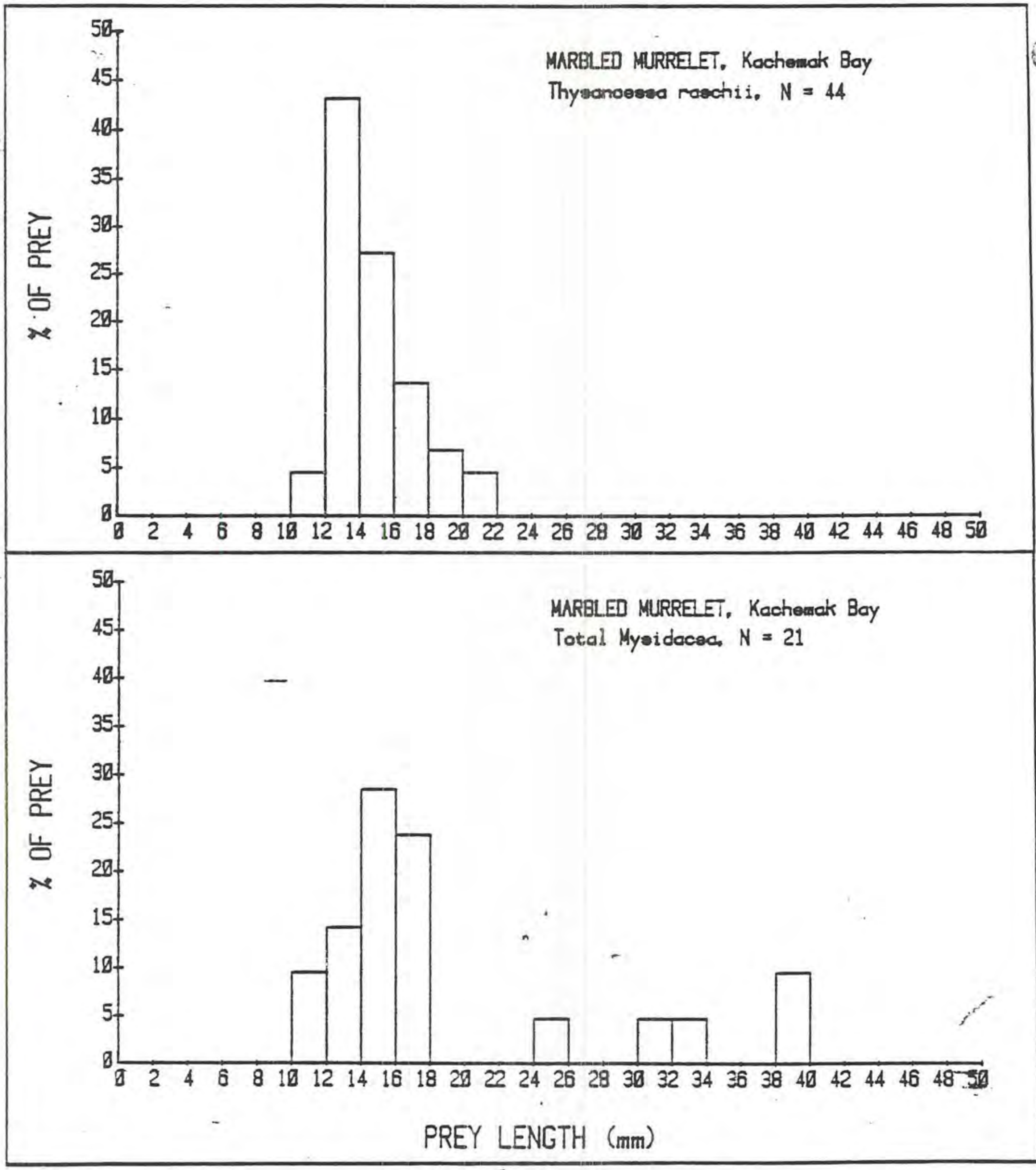

Figure 23. Length frequencies of the euphausiid crustacean Thysanoessa raschii and mysid crustaceans in the stomachs of marbled murrelets from Kachemak Bay in winter.

prey of marbled murrelets off British Columbia during the breeding season (Sealy 1975).

Monthly Changes in Prey Importance. The small sample sizes (3 to 6) preclude statistical inferences about monthly changes in the importance levels of prey, but some interesting trends are suggested. The prey importance levels of capelin and sand lance (Figure 24) appear to vary in inverse proportion, a possibility also suggested for total mysids and total euphausiids. The prey importance levels of both total fish and total crustacea remained consistently high (three or four) from January through April.

Food Weight as a Percent of Body Weight. Food weight ranged from 0 (empty stomach) for one bird in February, to a maximum of 6.6% of net body weight for a bird in March (Table 6). The latter value resulted from 15 g of food in a 228 g bird. Average values were low, ranging from 3.0% (S.E.=1.8) in March to 1.5% (S.E.=0.6) in April. Twelve birds (67%) had values less than 2.0% and only five birds (285) had values greater than 5.0%.

Feeding Behavior and Feeding Habitats

The locations of the murrelet collection sites (Figure 7) and the known habits of their dominant prey species (capelin, euphausiids) suggest that the birds fed mostly over rocky habitats, at mid-water depths. However, the presence in their diet of sand lance, gammarid amphipods, and mysids shows that the murrelets spent some of their time feeding in epibenthic/demersal habitats (Figure 30).

Net Body Weight and Fat Index

There were no significant differences in overall mean weights of seven males (245 g) and 12 females (233 g) (Table 7) nor among monthly mean weights of both sexes combined, as determined by least squares analyses of variance. Weights of individual birds ranged from 212 to 281 g.

The fat index (Table 8; Figure 15) ranged from one to four for individual birds, and averaged 2.6 (S.E.=0.15) for the 21 birds sampled. A one-way analysis of variance between the monthly means indicated no significant difference at the .05 level (F=2.43; D=0.10). This suggests that there was little change in the nutritional state of the murrelets throughout the study.

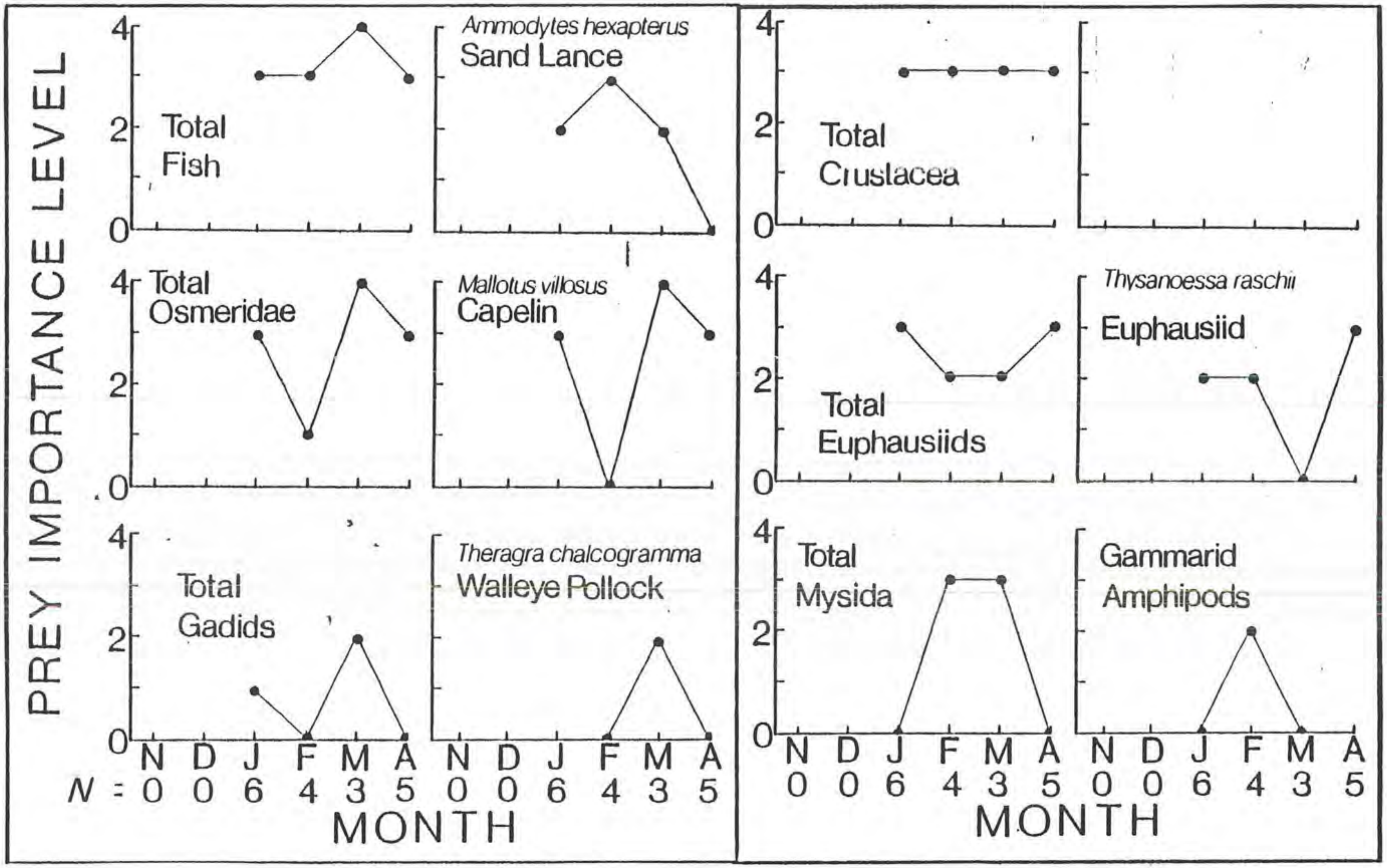

Figure 24. Monthly changes in the importance of fish (left) and crustaceans (right) in the diet of marbled murrelets from Kachemak Bay in winter.

RESULTS - TROPHIC RELATIONSHIPS

Table 13 lists and compares the importance levels of all of the prey taxa for the seven species of birds we studied. In sum, the birds ate a minimum of 79 prey species which occurred in eight phyla, including one protozoan (foraminifera), 12 polychaetes (annelida) in 10 families, 29 molluscs, including 16 gastropods and 13 bivalves, 25 crustaceans (arthropoda), one sipunculid, one ectoproct, four echinoderms, and six fishes.

Forty-seven (66%) prey species occurred in only a single species of bird, and 19 (27%) occurred in only two species. Only five (7%) of the prey species occurred in three species of birds, and none were found in four or more species. A general rule seems to be that if a species of prey was eaten by more than two bird species, it was a major prey of at least one. In contrast, if a prey species was eaten by only one bird species, it was of minor importance. Each of five prey species eaten by three bird species were of major importance to at least one of the birds. Mytilus edulis, eaten by oldsquaw, white-winged scoters, and black scoters (n=1), was a major prey of white-wings; mysids were important to both murres and murrelets; humpy shrimp (Pandalus goniuris) was a major prey of pigeon guillemots; and sand lance was a major prey of oldsquaw.

Table 14 lists the principal prey species of the bird community and indicates their probable habitats. A certain amount of conjecture (noted above) was used to assign "probable" habitats to many nektonic prey, but we believe this assessment is essentially correct. We arbitrarily classified an animal as a "principal" prey if it had a prey importance level of at least two (IRI=100) in one or more of the bird species. This assessment suggests a major conclusion about the trophic structure of the bird community: The overall diet of the birds is dominated by benthic and demersal fauna, of which most are filter- or deposit-feeders.

A detailed analysis of the trophic structure of the bird community is beyond the scope of this report. Nevertheless, it is reasonable to assume that the lower trophic levels of the Kachemak Bay ecosystem are similar to those typical of detrital food chains in other coastal marine ecosystems (Tenore 1977). That is, organic detritus--microbenthos (animals less than 0.1 mm)--meiobenthos (animals 0.1-1.0 mm)--macrobenthos (animals greater than 1 mm)--fish.

In Kachemak Bay, starfish are apex predators along with fish and birds (Dennis Lees, personal communication). However, it is difficult to state precisely the trophic level(s) at which a bird species feeds because the nature of the links among the microbenthos and meiobenthos are virtually unknown. The filter- and deposit-feeding animals comprising most of the prey of the bird community could feed on any of these kinds of animals, and also directly ingest the bacterially enriched detritus. Thus, depending on

Table 13. The relative importance of 79 species of prey to seven species of marine birds in Kachemak Bay, Alaska in winter. The importance categories are based on the Index of Relative Importance values of the prey species, as follows: + = 0-9; 1 = 10-99; 2 = 100-999; 3 = 1,000 and up.

	Importance Level of Prey to Bird Species[a/]						
	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Number of Specimens	28	39	2	4	31	3	21
Number with Prey	27	37	1	2	28	3	18
PREY SPECIES							
PROTOZOA							
Foraminifera							
Unidentified	+						
POLYCHAETA							
Unidentified	1	+				2	
Polynoidae							
Halosydna brevisetosa		+					
Harmothoe extenuata	+						
Sigalionidae							
Phloe minuta	+						
Phyllodocidae							
Anaitides mucosa	+						
Eteone sp.	+						
Unidentified	+						
Nereidae							
Unidentified	+				+		
Nephtyidae							
Nephtys sp.		+		3			
Goniadidae							
Glycinde sp.	+						

	BIRD SPECIES[a]						
	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Number of Specimens	28	39	2	4	31	3	21
Number with Prey	27	37	1	2	28	3	18
Lumbrineridae							
Lumbrinereis sp.	+						
Pectinariidae							
Pectinaria sp.	1						
Ampharetidae							
Ampharete sp.	+						
Unidentified	+						
Terebellidae							
Unidentified				2			
MOLLUSCA							
Gastropoda (Snails & allies)							
Unidentified	1	2					
Limpet species	+						
Trochidae							
Margarites pupillus		2					
Margarites sp.		1					
Lacunidae							
Lacuna variegata	1	+					
Lacuna sp.		+					
Littorinidae							
Littorina sp.		+					

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Rissoidae							
Alvina compacta	1						
Cerithiidae							
Cerithiopsis sp.	+						
Trichotropidae							
Trichotropis cancellata		1					
Naticidae							
Natica clausa	+	1					
Muricidae							
Trophonopsis pacificus	+						
Pyrenidae							
Mitrella tuberosa	+						
Neptuneidae							
Neptunea lyrata	+	1					
Neptunea sp.		1					
Cancellariidae							
Admete couthouyi	+	1					
Turridae							
Oenopota sp.	2						
Unidentified	+			2			
Pyramidellidae							
Odostomia sp.	+						
Aglajidae							
Aglaja diomedeum	+						

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Retusidae							
Retusa sp.	+						
Onchidorididae							
Onchidoris bilamellata	1						
Bivalvia (Clams and mussels)							
Unidentified	1	2		3			
Nuculidae							
Nucula tenuis	2			2			
Nuculanidae							
Nuculana c.f. *fossa*	2						
Glycymerididae							
Glycymeris subobsoleta	2	1					
Glycymeris sp.	+						
Mytilidae							
Mytilus edulis	2	3	3				
Montacutidae							
Orobitella sp.	+						
Astartidae							
Astarte rollandi		+					
Cardiidae							
Clinocardium sp.	+						
Mactridae							
Spisula polynyma	2						

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Tellinidae							
Macoma balthica	+						
Macoma sp.	2	1					
Veneridae							
Saxidomus gigantea	+			2			
Psephidia lordi	+						
Protothaca staminea	1	3		2			
Unidentified		1					
Myidae							
Mya sp.	1	+					
CRUSTACEA (Phylum Arthropoda)							
Cirripedia *(Barnacles)*							
Unidentified	+	+					
Mysida (Opossum shrimp)							
Neomysis rayii					3		
Unidentified	+					2	2
Cumacea							
Lamprops sp.	+						
Unidentified	+						
Isopoda ("Pill bugs")							
Gnorimosphaeroma oregonensis	+						

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Gammaridea Amphipoda[b/]							
Unidentified	2						1
Ampeliscidae (?)							
Unidentified	p						
Atylidae							
Atylus sp.	p						
Beaudettidae							
Unidentified	p						
Gammaridae							
Melita sp.	p						
Haustoriidae							
Unidentified	p						
Lys ianassidae							
Anonyx (laticoxae ?)	p						
Anonyx sp.	p						
Oedicerotidae							
Unidentified	p						
Phoxocephalidae							
Unidentified	p						
Euphausiacea (Euphausiids or krill)							
Thysanoessa inermis							+
Thysanoessa raschii							2
Thysanoessa spinifera							+

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Thscanoessa sp.							2
Unidentified							1
Decapoda Natantia (Shrimp)							
Spirontocaris spina	+					2	
Eualus fabricii						1	
Eualus sp.					+		
Pandalus borealis					2		
Pandalus goniurus	1				+	3	
Pandalus jordani	+						
Pandalus sp.					+		
Unidentified pandalidae	+				1		
Crangon septemspinosa	1					3	
Crangon franciscorum					1		
Crangon sp.				2			
Sclerocrangon alata						2	
Unidentified	+	+			1	1	
Decapoda Reptantia (Crabs)							
Hyas lyratus	1						
Cancer oregonensis	1					3	
Cancer sp.	1						
Unidentified		1				2	

	OLSQ	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
SIPUNCULA (Peanut Worms)							
Sipunculus sp.		+					
ECTOPROCTA (Bryozoans)							
Microporina borealis	+						
ECHINODERMATA							
Ophiuroidea (Brittle Stars)							
Ophiopholis aculeata	1						
Amphipholis pugetana	+						
Unidentified	1						
Echinoidea (Sea Urchins)							
Strongelocentrotus droebachiensis		+					
Unidentified	+	+			—		
Holothuroidea							
Unidentified		+					
OSTEICHTHYES (Bony Fish, Phylum Vertebrata)							
Unidentified	+				1	2	2
Clupeidae (Herring)							
Clupea harengus (Pacific Herring)					1		
Osmeridae (Smelts)							
Mallotus villosus (Capelin)					2		3
Unidentified					1		+

	OLSC	WWSC	BLSC	SUSC	COMU	PIGU	MAMU
Gadidae (Cods)							
Theragra chalcogramma (Walleye Pollock)					2		+
Unidentified					+		+
Cottidae (Sculpins)							
Unidentified	+						
Stichaeidae (Pricklebacks)							
Lumpenus maculatus (Daubed Shanny)					+		
Unidentified					+		
Ammodytidae							
Ammodytes hexapterus (Pacific Sand Lance)	3				+		2

Footnotes

a/ Bird Species: OLSQ = Oldsquaw; WWSC = White-winged Scoter; BLSC = Black Scoter; SUSC = Surf Scoter; COMU = Common Murre; PIGU = Pigeon Guillemot; MAMU = Marbled Murrelet

b/ For gammarid amphipods, "P" indicates animal was present, but volume, numbers, or frequency of occurrence were undetermined.

Table 14. Probable habitats of the main prey species of marine birds in Kachemak Bay in winter. Prey species are included if they have an importance level of 2 or 3 in at least one bird species. species. ? = Uncertain of habitat.

Prey Importance Level	Prey Species and Their Probable Habitats		
		SURFACE/EPIPELAGIC	
3		Capelin	
2		*Thysanoessa raschii* (Euphausiids)	
		MIDWATER	
3	? *Neomysis rayii* (Mysids)	*Pandalus goniuris* (Humpy Shrimp)	Capelin
2	*Thysanoessa raschii* (Euphausiids)	*Pandalus borealis* (Pink Shrimp)	Walleye Pollock Sandlance
		DEMERSAL	
3	? *Neomysis rayii*	*Pandalus goniuris*	
2	*Spirontocaris spina* (Shrimp)	*Pandalus borealis* (Pink Shrimp)	Walleye Pollock Sandlance

Table 14. Continued

EPIBENTHIC

3	Mud/Sand	*Crangon septemspinosa* (Sand Shrimp) Sandlance	Boulders/Cobbles	*Cancer oregonensis* (Red Rock Crab) *Mytilus edulis* (Blue Mussel) ? *Neomysis rayii* (Mysids)
2	Mud/Sand	*Oenopota* (Turrid Snail) Gammarid Amphipods *Sclerocrangon alata* (Crangonid Shrimp)	Shell Debris	*Margarites pupillus* (Puppet Margarite Snail) ? *Spirontocaris spina* (Carid Shrimp) Gammarid Amphipods *Mytilus edulis* (Blue Mussel)

****

INFAUNAL

3	Mud/Sand	*Protothaca staminea* (Common Littleneck Clam)	Shell Debris	*Protothaca staminea* (Common Littleneck Clam)
2	Mud/Sand	*Nucula tenuis* (Clam) *Nucula foss* (Clam) *Glycymeris subobsoleta* (Clam)	Mud/Sand	*Spisula polynyma* (Clam) *Macoma* sp. (Clam) Gammarid Amphipods

which of these links are present in the food web of Kachemak Bay, a bird species may function as a first-to fourth-order carnivore.

With these points in mind, it is possible to depict the ecological processes and energy pathways probably operating ~~at the base of the trophic~~ structure of birds wintering in Kachemak Bay (Figure 25). These processes and pathways may be summarized as follows:

1. Stocks of kelp around the southern perimeter of Kachemak Bay and in Kennedy Entrance grow intensively in spring and summer, before and during the period when phytoplankton stocks in Kachemak Bay and adjacent lower Cook Inlet also bloom intensively;

2. Fecal pellets produced by zooplankton grazing on phytoplankton, and the abrasion and seasonal die-off of kelp both produce a rich source of organic detritus;

3. Ocean currents carry the kelp detritus from Kennedy Entrance into Kachemak Bay;

4. At some point in this sequence, bacteria colonize the detritus;

5. The microbially-enriched detritus supports a rich community of deposit- and filter-feeding demersal and benthic fauna, probably via one or two trophic links in the form of micro- and meiofauna;

6. The deposit- and filter-feeding animals in turn support the marine birds wintering in Kachemak Bay, as well as a host of other apex predators.

Food web relationships between the birds and their principal prey are shown schematically as "sink food webs" (cf. Cohen 1978). For this purpose, only those prey species with an IRI of at least 100, and which also comprise at least 1% of the aggregate prey volume are considered "principal prey." Such food webs are indicated for oldsquaw (Figure 26), white-winged scoters (Figure 27), common murres (Figure 28), pigeon guillemots (Figure 29), and marbled murrelets (Figure 30). Also shown are the probable feeding habitats of the oldsquaw, white-winged scoters, and marbled murrelets. It seems likely that the guillemots and the murres captured their prey in demersal and epibenthic habitats; and the locations of the murre collection sites (Figure 6) indicate that they were over rocky substrates.

RELATIVE SIZES OF PREY

Insight is gained into the trophic relationships between ecologically similar bird species by comparing their mouth areas (culmen length x bill width) and the lengths of their prey (Figure 31). Comparisons of the mean

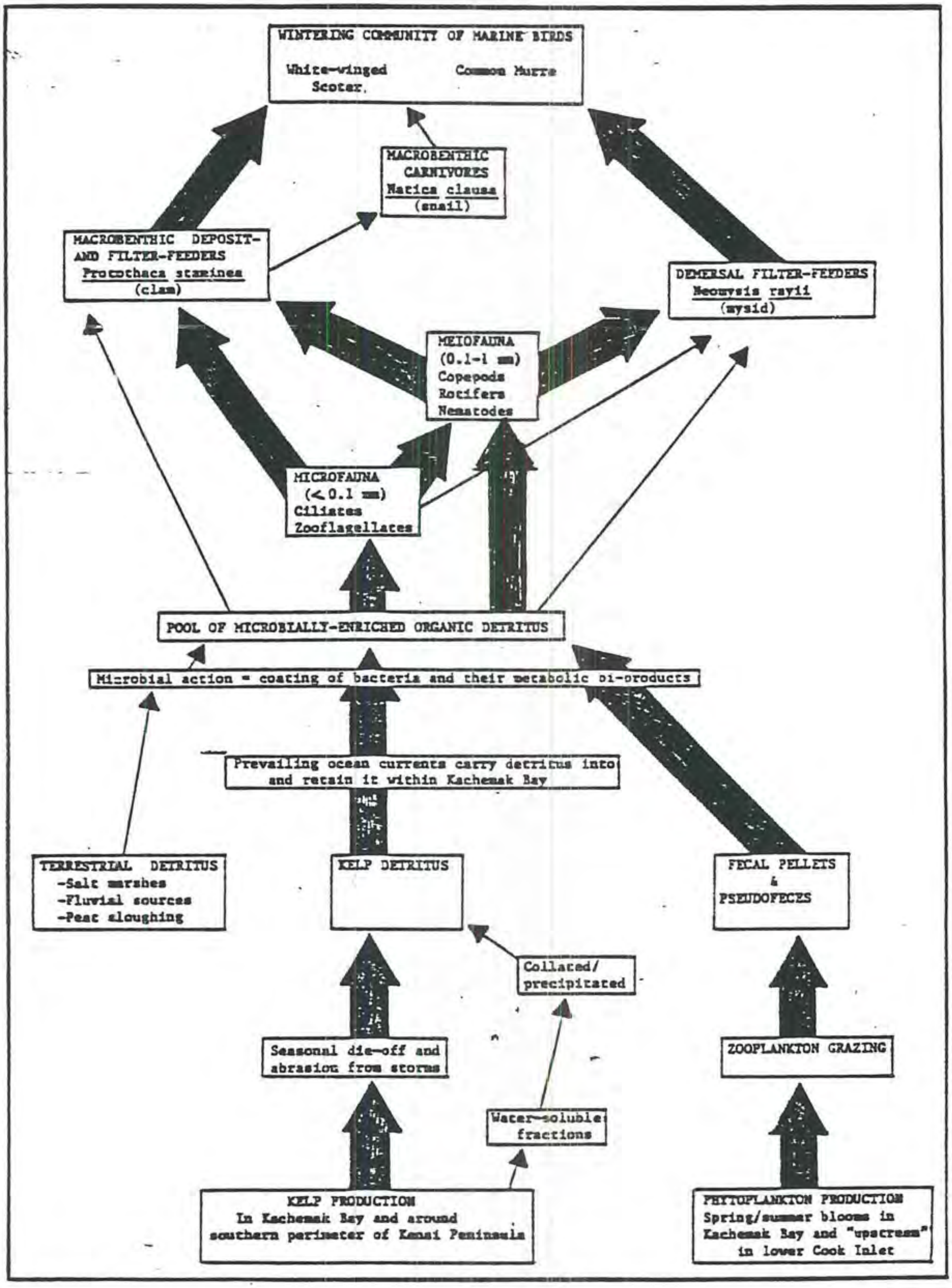

Figure 25. Hypothetical scheme of the trophic relationships and environmental mechanisms operating in the ecosystem of marine birds wintering in Kachemak Bay. Representative species or kinds of animals indicated.

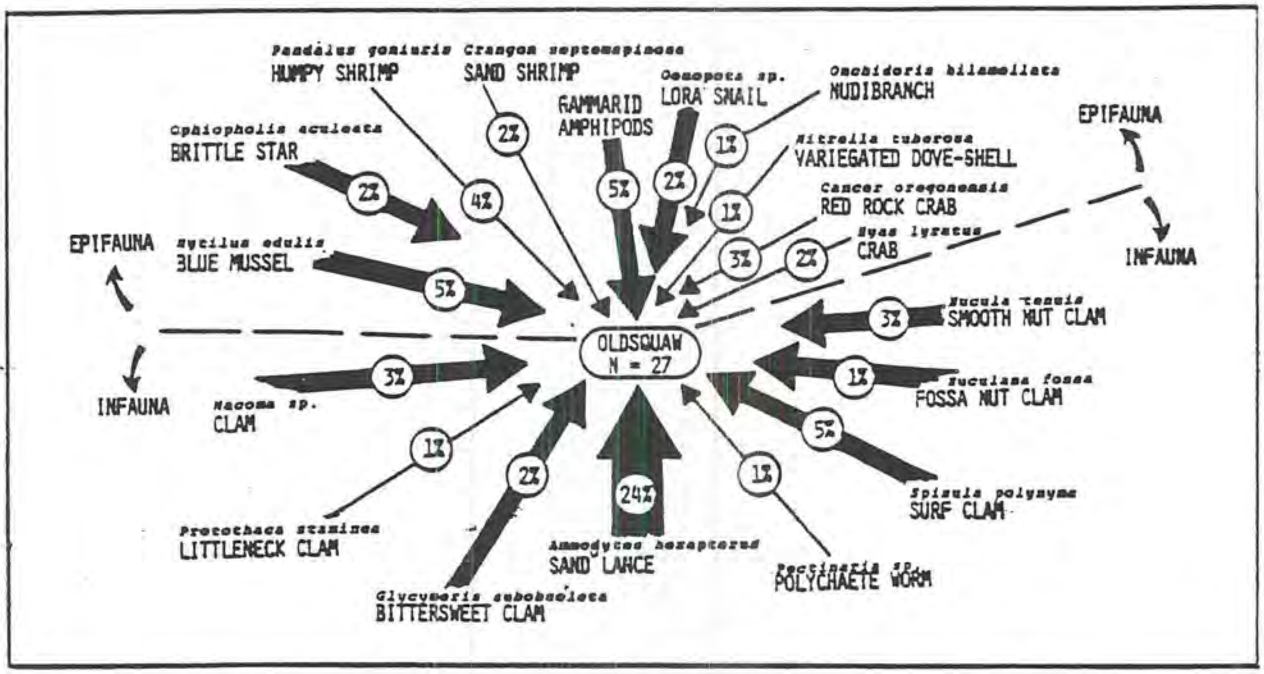

Figure 26. Food web for oldsquaw wintering in Kachemak Bay, indicating the 18 primary prey species and their relative importance. Percent volume of prey indicated, and arrow thickness proportional to prey's index of relative importance (IRI).

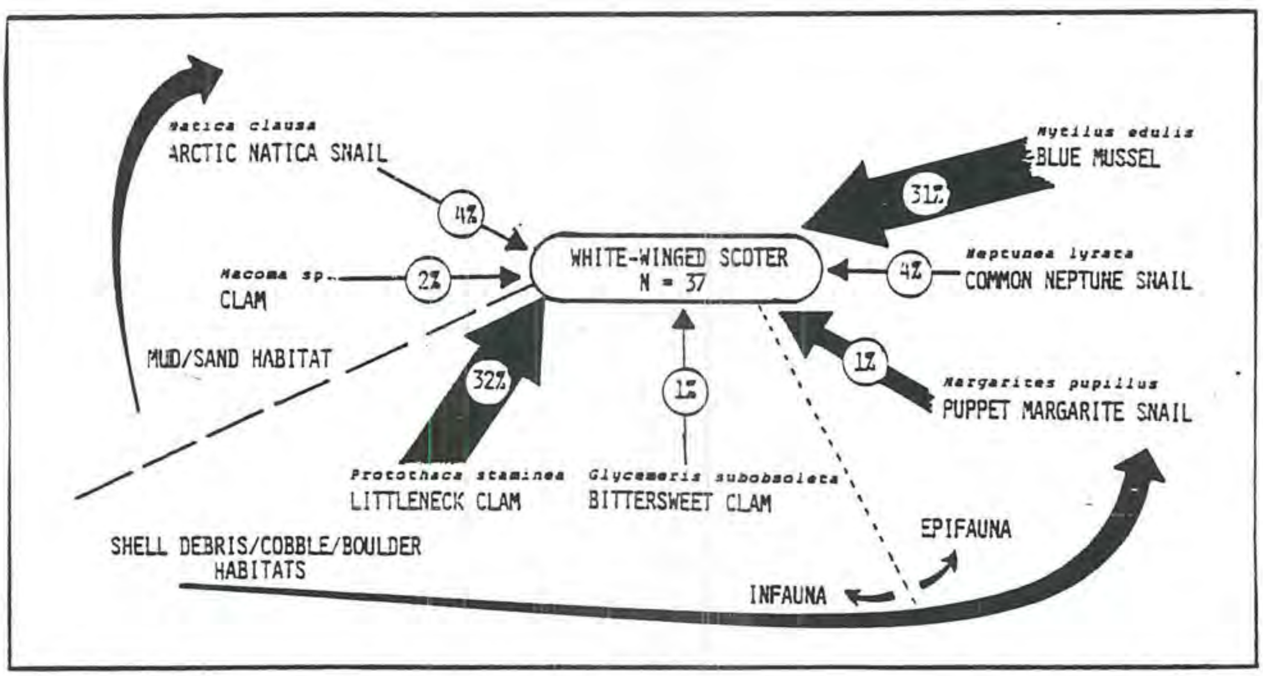

Figure 27. Food web for white-winged scoters wintering on Kachemak Bay, showing the 7 primary prey species, their relative importance and the habitat where the birds most likely captured them. Percent volume of prey indicated, and arrow thickness proportional to prey's index of relative importance (IRI).

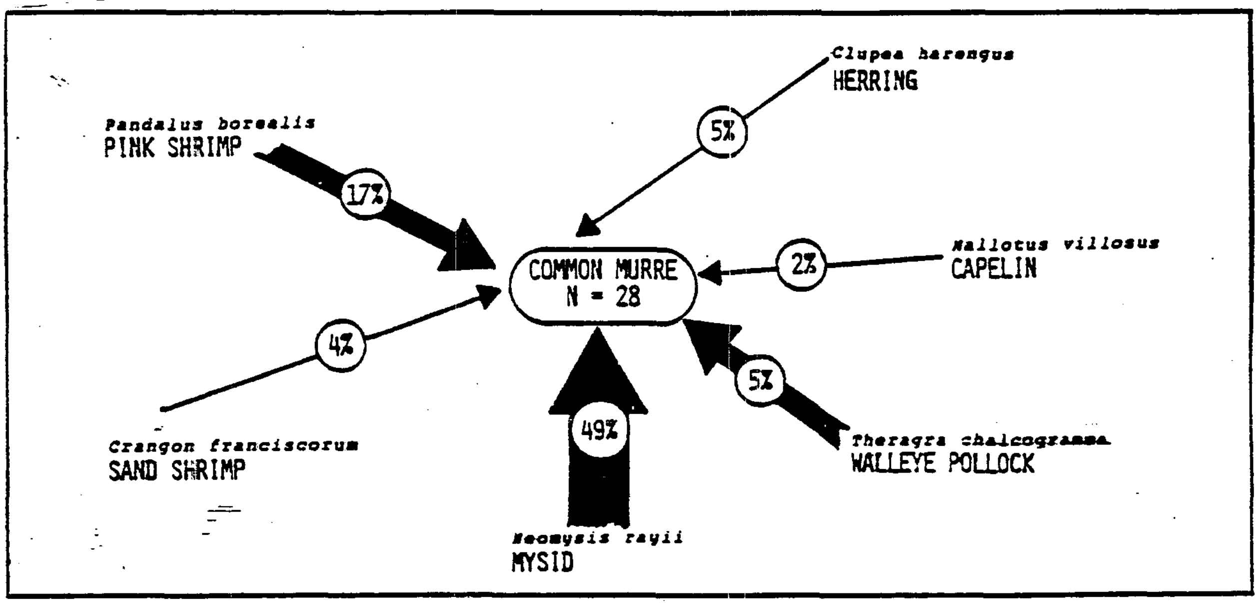

Figure 28. Food web for common murres wintering on Kachemak Bay, showing the six primary prey species and their relative importance to the birds. Percent volume of prey indicated, and arrow thickness proportional to prey's index of relative importance (IRI).

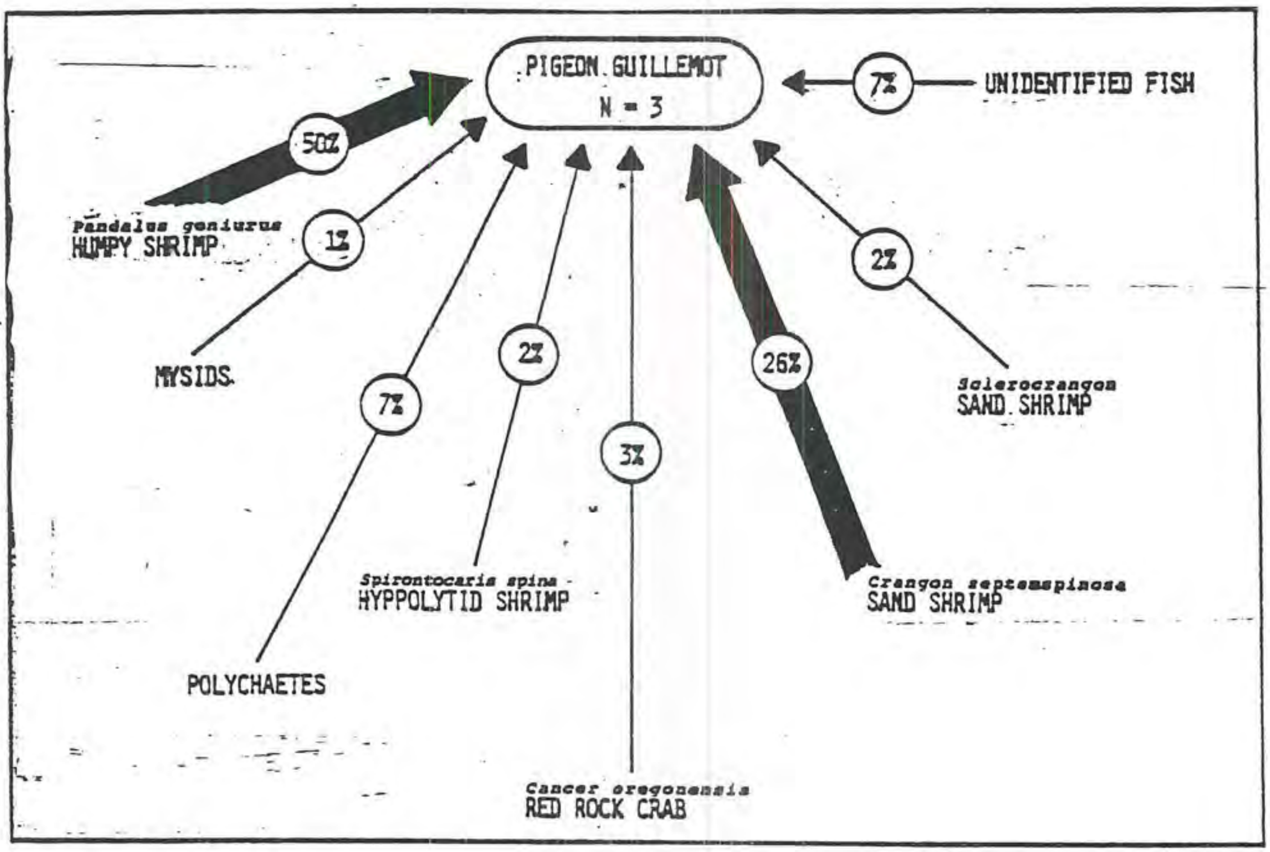

Figure 29. Food web for pigeon guillemots wintering on Kachemek Bay, showing the eight major prey species and their relative importance to the guillemots. Percent volume of prey indicated, and arrow thickness proportional to prey's index of relative importance (IRI).

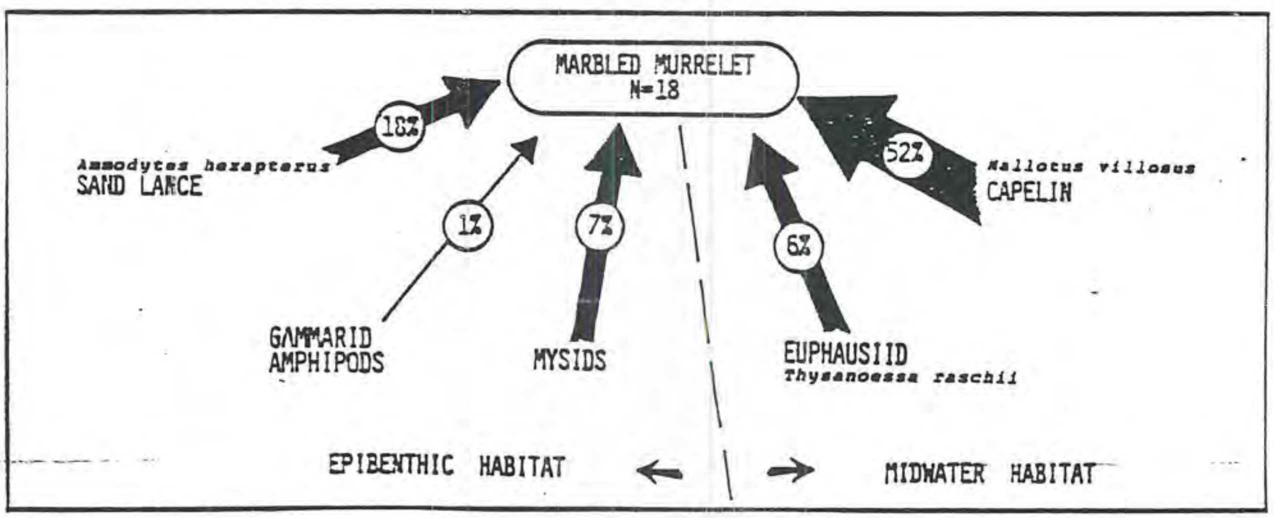

Figure 30. Food web for marbled murrelets wintering on Kachemak Bay, showing the five primary prey species and their relative importance to the birds. Percent volume of prey indicated, and arrow thickness proportional to prey's index of relative importance (IRI).

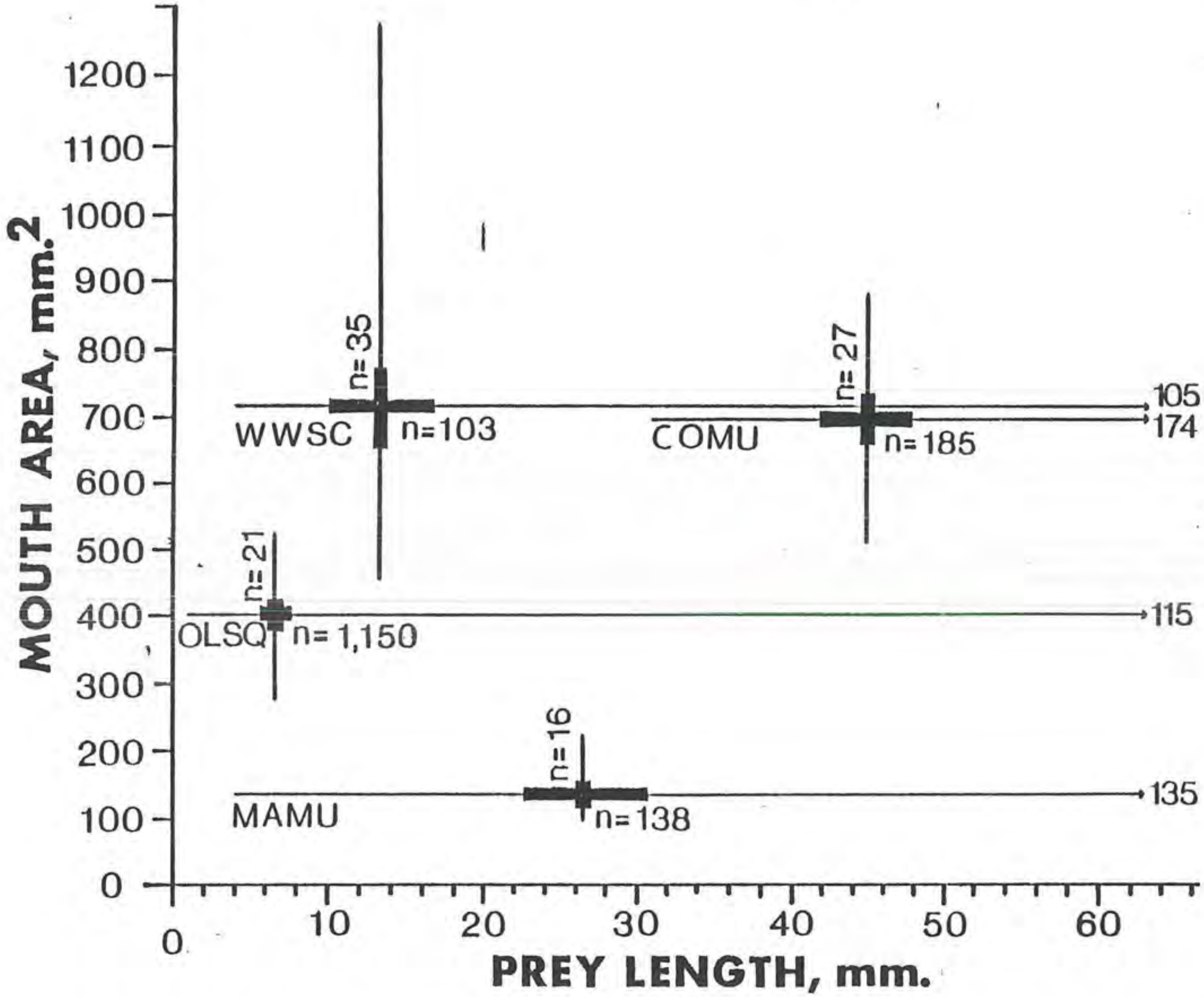

Figure 31. Relationship between mouth area (bill width X culmen length) and prey length for oldsquaw (OLSQ), white-winged scoters (WWSC), common murres (COMU), and marbled murrelets (MAMU), showing mean, ± two standard errors of the mean, and maximum and minimum values. Sample sizes (n) indicate number of birds and number of all prey pooled from the sample of birds.

mouth areas between the benthic-feeding oldsquaw and white-winged scoters, and between the pelagic-feeding murres and murrelets both showed differences at the 99% level of significance (t-test of the differences between two means, Sokal and Rohlf 1969:222). Similar comparison between the mean lengths of the prey of the two waterfowl, and of the two alcids also each showed differences at the 99% level of significance.

These differences are further illustrated when the lengths of prey taxa eaten by two bird species are compared. Mytilus was eaten by both oldsquaw and white-winged scoters, but the 503 mussels from the oldsquaw were all less than 10 mm (Table 4), while the three from the scoters were 50 to 69 mm (Table 9). Similarly, the 19 Protothaca clams from the oldsquaw were less than 10 mm, while the four Protothaca from the scoters ranged from 10 to 49 mm.

Similarly, 151 mysids eaten by the murres ranged from about 30 to 50 mm, while the 21 measurable mysids from the murrelets ranged from about 10 to 40 mm, with 16 (76%) of these being less than 20 mm (Table 10).

Although the height or girth of a prey may be indicative of the maximum size a seabird may choose in experimental conditions (Swennen and Duiven 1977), these data show highly significant differences in the lengths of prey eaten by the birds we studied. A reasonable general conclusion seems to be that any number of parameters could be used to compare prey sizes.

GENERAL DISCUSSION

BIOLOGICAL AND ECOLOGICAL CONSIDERATIONS

Oldsquaw and white-winged scoters ate the same general categories of prey reported previously (Stott and Olson 1973; Nilsson 1972; Madsen 1954; Cottam 1939). Both species eat mostly bivalves, gastropods and crustaceans in varying proportions, depending on the species of benthos present locally.

The dominance of pandalid shrimp and mysids in the diet of common murres contrasted markedly with the dominance of fish in their diets elsewhere in summer (e.g., Ogi and Tsujita 1973; Sanger et al. 1978). This may have reflected a greater abundance or at least availability of these crustaceans over forage fishes in Kachemak Bay in winter, although we have no corroborating data.

Despite recent surveys of the benthos in Kachemak Bay, knowledge of the distribution, abundance and availability of the prey species of the benthic feeding oldsquaw and scoters remains sketchy. Specimens of oldsquaw and scoters were collected in water depths between one and 10 fathoms (2-20 m) at mean lower-low water (NOAA Nautical Chart #16645). Other than visual, SCUBA diving surveys along the north shore of the outer bay mostly in summer (Lees 1978; Rosenthal and Lees 1977), there have been no systematic surveys of benthos in the depth ranges frequented by waterfowl during this study. We do not know precisely the depths at which sea ducks fed, but we assumed that a bird specimen had eaten its prey in the general vicinity of its collection site. Regardless, it is likely that white-winged scoters collected in the outer bay fed mostly at depths shallower than those studied by Feder and Paul (1980) (ca. 29 m) and by Driskell and Lees (1977) (ca. 12-65 m), and deeper than the intertidal areas studied by Lees et al. (1980). However, the presence of *Mytilus edulis* in both oldsquaw and white-winged scoters indicates that they fed at least part of the time over intertidal areas at high tide (Lees 1978; Rosenthal and Lees 1977). Moreover, the absence of horse mussels (*Modiolus modiolus*) from their diet suggests that they did not feed over rocky areas when they fed subtidally (Lees 1978; Rosenthal and Lees 1977)

The studies noted above are the only surveys of macrobenthos in Kachemak Bay; and besides the intertidal surveys of Lees et al. (1980) at Homer Spit, none were in winter. Differences in the kinds of prey eaten by the birds and the species reported by these authors (see below) suggests that there may be real differences between the animal communities in the birds' feeding habitats and the areas studied by these authors. It is also possible that their sampling schemes missed major components of the birds' diets, and that the birds selected prey in different proportions to their occurrence in nature.

Regardless of dissimilarities, the incomplete nature of information on the distribution and availability of the birds' prey is illustrated by comparing the present results with those of the authors noted above. In February and March 1977, Lees et al. (1980) sampled the intertidal fauna on the outer beach of Homer Spit. Polychaete worms comprised 76% to 85% of the numbers of prey, gammarid amphipods comprised another 13 to 17%, and clams (Spisula polynyma) and sand lance were minor components. Of these animals, only Spisula, the polychaete Nephtys, and sand lance were important prey of one or more of the bird species. A host of other species of crustaceans, clams, and gastropods, not found by Lees et al. (1980) were important to the birds in the subtidal epibenthic and infaunal habitats. Many species of crustaceans, at least, are highly mobile, and likely migrate to intertidal areas to feed at high tide.

Similar marked differences exist between prey species of the white-winged scoters collected off the north shore of the outer bay, and species observed as dominant there by Lees (1978) and Rosenthal and Lees (1977) during diving surveys. These investigators reported a number of benthic species as dominant on rocky substrates between depths of about four and 15 m. They listed the horse mussel (Modiolus modiolus), the matting polychaete Potamilla and the butter clam Saxidomus as the most important suspension feeders, the sea urchin Strongylocentrotus droebachiensis as a conspicuous grazer, and the moon snail Neptunea lyrata as an important predator. Of these species, only Neptunea lyrata was moderately important to white-winged scoters, and Strongylocentrotus was of minor importance; none of the other species was present in the scoters' diet.

Although Driskell and Lees (1977) indicate well defined boundaries between types of bottom substrates off the north shore of the outer bay (Figure 2), substrates within the general area actually consist of a mosaic of rocky areas, shell debris, mud and sand (Dennis Lees, personal communication). It thus appears that white-winged scoters feed largely in shell debris substrates, which was not specifically studied during diving surveys (e.g., Lees 1978). The scoters also appear to select fauna smaller than normally seen during the visual diving surveys in rocky areas (Dennis Lees, personal communication).

In sum, the exisitng surveys of benthic fauna in intertidal (Lees et al. 1980) and deeper areas (Driskell and Lees 1977; Feder and Paul 1979) have limited use in interpreting the results of studies of benthic-feeding birds in Kachemak Bay. A field program is needed which is specifically tailored to study the feeding habits of the birds concurrently with sampling the epibenthos and infauna within the 1- to 20-m depth zone, and to sample the epibenthos in intertidal areas at high tide.

Even less is known about the pelagic fauna of the murres and murrelets. However, the dominance of the mysid Neomysis rayii of 30-45 mm in the diet of the murres, which usually eat prey of at least 80-100 mm (e.g., Sanger et al. 1978), suggests very high densities of mysids in the deep portion of the inner bay in January and February. The mysids would have to have been abundant and fairly concentrated for it to have been energetically feasible for the murres to eat them to the extent that they did. Similarly, the dominance of pandalid shrimp in the diet of murres from February through April suggests an abundance of these shrimp then. Feder and Paul (1980) noted the highest densities of pink shrimp (Pandalus borealis) in the lower Cook Inlet area in summer in inner Kachemak Bay. The consistent importance of euphausiids in the diet of murrelets from January through April indicates like high concentrations of these crustaceans in the deepwater portion of the inner bay.

Amounts of food in the birds--expressed as percent of net body weight--were generally low. They ranged from empty stomachs in a few specimens of all species except oldsquaw and pigeon guillemots, to a high of 6.6% for a marbled murrelet (Table 6). Average values for the four primary species ranged from 1.0% for common murres, to 2.2% for white-winged scoters (Table 6). Despite this seeming paucity of food, however, data on net body weights (Table 7) and fat indices (Table 8) generally reflect a healthy physiological condition throughout the study. Thus, adequate amounts of food were available for benthic feeding species as well as pelagic species. These data also imply rapid rates of digestion (van Koersveld 1950) and frequent small feedings, rather than sporadic gorging as in the case with short-tailed shearwaters, whose stomach contents can approach 20% of their net body weight (Sanger et al. 1978).

Since the species of waterfowl we studied spend their nesting season in freshwater/terrestrial habitats, the birds should be unaffected by changes in salinity in itself. On the other hand, water and air temperatures can have a profound influence on the birds by increasing their rate of metabolism, and therefore, their need for food in colder temperatures (Calder and King 1974). In south Sweden, food seeking rates of oldsquaw and other species were highest during the coldest winter months (Nilsson 1970), indicating an increased energetic cost to the birds. Similarly, particularly cold winters can be expected to place added energetic stress on birds wintering on Kachemak Bay. The presence of ice in the shallow inner bay, however, appeared to have no effect on the birds. Oldsquaw readily occurred and dived within the ice, which may have actually shielded the birds from the wind.

IMPACTS OF BIRDS ON COMMERCIAL FISHERIES

In most cases, impacts of birds wintering on Kachemak Bay on commercial species of fish and shellfish appear to be minimal. Juvenile walleye pollock were a minor component of the diet of common murres (5% by aggregate volume, Figure 40), but neither salmonids nor other species of commercial fin-fishes were present in the stomach samples. Juvenile salmonids are not abundant in the bay until late May (Blackburn 1978).

Although pink shrimp (Pandalus borealis) comprised 17% of the aggregate volume of food eaten by common murres (Figure 40), it is difficut to translate this into degree of impact on the fishery without having better information on the size of the population of murres wintering in Kachemak Bay. Similarly, humpy shrimp (P. goniuris) comprised 50% of the volume of the stomach contents of the three pigeon guillemots sampled, but larger sample sizes of birds and a better idea of their population size in the Bay would be needed to calculate their impact on the shrimp stocks.

The highest densities of settling juvenile king crabs (Paralithodes camchatica) in Kachemak Bay were in the cobble-boulder area off the north shore of the outer bay (Haynes 1977; Gundberg and Clausen 1977) where we found maximum concentrations of white-winged scoters, but crabs were not part of the diets of the birds. The crabs do not settle to the bottom until late spring, after the wintering, bottom-feeding birds have migrated out of the bay, and the crabs themselves migrate to deeper waters before the birds return (SAI 1979).

POTENTIAL FOR IMPACT TO WINTERING BIRDS FROM OCS OIL AND GAS ACTIVITIES

Any potential impact to marine birds in Kachemak Bay resulting from oil exploration, development, processing, or transport must be weighed in light of the ocean current patterns summarized in a preceding section of this report. To briefly review, water enters Kachemak Bay from the Gulf of Alaska, via Kennedy Entrance. Gyral currents in outer Kachemak Bay imply residence times of the water in the outer bay on the order of several days, or perhaps longer. Water enters the inner bay from the outer bay at depth. Water exits Kachemak Bay in a northwesterly direction along the north shore of the outer bay, to join a moderately strong northerly flow along the east side Cook Inlet which extends at least as far north as the Forelands. Thus, the potential severity of acute or chronic oil spills to marine birds in Kachemak Bay, or to any of the biota for that matter, depends on whether the mishap is "upstream" or "downstream" from the bay.

Drilling Platforms

Depending on wind and current patterns during and immediately after an oil spill from any of the drilling rigs projected for lower Cook Inlet in the Bureau of Land Management (BLM) developmental scenario, it appears that the rigs would be far enough west of the normal current patterns that they would not directly affect Kachemak Bay. If a spill did reach the bay, however, the general habitat of greatest importance to the birds includes the entire perimeter of the bay at depths shallower than 20 m. None of the bird species we studied feed intertidally on low tides. Murres, murrelets, and occasionally white-winged scoters, utilize habitats over deeper water, but areas less than 20 m seem to be the main habitat for most of the wintering bird community.

The species we studied included waterfowl or alcids, the two major groups of seabirds most susceptible to direct oiling (King and Sanger 1979). Although most of the prey species eaten by the bird community are probably eaten subtidally, Mytilus, at least, is probably eaten by the waterfowl in intertidal areas on high tides.

Secondary effects could result with contamination or reduction of food organisms if spilled oil precipitated to the bottom in subtidal areas. Such effects could be of greater long-term significance than oiling of birds, but are not easily observed nor measured. The loss of benthos which would have the greatest potential for adverse impact to the marine bird community are the bivalves Mytilus, Protothaca, Spisula, Nucula, and Macoma, in descending order of importance. Similarly, pelagic prey of greatest importance to the wintering bird community include the mysid Neomysis rayii, pink shrimp Pandalus borealis, the euphausiid Thysanoessa raschii, and two fishes, capelin and sand lance.

Any other potential environmental threat from drilling platforms would appear to be confined to the immediate vicinity, and would be unlikely to have a discernible effect on birds wintering in Kachemak Bay. These would include drill cuttings and drilling muds, entrainment by cooling systems, and chronic contamination from formation waters.

Potential Shore-Based Facilities-Tanker Terminals

The BLM development scenario lists two general areas for potential shoreside facilities, one in the vicinity of Anchor Point, and another in an area adjacent to Kennedy Entrance extending generally from Port Graham to the Chugach Islands. Of these two areas, it appears that Kennedy Entrance would pose the highest threat to marine birds in Kachemak Bay, since oil spilled from tankers and pipelines at this location is most likely to be carried by the prevailing ocean currents into the bay. Conversely, the Anchor Point area is downstream from most of Kachemak Bay and oil is likely to be carried away from Kachemak Bay.

Pipelines

The laying of pipelines in the areas suggested as pipeline corridors in the BLM development scenario would appear to have little effect on marine birds wintering in Kachemak Bay. However, in areas immediately adjacent to shore, they may temporarily disrupt the local distribution of foraging birds. Depending on where pipeline breaks and chronic leaks occurred, they could pose a severe threat to the birds, their prey, and organisms and processes at the base of their food web. The main consideration is the proximity of the break/leak to Kachemak Bay. A break or leak near shore in the Kennedy Entrance area would be particularly threatening to the birds and to fauna at lower trophic levels in their food web. The key habitats and species would be the same as those mentioned above.

Tanker Routes

The BLM development scenario indicates tanker routes roughly paralleling the north and south shores of outer Kachemak Bay. Any spill here could have dire consequences for marine birds, both by direct oiling and by contaminating their food and organisms at lower trophic levels in the food web. The key habitats and species would be the same as those mentioned above. Routes along the south shore woud appear to pose the greatest threat, however, because they are upstream from most areas of the Bay. Spills here would have a greater chance of remaining within the gyral currents of the bay, thus exposing the birds and their prey to contamination for greater periods of time.

Physical Disturbances

It is difficult to assess the possible negative effects of disturbance to the wintering birds from aircraft and boat traffic. The main problem is the lack of comparative quantitative information on "before and after" conditions on populations of birds in other areas. All of the species of birds we studied are known to inhabit other areas in Alaska and elsewhere on the Pacific Coast which have aircraft and particularly boat traffic. Chiniak Bay on Kodiak Island and Puget Sound, Washington, are two such examples. During our studies, the white-winged scoters were particularly skittish at the approach of our boat, a situation we also experienced in the Kodiak Area. However, fishermen are known to shoot marine birds for crab bait and it is possible that the scoters have learned to be wary of the approach of any boat.

SUMMARY AND CONCLUSIONS

1. We studied the food habits, feeding behavior, and trophic relationships of selected species of birds wintering on Kachemak Bay, Alaska, from November 1977 to April 1978. Studies were concentrated on oldsquaw (Clangula hyemalis), white-winged scoters (Melanitta deglandi), common murres (Uria aalge), and marbled murrelts (Brachyramphus marmoratus). We gathered peripheral information of surf and black scoters (M. perspicillata and M. nigra), and pigeon guillemots (Cepphus columba).

2. Marine birds winter in Kachemak Bay because of an abundant food supply and the presence of ice-free resting areas.

3. The above species ate a minimum of 79 species of prey in eight phyla, including one protozoan, 12 polychaetes, 16 gastropods, 13 bivalves, 25 crustaceans, one sipunculid, one extoproct, four echniodernms, and six fishes. In general, waterfowl ate mostly benthic bivalves and gastropods, and some crustaceans and fish, while the alcids ate mostly pelagic and demersal crustaceans and fish. Although species differed, the birds ate similar kinds of prey as reported for other areas.

4. Oldsquaw were extreme generalists on bethos, eating a minimum of 60 prey species. In descending order of importance, the oldsquaw ate bivalves, crustaceans, fish, gastropods, and polychaetes. The most important species of prey were sand lance (Ammodytes hexapterus), and the bivalves Spisula polynyma and Mytilus edulis. Oldsquaw usually foraged in water less than 18 m over substrates of sand and mud, but occasionally over shell debris, cobbles and boulders.

5. White-winged scoters were generalists on benthic molluscs, primarily bivalves. They ate a minimum of 22 species of prey, the most important being the bivalves Mytilus edulis and Protothaca staminea, and the gastropod Margarites pupillus. Scoters foraged generally in water less than 20 m over substrates of cobbles and shell debris, but occasionally over substrates of mud and sand.

6. Common murres ate a minimum of 11 species of mid-water and demersal prey, mostly crustaceans, but including some fish. The most important prey species were the mysid crustacean Neomysis rayii, and pink shrimp, Pandalus borealis. Murres generally fed over rock substrates in water depths greater than 20 meters, at mid and demersal depths in the water column. The preponderance of crustaceans in the diet of the murres was unexpected, since murres are generally considered to be piscivorous.

7. Marbled murrelets ate at least eight species of prey, primarily fish, but also included some crustaceans in their diet. Capelin (Mallotus villosus) was the most important prey species, followed by sand lance,

the euphausiid crustacean *Thysanoessa raschii*, and mysids. The feeding habitat of the murrelets was basically similar to the murres, although they tended to occur closer to shore.

8. There was very little overlap in the prey species eaten by different species of birds. When overlap did occur, a prey species was generally important to only one bird species, or the two species of birds ate different sizes of prey.

9. Among the four primary species of birds studied, there were significant differences between "mouth area" (culmen length x bill width) and average length of prey.

10. The base of the trophic structure of Kachemak Bay in winter apparently depends on the production and availability of organic detritus. The main source of the organic detritus appears to be mainly from extensive beds of kelp in Kachemak Bay and around the southern perimeter of the Kenai Peninsula, and from fecal pellets produced by zooplankton grazing on spring blooms of phytoplankton. Assuming that the ecosystem of Kachemak Bay is similar to other coastal marine ecosystems, the organic detritus is colonized by bacteria, which provides food for communities of microfauna (animals less than 0.1 mm) and meiofauna (0.1-1.0 mm), all of which are ingested by the filter- and deposit-feeding fauna comprising the bulk of the prey eaten by the birds.

11. Existing knowledge of the distribution and abundance of the prey species in winter is inadequate to determine their availability to the birds. Waterfowl feed in shallow subtidal depths out to about 20 meters, a zone which has been largely unsampled by both shore-based and vessel-based studies. Winter studies of the principal pelagic prey of the birds such as mysids, euphausiids, juvenile shrimp and capelin have been sketchy or non-existent.

12. The birds appear to have a minimal impact on the commercial fisheries of Kachemak Bay.

13. Birds wintering in Kachemak Bay appear to be at high risk from both acute and chronic oil spills. Most of the wintering community of birds are either waterfowl or alcids, the two major groups of birds most susceptible to oiling. Pollution that interferes substantially with the production of organic detritus, particularly from the extensive beds of kelp, could have more serious long-term consequences to the birds than direct oiling. In general, any potential threats to the bird community from petroleum activities needs to be evaluated in terms of the pattern of ocean currents. Accidents which may occur on the south side of the outer Kachemak Bay, and around the southern perimeter of the Kenai Peninsula would threaten the birds and their ecosystem more seriously than ones on the north side of the Bay, which are "downstream" from most of Kachemak Bay.

ACKNOWLEDGEMENTS

Several people contributed to the success of this project in many ways. Jones supervised the field work, and he was assisted, in chronological order, by Allan Fukuyama, Tony DeGange, Bob Gill, Sanger, Margaret Petersen and David Nysewander. We give special thanks to Loren Flagg, David Hardy and Craig Larson, Alaska Department of Fish and Game, Homer, for their excellent cooperation. They allowed us to store our boat on their property, assisted in launching and retrieving the boat, and were generally hospitable during our field trips.

Processing and identification of the stomach contents were done by David Wiswar (white-winged scoters and common murres), Fukuyama (oldsquaw) and Valerie Hironaka (marbled murrelets). A number of taxonomic specialists assisted with identification of the prey. They, and their taxonomic specialities were: Jim Blackburn, larval and adult fishes; Ken Coyle, gammarid amphipods and mysids; Bill Driskell, gastropods; Nora Foster, gastropods and pelycypods; Kathy Frost, fish otoliths; Howard Jones, polychaetes; Hiro Kajimura, fish bones; Lloyd Lowry, fish otoliths; Gary McDonald, gastropods (nudibranchs); George Mueller, bryozoans, crustaceans, ophiuroids and polychaetes; Lisa Shon, shrimp and isopods; Beverly Yoshioka, mysids. George Mueller and his staff at the Marine Sorting Center, University of Alaska, gave generously of their time and were particularly helpful with many of the identifications.

We thank Paul Anderson, and particularly David Erikson, for helpful discussions on Kachemak Bay and its birds. Bob Griffiths provided helpful discussion on the microbiology of Kachemak Bay and processes at the base of the food web. Discussions and correspondence with Dennis Lees on macrophytes and intertidal and shallow subtidal benthos were very helpful.

Wiswar and Tara Martinson gave excellent assistance with the data analyses, and Martinson did most of the graphics. Debbie Amos helped design data anlaysis techniques, and further provided helpful discussions and assistance with statistics. People who read an earlier draft of this report and provided useful comments include Amos, Fukuyama, Lynne Krasnow. Lees, Cal Lensink, Byron Morris, Petersen and Wiswar.

To all of the above-named people, and those we may have inadvertently missed, we express our thanks.

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Appendix Table 1. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence and Index of Relative Importance (IRI) of the Prey of Oldsquaw Collected in Kachemak Bay.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Pooled Samples, November 1977 - April 1978, n = 27				
PROTOZOA				
Unidentified Foraminifera	0.0	0.0	3.7	0
POLYCHAETA				
Unidentified species	0.5	2.8	25.9	85
Harmothoe extenuata	0.0	0.2	3.7	1
Phloe minuta	2.0	0.3	3.7	8
Anaitides mucosa	0.0	0.2	3.7	1
Eteone sp.	0.0	0.3	3.7	1
Unidentified Phyllodocid	0.0	0.0	3.7	0
Unidentified Nereid	0.0	0.1	3.7	1
Glycinde sp.	0.0	0.2	3.7	1
Lumbrinere sp.	0.0	0.0	3.7	0
Pectinaria sp.	0.8	1.3	14.8	32
Ampharete sp.	0.2	1.3	3.7	6
Unidentified Ampharetid	0.9	1.3	3.7	8
Total Polychaeta	4.4	8.0	25.9	321
GASTROPODA				
Unidentified species	3.3	0.9	18.5	78
Unidentified Limpet	0.0	0.2	3.7	1
Lancuna variegata	0.9	0.2	18.5	20
Alvina compacta	0.8	0.3	25.9	28
Cerithiopsis sp.	0.0	0.1	3.7	0
Natica clausa	0.2	1.9	3.7	8

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Trophonopsis pacificus	0.0	0.0	3.7	0
Mitrella tuberosa	1.2	1.3	3.7	10
Neptunea sp.	0.0	0.1	3.7	0
Admete couthouyi	0.1	0.1	3.7	1
Oenopota sp.	3.7	2.5	18.5	114
Unidentified Turrid	0.2	0.3	7.4	4
Odostomia sp.	0.4	0.1	18.5	10
Aglaja diomedeum	0.1	0.0	3.7	0
Retusa sp.	0.0	0.0	3.7	0
Onchidoris bilamellata	0.1	1.2	7.4	10
Total Gastropoda	11.0	9.2	18.5	374
BIVALVIA				
Unidentified species	0.2	1.7	18.6	35
Nucula tenuis	2.4	3.4	37.0	219
Nuculana c.f. *fossa*	2.2	1.4	29.6	108
Glycymeris subobsoleta	7.1	1.7	22.2	196
Glycymeris sp.	0.0	0.1	3.7	0
Mytilus edulis	21.9	4.9	33.3	894
Orobitella sp.	0.0	0.0	3.7	0
Clinocardium sp.	0.0	0.0	3.7	0
Spisula polynyma	26.5	5.1	29.6	937
Macoma balthica	0.0	0.0	3.7	0
Macoma sp.	9.8	3.0	11.1	142
Saxidomus gigantea	0.0	0.0	3.7	0
Psephidia lordi	0.2	0.1	3.7	1

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Protothaca staminea	1.2	1.1	29.6	66
Mya sp.	0.8	0.4	22.2	26
Total Bivalvia	72.3	22.9	29.6	2,818
CRUSTACEA				
Unidentified Barnacle	0.1	0.8	7.4	6
Unidentified Mysid	0.0	0.1	3.7	0
Lamprops sp. (Cumacean)	0.1	0.1	3.7	1
Unidentified Cumacean	0.0	0.1	7.4	2
Gnorimosphaeroma oregonensis (Isopod)	0.0	0.1	3.7	0
Unidentified Gammarid Amphipoda	2.0	5.4	51.8	382
Unidentified Decapod	0.2	0.7	7.4	7
Decapoda Natantia (Shrimp)				
Spirontocaris spina	0.1	0.8	7.4	7
Pandalus goniurus	0.8	3.6	7.4	32
Pandalus jordani	0.0	0.3	3.7	1
Unidentified shrimp	0.1	0.2	3.7	1
Total Shrimp	1.7	6.3	7.4	59
Decapoda Reptantia (Crabs)				
Hyas lyratus	1.5	2.1	14.8	54
Cancer oregonensis	0.7	2.8	14.8	52
Cancer sp.	0.4	1.7	11.1	23
Unidentified species	0.3	0.4	7.4	5
Total Crabs	2.9	7.0	14.8	147
Total Crustacea	7.1	20.6	51.8	1,435

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
ECHIURA				
Echiurus echiurus alaskanus	0.0	0.8	3.7	3
ECTOPROCTA				
Microporina borealis	0.0	0.2	3.7	1
ECHINODERMATA				
Ophiuroidea				
Ophiopholis aculeata	1.3	2.3	3.7	13
Amphipholis pugetana	0.2	0.4	3.7	2
Unidentified species	0.3	8.4	7.4	64
Total Ophiuroidea	1.8	11.1	7.4	95
Unidentified Echinoid	0.0	0.1	3.7	1
Total Echinodermata	1.8	11.2	7.4	96
OSTEICHTHYES				
Unidentified species	0.1	0.3	7.4	3
Unidentified Cottid	0.0	2.3	3.7	9
Ammodytes hexapterus	2.1	23.9	40.7	1,059
Total Osteichthyes	2.1	26.5	40.7	1,168
November 1977, n = 5				
POLYCHAETA				
Unidentified species	0.1	0.3	20.0	9
Pectinaria sp.	0.4	3.5	20.0	78
Total Polychaeta	0.5	3.8	20.0	86
GASTROPODA				
Lacuna variegata	0.8	0.2	20.0	21

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Alvina compacta	0.8	0.8	60.0	94
Neptunea sp.	0.1	0.4	20.0	10
Oenopota sp.	3.5	3.9	40.0	299
Odostomia sp.	0.3	0.1	20.0	7
Onchidoris billamellata	0.3	1.8	20.0	40
Total Gastropoda	5.8	7.2	60.0	780
BIVALVIA				
Nucula tenuis	0.7	0.9	40.0	62
Nuculana c.f. *fossa*	0.1	0.3	20.0	9
Glycymeris subobsoleta	9.1	3.8	40.0	518
Mytilus edulis	14.8	2.7	60.0	1,051
Spisula polynyma	60.3	23.6	60.0	5,033
Psephidia lordi	0.5	0.7	20.0	25
Protothaca staminea	0.7	2.1	60.0	167
Mya sp.	1.4	1.4	20.0	55
Total Bivalvia	87.6	35.5	60.0	7,386
CRUSTACEA				
Lamprops sp. (Cumacean)	0.3	0.7	20.0	19
Unidentified Gammarid Amphipoda	0.5	0.9	20.0	28
Unidentified Decapod	0.3	3.5	20.0	75
Pandalus goniurus (Shrimp)	2.2	22.1	40.0	970
Decapoda Reptantia (Crabs)				
Hyas lyratus	0.4	1.2	40.0	64
Cancer oregonensis	1.2	3.4	20.0	92
Cancer sp.	0.1	0.3	20.0	9

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Total Crabs	1.7	4.9	40.0	264
Total Crustacea	5.0	32.1	40.0	1,484
OSTEICHTHYES				
Ammodytes hexapterus	1.0	21.6	60.0	1,350
December 1977, n = 5				
PROTOZOA				
Unidentified Foraminifera	0.3	0.2	20.0	10
POLYCHAETA				
Unidentified species	0.3	0.2	20.0	10
Pectinaria sp.	0.6	0.6	20.0	23
Total Polychaeta	0.9	0.8	20.0	34
GASTROPODA				
Unidentified species	0.3	0.0	20.0	6
Alvina compacta	2.5	0.8	60.0	199
Trophonopsis pacificus	0.3	0.9	20.0	7
Oenopota sp.	4.7	1.5	20.0	123
Odostomia sp.	0.6	0.3	40.0	35
Total Gastropoda	8.4	3.5	60.0	714
BIVALVIA				
Nucula tenuis	10.5	15.1	100.0	2,557
Nuculana c.f. *fossa*	11.8	3.5	100.0	1,534
Glycymeris subobsoleta	20.9	4.8	60.0	1,546
Glycymeris sp.	0.3	0.3	20.0	12
Mytilus edulis	0.3	0.2	20.0	10

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Spisula polynyma	30.6	6.2	100.0	3,675
Protothaca staminea	5.0	3.2	80.0	654
Mya sp.	0.8	0.5	60.0	82
Total Bivalvia	80.2	33.9	100.0	11,410
CRUSTACEA				
Unidentified Cumacean	0.3	0.2	20.0	10
Unidentified Gammarid Amphipoda	0.3	0.6	20.0	17
Unidentified Shrimp	0.6	0.9	20.0	30
Unidentified Crab	1.4	0.9	20.0	46
Total Crustacea	2.6	2.6	20.0	104
OSTEICHTHYES				
Ammodytes hexapterus	8.0	59.7	100.0	6,768
January 1978, n = 5				
POLYCHAETA				
Unidentified species	3.1	17.4	60.0	1,229
Unidentified Phyllodocid	0.6	0.2	20.0	17
Glycinde sp.	0.6	1.4	20.0	40
Lumbrinereis sp.	0.6	0.2	20.0	17
Ampharete sp.	3.1	9.8	20.0	256
Total Polychaeta	8.0	29.0	60.0	2,220
BIVALVIA				
Unidentified species	1.2	6.6	40.0	314
Mytilus edulis	72.4	11.2	20.0	1,671
Clinocardium sp.	0.6	0.2	20.0	17

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Macoma sp.	6.1	11.2	20.0	346
Total Bivalvia	80.3	29.2	40.0	4,380
CRUSTACEA				
Unidentified Cammarid Amphipod	3.1	2.8	20.0	117
Grangon septemspinosa (Shrimp)	0.6	2.4	20.0	61
Decapoda Reptantia (Crabs)				
Cancer magister	3.7	16.4	60.0	1,203
Cancer sp.	3.1	8.7	20.0	236
Unidentified Crab	0.6	1.7	20.0	46
Total Crabs	7.4	26.8	60.0	2,052
Total Crustacea	11.1	32.0	60.0	2,586
OSTEICHTHYS				
Ammodytes hexapterus	0.6	9.8	20.0	207
February 1978, n = 5				
POLYCHAETA				
Harmothoe extenuata	0.2	1.6	20.0	34
Phloe minuta	6.2	2.1	20.0	166
Anaitides mucosa	0.2	1.6	20.0	34
Eteone sp.	0.2	2.1	20.0	45
Unidentified Nereid	0.2	1.0	20.0	24
Pectinaria sp.	1.8	4.5	40.0	254
Ampharete sp.	2.7	9.4	20.0	242
Total Polychaeta	11.5	22.3	40.0	1,352

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
GASTROPODA				
Unidentified species	10.2	5.2	40.0	616
Lacuna variegata	1.5	0.6	60.0	125
Alvina compacta	0.2	0.1	20.0	6
Oenopota sp.	4.3	10.4	20.0	293
Unidentified Turrid	0.5	0.4	20.0	16
Odostomia sp.	0.6	0.4	40.0	41
Aglaja diomedeum	0.3	0.4	20.0	13
Retusa sp.	0.2	0.4	20.0	10
Onchidoris bilamellata	0.2	6.8	20.0	138
Total Gastropoda	18.0	24.7	60.0	2,562
BIVALVIA				
Unidentified species	0.2	2.8	20.0	59
Nucula tenuis	1.4	1.5	60.0	174
Glycymeris subobsoleta	0.9	0.7	20.0	32
Mytilus edulis	35.1	21.0	80.0	4,492
Orobitella sp.	0.2	0.1	20.0	6
Macoma balthica	0.2	0.4	20.0	10
Macoma sp.	29.6	10.8	40.0	1,616
Saxidomus gigantea	0.2	0.4	20.0	10
Mya sp.	0.5	0.5	40.0	38
Total Bivalvia	68.3	38.2	80.0	8,520
CRUSTACEA				
Unidentified Gammarid Amphipoda	2.3	6.1	80.0	668

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Cancer sp. (Crab)	0.3	3.5	20.0	76
Total Crustacea	2.6	9.6	80.0	976
ECHIURA				
Echiurus echiurus alaskanus	0.2	5.6	20.0	114
		March 1978, n = 6		
POLYCHAETA				
Unidentified species	2.0	0.9	33.3	99
GASTROPODA				
Unidentified species	1.4	0.5	33.3	63
Unidentified Limpet	0.7	0.5	16.7	20
Lacuna variegata	1.4	0.3	16.7	27
Cerithiopsis sp.	0.7	0.3	16.7	16
Natica clausa	3.4	5.7	16.7	151
Admete couthouyi	2.0	0.3	16.7	38
Oenopota sp.	4.1	0.2	16.7	72
Unidentified Turrid	1.4	0.7	16.7	34
Total Gastropoda	15.1	8.5	16.7	394
BIVALVIA				
Unidentified species	1.4	1.1	33.3	82
Nuculana c.f. *fossa*	1.4	2.0	33.3	112
Protothaca staminea	0.7	0.2	16.7	15
Total Bivalvia	3.5	3.3	33.3	226
CRUSTACEA				
Unidentified Barnacles	1.4	2.3	33.3	123

Appendix Table 1 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Unidentified Mysid	0.7	0.2	16.7	15
Unidentified Cumacean	0.7	0.2	16.7	15
Gnorimosphaeroma oregonensis (Isopod)	0.7	0.3	16.7	16
Unidentified Gammarid Amphipoda	11.6	11.5	66.7	1,541
Unidentified Decapoda	2.0	0.4	16.7	40
Decapoda Natantia (Shrimp)				
Spirontocaris spina	1.4	2.4	33.3	126
Unidentified Pandalidae	9.5	4.0	16.7	226
Total Shrimp	10.9	6.4	33.3	576
Hyas lyratus (crab)	17.7	4.0	16.7	362
Total Crustacea	45.7	25.3	66.7	4,736
ECTOPROCTA				
Microporina borealis	0.7	0.7	16.7	23
ECHINODERMATA				
Ophiuroidea				
Unidentified Ophiuroid	4.1	25.0	33.3	970
Ophiopholis aculeata	19.0	6.8	16.7	430
Amphipholis pugetana	2.7	1.4	16.7	68
Total Brittle Stars	25.8	33.2	33.3	1,965
Unidentified Echinoid	0.7	0.4	16.7	17
OSTEICHTHYES				
Unidentified species	1.4	0.8	33.3	72
Unidentified Cottid	0.7	6.8	16.7	124
Ammodytes hexapterus	4.8	20.2	16.7	417

Appendix Table 1 (concluded)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Total Fish	6.9	27.8	33.3	1,156
	April 1978, n = 1			
GASTROPODA				
Mitrella tuberosa	89.7	70.0	100.0	15,966
CRUSTACEA				
Hyas lyratus (crab)	10.3	30.0	100.0	4,034

Appendix Table 2. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence and Index of Relative Importance (IRI) of the Prey of White-winged Scoters Collected in Kachemak Bay.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Pooled Samples, November 1977 - April 1978, n = 35				
POLYCHAETA				
Unidentified species	1.1	0.5	5.6	9
Halosydna brevisetosa	0.4	0.3	2.8	2
Nephtys sp.	0.4	0.2	2.8	2
Total Polychaeta	1.9	.9	5.6	16
GASTROPODA				
Unidentified species	4.4	2.3	25.0	167
Margarites pupillus	17.2	0.9	8.3	151
Margarites sp.	4.4	0.5	2.8	13
Lacuna variegata	0.4	0.0	2.8	1
Lacuna sp.	0.7	2.4	2.8	9
Littorina sp.	0.4	0.0	2.8	1
Trichotropis cancellata	4.4	0.3	2.8	13
Natica clausa	1.5	3.5	2.8	14
Neptunea lyrata	3.6	3.6	8.3	60
Neptunea sp.	5.5	0.3	2.8	16
Admete couthouyi	3.6	0.5	2.8	11
Total Gastropoda	46.1	14.3	25.0	1,510
BIVALVIA				
Unidentified species	7.3	14.4	38.9	845

Appendix Table 2 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Glycymeris subobsoleta	6.2	1.4	2.8	21
Mytilus edulis	21.2	30.6	22.2	1,158
Astarte rollandi	1.1	0.1	2.8	3
Macoma sp.	1.1	1.6	8.3	22
Protothaca staminea	9.8	32.4	47.2	1,996
Unidentified Venerid	0.7	1.1	5.6	10
Mya sp.	0.4	0.1	2.8	1
Total Bivalvia	47.8	81.7	47.2	6,112
CRUSTACEA				
Unidentified Barnacle	0.4	0.4	2.8	2
Unidentified Shrimp	0.4	0.1	2.8	1
Unidentified Crab	2.2	0.4	13.9	36
Total Crustacea	3.0	0.9	13.9	54
SIPUNCULA				
Sipunculus sp.	0.4	1.4	2.8	2
ECHINODERMATA				
Strongylocentrotus droebachiensis (Echinoid)	0.4	0.7	2.8	3
Unidentified Strongylocentrotidae	0.4	0.0	2.8	1
Unidentified Holothuroidea	0.4	0.4	2.8	2
Total Echinodermata	1.2	1.1	2.8	6
November 1977, n = 1				
BIVALVIA				
Mytilus edulis	100.0	100.0	100.0	20,000

Appendix Table 2 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
	December 1977, n = 2			
BIVALVIA				
Mytilus edulis	100.0	100.0	100.0	20,000
	January 1978, n = 14			
POLYCHAETA				
Unidentified species	0.8	1.4	7.1	16
Nephtys sp.	0.8	0.8	7.1	11
Total Polychaeta	1.6	2.2	7.1	27
GASTROPODA				
Unidentified species	2.5	0.2	7.1	20
Margarites pupillus	39.0	2.3	14.3	590
Littorina sp.	0.8	0.0	7.1	6
Trichotropis cancellata	10.2	0.9	7.1	79
Neptunea lyrata	1.7	1.9	7.1	26
Neptunea sp.	12.7	1.0	7.1	98
Total Gastropoda	66.9	6.3	14.3	1,047
BIVALVIA				
Unidentified species	9.3	25.5	57.1	1,991
Macoma sp.	1.7	4.4	14.3	87
Protothaca staminea	10.2	50.7	64.3	3,914
Unidentified Vernerid	1.7	3.4	14.3	73
Total Bivalvia	22.9	84.0	64.3	6,874
CRUSTACEA				
Unidentified Barnacle	0.8	1.4	7.1	16

Appendix Table 2 (continued)

Prey Form	Percent			IRI
	No.	Vol.	F.O.	
Unidentified Crab	4.2	1.3	28.6	158
Total Crustacea	5.0	2.7	28.6	220
SIPUNCULA				
Sipunculus sp.	0.8	1.4	7.1	16
ECHINODERMATA				
Strongelocentrotus droebachiensis (Echinoid)	0.8	2.0	7.1	20
Unidentified Strongylocentrotidae	0.8	0.1	7.1	7
Unidentified Holothuroidea	0.8	1.3	7.1	16
Total Echinodermata	4.0	5.5	7.1	67
February 1978, n = 9				
POLYCHAETA				
Unidentified species	4.3	0.3	11.1	50
GASTROPODA				
Margarites pupillus	2.1	0.6	11.1	31
Neptunea lyrata	14.9	1.9	11.1	187
Total Gastropoda	17.0	2.5	11.1	216
BIVALVIA				
Unidentified species	4.3	5.0	22.2	206
Mytilus edulis	51.1	62.8	55.6	6,327
Protothaca staminea	21.3	29.0	55.6	2,792
Mya sp.	2.1	0.4	11.1	28
Total Bivalvia	78.8	97.2	55.6	9,786

Appendix Table 2 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
March 1978, n = 4				
POLYCHAETA				
Halosydna brevisetosa	5.3	2.0	25.0	183
GASTROPODA				
Unidentified species	21.0	8.2	75.0	2,195
Natica clausa	21.0	26.3	25.0	1,184
Total Gastropoda	42.0	34.5	75.0	5,738
BIVALVIA				
Unidentified species	21.0	18.8	50.0	1,993
Macoma sp.	5.3	0.8	25.0	151
Protothaca staminea	21.0	42.9	50.0	3,200
Total Bivalvia	47.3	62.5	50.0	5,490
CRUSTACEA				
Unidentified Shrimp	5.3	0.9	25.0	154
April 1978, N = 5				
GASTROPODA				
Unidentified species	13.9	11.0	100.0	2,488
Margarites sp.	33.3	4.4	20.0	756
Lacuna variegata	2.8	0.2	20.0	59
Lacuna sp.	5.6	22.8	20.0	566
Neptunea lyrata	2.8	22.8	20.0	511
Admete couthouyi	27.8	4.4	20.0	643
Total Gastropoda	86.2	65.6	100.0	15,180

Appendix Table 2 (concluded)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
BIVALVIA				
Unidentified species	8.3	20.1	40.0	1,138
Protothaca staminea	2.8	14.3	20.0	341
Total Bivalvia	11.1	34.4	40.0	1,820
CRUSTACEA				
Unidentified Crab	2.8	0.1	20.0	58

Appendix Table 3. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence, and Index of Relative Importance (IRI) of the Prey of Black Scoters and Surf Scoters Collected in Kachemak Bay.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Black Scoter, November 1977, N = 1				
BIVALVIA				
Mytilus edulis	100.0	100.0	100.0	20,000
Surf Scoter, December 1977, N = 2				
POLYCHAETA				
Nephtys sp.	15.4	42.6	50.0	2,900
Unidentified Terebellid	7.7	0.5	50.0	408
GASTROPODA				
Unidentified Turrid	7.7	0.5	50.0	408
BIVALVIA				
Unidentified	23.1	51.6	50.0	3,733
Nucula tenuis	7.7	0.5	50.0	408
Saxidomus gigantea	7.7	0.5	50.0	408
Protothaca staminea	15.4	0.5	50.0	796
CRUSTACEA				
Crangon sp. (Shrimp)	7.7	1.0	50.0	432

Appendix Table 4. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence, and Index of Relative Importance (IRI) of the Prey of Common Murres Collected in Kachemak Bay.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Pooled Samples, December 1977 to April 1978, n = 28				
POLYCHAETA				
Unidentified Nereid	0.3	0.0	3.6	1
CRUSTACEA				
Unidentified Species	1.1	2.2	14.3	46
Neomysis rayii (Mysids)	83.3	49.0	39.3	5,200
Decapoda Natantia (Shrimp)				
Eualus sp.	0.3	0.6	3.6	3
Pandalus borealis	5.6	16.7	17.9	398
Pandalus goniurus	0.3	0.4	3.6	2
Pandalus sp.	0.3	1.4	3.6	6
Unidentified Pandalidae	0.8	3.9	10.7	51
Total Pandalid Shrimp	6.9	22.5	35.7	1,049
Crangon franciscorum	0.8	3.9	10.7	50
Crangon sp.	0.3	1.1	3.6	5
Unidentified Species	0.8	3.9	10.7	51
Total Shrimp	9.1	32.0	17.9	736
Total Crustacea	93.5	83.2	39.3	6,944
OSTEICHTHYES				
Unidentified Species	1.3	1.1	17.9	42
Clupea harengus	0.3	5.3	3.6	20
Mallotus villosus	0.5	2.5	7.1	22
Unidentified Osmerid	1.8	0.8	14.3	37

Appendix Table 4 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Total Osmeridae	2.3	3.3	14.3	80
Theragra chalcogramma	1.3	5.2	17.9	117
Unidentified Gadid	0.3	0.1	3.6	1
Total Gadidae	1.6	5.3	17.9	123
Lumpenus maculatus	0.3	1.3	3.6	5
Unidentified Stichaeid	0.3	0.6	3.6	3
Total Stichaeidae	0.6	1.9	3.6	9
Ammodytes hexapterus	0.3	0.0	3.6	1
Total Fish	6.4	16.9	17.9	417
December 1977, n = 6				
CRUSTACEA				
Neomysis rayii (Mysids)	96.0	73.4	83.3	14,116
OSTEICHTHYES				
Unidentified Species	1.2	1.4	33.3	36
Clupea harengus	0.6	15.8	16.7	273
Mallotus villosus	0.6	3.2	16.7	6
Theragra chalcogramma	0.6	6.0	16.7	109
Ammodytes hexapterus	0.6	0.0	16.7	10
Total Fish	3.6	26.4	33.3	999
January 1978, n = 9				
POLYCHAETA				
Unidentified Nereid	0.6	0.1	11.1	8
CRUSTACEA				
Unidentified Species	1.8	5.8	33.3	255

Appendix Table 4 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Neomysis rayii (Mysids)	90.8	75.9	66.7	11,111
Decapoda Natantia (Shrimp)				
Pandalus goniurus	0.6	1.3	11.1	22
Unidentified shrimp	0.6	0.7	11.1	15
Total Shrimp	1.2	2.0	11.1	36
Total Crustacea	93.8	83.7	66.7	11,839
OSTEICHTHYES				
Mallotus villosus	0.6	4.4	11.1	56
Unidentified Osmerid	3.7	2.2	33.3	195
Total Osmeridae	4.3	6.6	33.3	363
Theragra chalcogramma	1.2	9.6	22.2	241
Total Fish	5.5	16.2	33.3	723
February 1978, n = 3				
CRUSTACEA				
Unidentified species	25.0	11.1	33.3	1,204
Decapoda Natantia (Shrimp)				
Eualus sp.	25.0	23.3	33.3	1,611
Pandalus sp.	25.0	54.4	33.3	2,648
Total Shrimp	50.0	77.7	33.3	4,252
Total Crustacea	75.0	88.8	33.3	5,454
OSTEICHTHYES				
Unidentified species	25.0	11.1	33.3	1,204

Appendix Table 4 (concluded)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
	March 1978, n = 5			
CRUSTACEA (All Shrimp)				
Pandalus borealis	60.0	47.3	40.0	4,295
Unidentified pandalidae	13.3	22.8	40.0	1,446
Total Pandalidae	73.3	70.2	40.0	5,740
Crangon franciscorum	6.7	12.3	20.0	379
Unidentified species	13.3	17.2	40.0	1,221
Total Shrimp	93.3	99.6	40.0	7,716
OSTEICHTHYES				
Unidentifies species	6.7	0.4	20.0	140
	April 1978, n = 5			
CRUSTACEA (All Shrimp)				
Pandalus borealis	54.6	58.0	60.0	6,750
Crangon franciscorum	9.1	17.1	40.0	1,045
Crangon sp.	4.6	0.0	20.0	91
Unidentified species	4.6	10.2	20.0	294
Total Shrimp	72.9	85.3	60.0	9,492
OSTEICHTHYES				
Unidentified Species	9.1	2.9	40.0	470
Theragra chalcogramma	9.1	0.9	40.0	400
Lumpenus maculatus	4.6	11.3	20.0	316
Unidentified Species	4.6	0.0	20.0	91
Total Fish	27.4	15.1	40.0	1,700

Appendix Table 5. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence and Index of Relative Importance (IRI) of the Prey of Three Pigeon Guillemots Collected in Kachemak Bay. One Specimen Each Collected in January, March, and April 1978.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
POLYCHAETA				
Unidentified species	1.5	6.9	33.3	281
CRUSTACEA				
Unidentified Mysida	3.1	0.8	33.3	130
Decapoda Natantia (shrimp)				
Spirontocaris spina	4.6	1.7	33.3	209
Eualus fabricii	1.5	1.1	33.3	88
Pandalus goniurus	35.4	49.7	33.3	2,832
Crangon septemspinosa	24.6	26.2	33.3	1,693
Sclerocrangon alata	6.2	1.7	33.3	260
Unidentified species	1.5	0.3	33.3	61
Total Shrimp	73.8	80.7	33.3	5,145
Decapoda Reptantia (crabs)				
Cancer oregonensis	13.8	3.4	33.3	576
Unidentified species	3.1	0.8	66.7	261
Total Crabs	16.9	4.2	66.7	1,407
Total Crustacea	93.8	85.7	66.7	11,973
OSTEICHTHYES				
Unidentified species	4.6	7.4	66.7	402

Appendix Table 6. Percent Aggregate Numbers and Volume, Percent Frequency of Occurrence and Index of Relative Importance (IRI) of the Prey of Marbled Murrelets Collected in Kachemak Bay, January - April 1978.

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
Pooled Samples, January - April 1978, n = 18				
CRUSTACEA				
Unidentified species	0.8	1.2	5.6	11
Unidentified Mysida	34.4	6.7	11.1	456
Unidentified Gammarid Amphipoda	1.2	1.4	11.1	30
Euphausiacea				
Thysanoessa inermis	0.5	1.2	5.6	9
Thysanoessa raschii	19.4	5.7	16.7	418
Thysanoessa spinifera	0.2	0.9	5.6	6
Thysanoessa sp.	22.1	4.0	16.7	435
Total *Thysanoessa*	42.2	11.8	16.7	902
Total Crustacea	78.6	21.1	16.7	1,665
OSTEICHTHYES				
Unidentified species	3.4	7.8	22.2	249
Mallotus villosus	11.1	51.8	50.0	3,146
Unidentified Osmerid	0.2	0.1	5.6	1
Theragra chalcogramma	0.2	0.2	5.6	2
Unidentified species	0.2	0.5	5.6	4
Ammodytes hexapterus	6.4	18.5	16.7	415
Total Fish	21.5	78.9	50.0	5,020

Appendix Table 6 (continued)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
	January 1978, n = 6			
CRUSTACEA (All Euphausiids)				
Thysanoessa raschii	14.7	4.2	16.7	315
Thysanoessa sp.	61.2	9.6	33.3	2,358
Unidentified species	2.2	4.2	16.7	107
Total Euphausiacea	78.1	18.0	33.3	3,200
OSTEICHTHYES				
Mallotus villosus	21.0	51.2	50.0	3,612
Unidentified species	0.4	1.7	16.7	35
Ammodytes hexapterus	0.4	29.2	16.7	494
Total Fish	21.8	82.1	50.0	5,195
	February 1978, n = 4			
CRUSTACEA				
Unidentified Mysida	72.2	17.9	25.0	2,252
Unidentified Gammarid Amphipoda	2.8	6.4	50.0	460
Euphausiacea				
Thysanoessa inermis	1.0	5.6	25.0	166
Thysanoessa raschii	5.2	3.6	25.0	219
Total Euphausiacea	6.2	9.2	25.0	385
Total Crustacea	81.2	33.5	50.0	5,735
OSTEICHTHYES				
Unidentified species	4.9	21.5	50.0	1,317
Unidentified Osmerid	0.4	0.4	25.0	20
Ammodytes hexapterus	13.5	44.6	25.0	1,455
Total Fish	18.8	66.5	50.0	4,265

Appendix Table 6 (contluded)

Prey Form	Percent No.	Percent Vol.	Percent F.O.	IRI
		March 1978, n = 3		
CRUSTACEA				
Unidentified Mysida	34.3	9.8	33.3	1,469
Thysanoessa spinifera (Euphausiid)	2.9	3.3	33.3	204
Total Crustacea	37.2	13.1	33.3	1,675
OSTHEICHTHYES				
Unidentified species	2.9	6.5	33.3	313
Mallotus villosus	54.3	78.9	100.0	13,320
Theragra chalcogramma	2.9	0.9	33.3	124
Ammodytes hexapterus	2.9	0.6	33.3	117
Total Fish	63.0	86.9	100.0	14,990
		April 1978, n = 5		
CRUSTACEA (All Euphausiids)				
Thysanoessa raschii	82.6	17.6	20.0	2,005
Thysanoessa sp.	4.3	5.9	20.0	205
Total Euphausiacea	86.9	23.5	20.0	2,208
OSTEICHTHYES				
Unidentified species	7.6	5.9	20.0	270
Mallotus villosus	5.4	70.6	60.0	4,561
Total Fish	13.0	76.5	60.0	5,370

Appendix Table 7. Data on culmen length (CL), bill width (BW) and mouth area (CL X BW) for birds collected in winter on Kachemak Bay, Alaska.

Species	Culmen Length, mm		Bill Width, mm		Mouth Area, mm^2	
	n	$\bar{X} \pm SE$ (range)	n	$\bar{X} \pm SE$ (range)	n	$\bar{X} \pm SE$ (range)
Oldsquaw	28	27.6±0.2 (25.5-29.8)	21	14.8±0.6 (10.0-18.0)	21	404±18 (273-529)
White-winged Scoter	38	38.6±0.4 (31.4-44.0)	35	18.4±0.8 (12.0-31.0)	35	717±32 (463-1,283)
Black Scoter	1	41.0	1	14.0	1	574
Surf Scoter	4	38.2±1.4 (35.3-42.0)	3	17.7±2.8 (12-21)	3	720±147 (442-941)
Common Murre	30	45.2±0.4 (41.0-50.0)	28	15.6±0.4 (11.0-19.0)	27	703±19 (517-885)
Pigeon Guillemot	3	35.0±0.2 (34.6-35.4)	3	11.7±0.7 (11.0-13.0)	3	408±21 (385-449)
Marbled Murrelet	18	15.9±0.2 (14.3-17.3)	18	9.0±0.6 (6.0-14.0)	16	140±10 (100-224)