FINAL REPORT
RU-77
ECOSYSTEM DYNAMICS BIRDS AND MARINE MAMMALS

Part II

ASPECTS OF THE FEEDING ECOLOGY OF BERING SEA AVIFAUNA

by

Gerald A. Sanger and Patricia A. Baird

ENVIRONMENTAL ASSESSMENT OF THE ALASKAN CONTINENTAL SHELF

Sponsored by

UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF LAND MANAGEMENT

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington 98112

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ABSTRACT

The authors spent about 65 person-days preparing a report on the birds of the eastern Bering Sea under a subcontract to OCSEAP RU-77 (Ecosystem Dynamics-Birds and Mammals). The pertinent literature was reviewed on ten species of marine birds which are important in that area either because of their large biomass, or as representatives of the diversity of the pelagic bird community. Dramatic seasonal changes occur in the abundance of birds in the eastern Bering Sea. Peak abundance occurs in early spring with the influx of Sooty and Short-tailed Shearwaters from their breeding grounds in the southern hemisphere, and with the staging of Alaskan breeding species prior to nesting.

During the Alaskan birds' breeding season, the distribution of all species except the shearwaters is strongly oriented toward colonies. Little is known about the diets of the birds, but the abundant shearwaters and murres appear to consume large quantities of euphausiids, and schooling pelagic and demersal fishes. Prey items range in size from copepods of 7 mm or less (eaten by Least Auklets) to fish of at least 25 cm (eaten by murres). Glaucous-winged Gulls, Black-legged Kittiwakes, and Northern Fulmars probably benefit greatly from offal produced by Walleye Pollock fisheries. The fisheries have possibly created an imbalance in the ecosystem which has benefitted planktivorous birds.

Recommendations to further refine ecosystem data on marine birds include: 1. More intensive studies on population sizes and the diets of the shearwaters; 2. Better estimates of colony population sizes, and the relationships between numbers of birds on the colonies and numbers at sea; 3. Many more food samples collected systematically throughout the year; 4. Included in the model of the ecosystem should be meroplankton (including ichthyoplankton); copepods; euphausiids; small pelagic fishes; epibenthic macroplankton; and fisheries offal.

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PREFACE

Research Unit 77 of the BLM/NOAA Outer Continental Shelf Energy Assessment Program, entitled "Ecosystem Dynamics - Birds and Mammals" was originally designed to provide a conceptual ecosystem model for marine bird and mammal populations in the eastern Bering Sea. The principal investigators and their parent agency, the National Marine Fisheries Service (NMFS), had no expertise on marine birds. They subcontracted to the U.S. Fish and Wildlife Service, Office of Biological Services - Coastal Ecosystems, Anchorage, AK, to provide a basic literature review of marine birds in the eastern Bering Sea. The literature review was to emphasize marine bird feeding studies and other ornithological information.

Correspondence between G. A. Sanger, and F. Favorite and T. Laevastu of the NMFS summarizing pertinent published and unpublished data on shearwaters and murres provided the initial marine bird data input to the model. This was followed by a 13-page preliminary report (Sanger 1976) which provided additional data on murres and shearwaters in the Bering Sea. The data emphasized feeding habits, pelagic populations, and breeding chronology. This final report provides similar data on eight more species, integrates essential information from the preliminary report, and attempts to present a general background picture of marine birds in the eastern Bering Sea and factors pertinent to their feeding ecology.

There is a glaring dearth of published information on marine birds in the eastern Bering Sea. A few years hence, when the present wealth of data beginning to accumulate from OCSEAP studies is analyzed, a much clearer picture of the ecology of marine birds in the eastern Bering Sea will be available. Meanwhile, we believe this report is reasonably complete in reviewing and integrating information pertinent to the role of marine birds in the ecosystem of the eastern Bering Sea.

INTRODUCTION

At least 130 species of "marine oriented" birds occur in the eastern Bering Sea or in its adjacent estuarine and intertidal habitats (Sanger and King in press). Since the initial ecosystem modeling attempts for the eastern Bering Sea (Laevastu and Favorite 1976) include only pelagic faunal communities, this report considers only pelagic species of birds. For an initial attempt at modeling a marine bird community, however, areas away from land are a good place to start; there are fewer variables affecting bird distribution and abundance here than in areas closer to shore (Sanger 1972a).

This report summarizes information and biological concepts important to a basic understanding of the role of birds in the ecosystem of the eastern Bering Sea. It is not an exhaustive review of the literature, but rather sets a basic ornithological and environmental background. It focuses on specific ecological factors on some ten species of marine birds which should be useful for portraying much of the marine bird community of the eastern Bering Sea in an ecosystem model. It is assumed the reader has little or no background in ornithology.

The specific objectives of the report are:

1. To give a general ornithological background for the eastern Bering Sea.

2. To give enough general environmental background of particular importance to birds so that they may be better understood as integral components of the ecosystem.

3. To give "best available" estimates of the seasonal distribution and abundance of a few key species of marine birds.

4. To provide lists of the prey species of ten species of marine birds.

5. Provide recommendations for further field and laboratory studies which would further our ecological understanding of marine birds in the eastern Bering Sea and enable further refinement of ecosystem models.

6. To provide recommendations for expanding the present list of components of an ecosystem model which will more accurately reflect the birds' feeding ecology.

GENERAL BIOLOGICAL BACKGROUND

The Distribution and Abundance of Prey and Predators

Any model of the eastern Bering Sea ecosystem must include data on the abundance of both prey and predator species during the breeding and non-breeding seasons, because seasonally different regulating factors may be operating on each of them (Fretwell 1972). Moreover, summer population sizes of consumers may be determined by winter food availability (Pulliam 1975). For seabirds, density-dependant winter mortality may occur in some species, and this usually affects young birds greatest since they are inferior competitors for food with adults (Ashmole 1971). In the eastern Bering Sea, only Shuntov (1972) has published information on winter populations of marine birds. The absolute abundance of prey is an important factor to consider in food web analyses; the prey may be locally abundant, but not high enough in overall abundance to be consistently located by consumers.

Similarly, distribution data on both prey and predators needs to be considered in ecosystem modeling. Many authors have noted close associations between predators and their prey (e.g.; Ashmole 1971, Royama 1970). In high latitudes with short, well defined seasons of biological productivity such as the eastern Bering Sea, similar influences no doubt act on prey availability (e.g.; Bedard 1969a). As noted below, this factor probably has influenced the locations of breeding colonies in the eastern Bering Sea.

Prey-Predator Relationships

Royama (1970) regards "percentage predation" (i.e., percent composition of all food comprised by a prey species) as an important variable to consider in studying food webs. This factor apparently varies in a curvilinear fashion with prey abundance. The very real possibility of preferential prey selectivity by a predator (Holling 1968, Ivlev 1961) needs to be known, but there apparently is little or no such data in the eastern Bering Sea.

Feeding rates depend on many factors other than availability of prey to the consumer. Royama (1970) believes that "What is important from a predator's viewpoint is not density of prey, but rather the actual amount of prey that a predator can collect for a given time in a given hunting situation." Feeding rates may also depend on absolute densities as stated above, or on behavioral interactions among the predators in feeding associations. In inter- and intra-specific situations, competition from other predators may affect feeding rates, so an ecosystem model must consider all consumers. Feeding rates can sometimes decrease when consumer density increases; this effect is apparently a mechanism for maintaining ecosystem stability (DeAngelis *et al* 1975). DeAngelis *et al* (1975) suggest that feeding rates should be examined as a function of relative densities of prey and consumers.

The maximum consumption rate upon a prey species by a predator must be differentiated from natural fluctuations in prey population (i.e., those caused by other predator species, physical environmental affects, etc.). Finally, an analyses of prey partitioning among all of its' predator species needs to be examined (Schoener 1974). However, for beginning attempts at modeling the relationships between marine birds and their prey, it would seem expedient to assume simple Lotka-Volterra relationships (predators and their prey are in equilibrium and their populations fluctuate roughly in inverse proportions) (Lotka 1925, Volterra 1926) until shown otherwise by hard data.

What is a Trophic Level?

Webster's Seventh New Collegiate Dictionary defines the word trophic as: "Of or relating to nutrition", and the word nutrition as: "The act or process of nourishing or being nourished." "Trophic" thus expands to "Of or relating to the act or process of nourishing or being nourished." In the context of a simple food chain, each link in the chain represents a level of nutrition, and thus represents a trophic level. In an ecosystem involving food webs, however, the existence of trophic levels is more a concept than a reality. In an exceedingly complex environment such as the eastern Bering Sea shelf, organisms exist in an infinite number of sizes ranging from the smallest detrital particles and phytoplankton up to the largest baleen whales. In a sense, there is also an infinite number of trophic levels. Also, as most planktonic and nektonic animals grow, they ascend to higher and higher trophic levels until fully grown. However, knowledge of the actual food web pathways and dynamics is imprecise. Thus, the assumption of distinct trophic levels is a useful tool to begin to portray an ecosystem in a model (Schaefer and Alverson 1968; Sanger 1972b).

Work by Parsons and LeBrasseur (1970) and LeBrasseur and Kennedy (1972) in coastal British Columbia and at Ocean Station Papa in the North Pacific Ocean has shown that food chains in coastal areas tend to be shorter than in oceanic areas. This is due to much of the oceanic primary production occurring from nannoplankton (phytoplankton less than 20 microns in size) which is not abundant in coastal areas. Thus, microzooplankton such as radiolarians are the herbivores in the oceanic areas, while the dominant phytoplankton along the coast are relatively large diatoms, which are preyed upon directly by the euphausiid, *Euphausia pacificus*. Offshore, *E. pacificus* prey upon the radiolarians, so the same species is thus two trophic levels apart in the two areas. In reality, what is termed a trophic level actually contains a range of sizes of organisms; their average sizes differ, but there can be considerable overlap in sizes from one level to the next.

Gallopin (1972) states that, to define a trophic level, the proportion of common prey species to total prey species of all predators must be examined as well as the magnitude of flow of biomass and energy. This flow depends in part on the relative abundance of prey and predators. The relative allocation of biomass flow from all species to each predator should also be known. Consumers are at the same trophic level if the proportions of the flow from the same prey are the same for the consumers being compared (Gallopin 1972). He thus suggests obtaining an index of similarity weighted by the proportion of biomass or energy flow to define trophic levels. However, Gallopin's (1972) scheme would seem more realistic if size classes of prey would be included.

ORNITHOLOGICAL BACKGROUND

General Aspects

Although marine birds are usually seen flying above the sea or floating on the water, they are very much a part of the nekton community. Most species are able to swim under water agilely, propelling themselves with their wings, or feet, or both. Many species in the eastern Bering Sea regularly and normally feed on or near the bottom, at depths ranging down to 75 meters (Ainley and Sanger in press). Even the surface feeders usually feed with at least their bills or heads beneath the surface. Depending on species, they may feed at or just beneath the surface (most gulls), in the upper few meters (shearwaters), at mid-depths (puffins, some other alcids), or from mid-depths to the bottom (murres, cormorants, sea ducks).

Two natural factors overwhelmingly influence the distribution of marine birds in the eastern Bering Sea: the distribution of sea ice in winter, and the locations of breeding colonies in spring and summer. The affect of the ice edge on the distribution and ecology of marine birds will only be mentioned in passing here; it is the subject of an ongoing OCSEAP Research Unit (RU #330, "The distribution, abundance and feeding ecology of birds associated with the Bering and Beaufort Seas Pack Ice"), and information from that study will be useful in modeling aspects of the marine bird community in winter.

The locations of the colonies and the chronology of breeding activities have a dramatic affect on bird distribution in the eastern Bering Sea. For all species except shearwaters, their populations are strongly concentrated in the general vicinity of the colonies from late spring through at least mid-summer. Definitive data on the distances birds range seaward to feed from the colonies is just beginning to accumulate. It appears that most species range only to within 20 to 50 miles seaward; one or two species may range regularly out to 80 miles, and still another probably regularly ranges to distances greater than 100 miles from the colonies during the breeding season. Specifics will be discussed below under the accounts of species. Regardless, it seems probable that for colonies to persist over the years, a persistent food supply nearby is essential. In strong contrast to the breeding birds, the shearwaters appear to be distributed quite patchily. They may or may not be abundant where breeding birds are abundant.

Another factor which has a tremendous, although unmeasured, influence on the distribution of marine birds in the eastern Bering Sea is the presence of the foreign fishing fleets. Scavenger species (gulls, kittiwakes, and fulmars) congregate around the fishing vessels, and particularly the motherships, in swarms of thousands or tens of thousands. This phenomenon and its possible implications will be discussed below.

Avifauna of the Eastern Bering Sea

Generally, about 132 species of marine or marine-oriented birds in 28 families or ducks subfamilies occur in the eastern Bering Sea or its adjacent estuarine and intertidal habitats (Sanger and King in press). Ecologically, because of their large numbers and/or biomass, three bird families are of overwhelming importance in pelagic areas of the eastern Bering Sea: the Procellariidae (fulmars and shearwaters); the Laridae (gulls and terns); and the Alcidae (murres, puffins, and auklets).

We have chosen 10 species to discuss in some detail in this report. The two shearwaters and the two murres are the most important species in terms of biomass, and probably numbers as well. Northern Fulmars, Glaucous-winged Gulls, and Black-legged Kittiwakes are also important in biomass and numbers, so should be considered. The auklets occur in large numbers, especially the Least Auklet, but because of their small size their biomass is relatively small. Their overall impact on the ecosystem is correspondingly small. However, we have also included data on three of the auklets, the Least, Crested, and Parakeet, because outstanding data is available for them (Bedard 1969a), and their inclusion provides a broader perspective for the entire bird community. Recommendations for the inclusion of additional species in future ecosystem modeling attempts will be made below.

Northern Fulmar: Fulmars are present in the eastern Bering Sea from late winter through late fall (Figure 1); most of the population is in the North Pacific proper in midwinter, ranging as far south as Baja California. There is very little information on sizes of fulmar colonies in the eastern Bering Sea, although their locations are known (Table 1, Figure 2). The largest colony apparently occurs on St. Matthew Island with the Pribilof colonies being large also. Large colonies exist in the Commander Island, and colonies of unknown size occur in the eastern Aleutians. Any of these could contribute birds to pelagic populations of

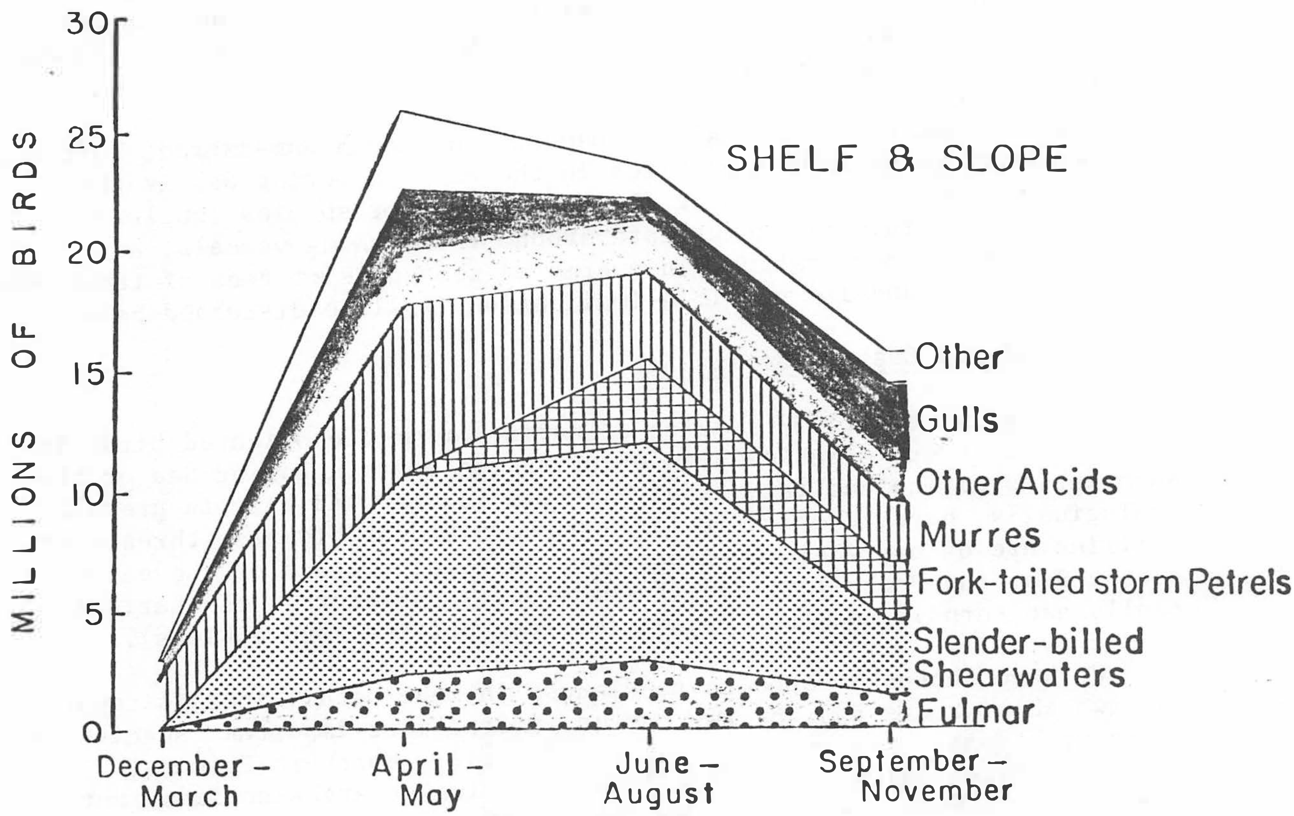

Figure 1. The seasonal abundance of marine birds over the shelf and slope of the eastern Bering Sea. Adapted from Sanger and King (in press).

Table 1. Estimated sizes* of colonies of Northern Fulmars, Glaucous-winged Gulls, Black-legged Kittiwakes, and Least, Parakeet and Crested Auklets in the eastern Bering Sea. X = present in undetermined numbers.

Colony Name	Estimated Colony Size, Thousands of Birds					
	NoFulm	GW Gull	BL Kit	Le Au	Cr Au	PaAu
Sledge Island			1.3			
Bluff Cliffs			3.5-6.1			0.1
Square Rock			0.6			
King Island			3-6			
Rocky Point			0.1			
Cape Denbigh			1.8			
Cape Darby			0.1			
Egg Island			0.5			
St. Lawrence Island			2.1	953	574	3(?)
St. Matthew Island	X					
Cape Peirce-Shaiak Is.		5.6	200.3			
Nelson Lagoon		12.4				0.3
Seal Islands		6.0				
St. George Island	X		100	200-400(?)		
St. Paul Island	X		20	51	X	X

*Adapeted from: Bedard 1969b; Drury 1976; Hickey 1976; Petersen and Sigman 1977; Gill et al 1977.

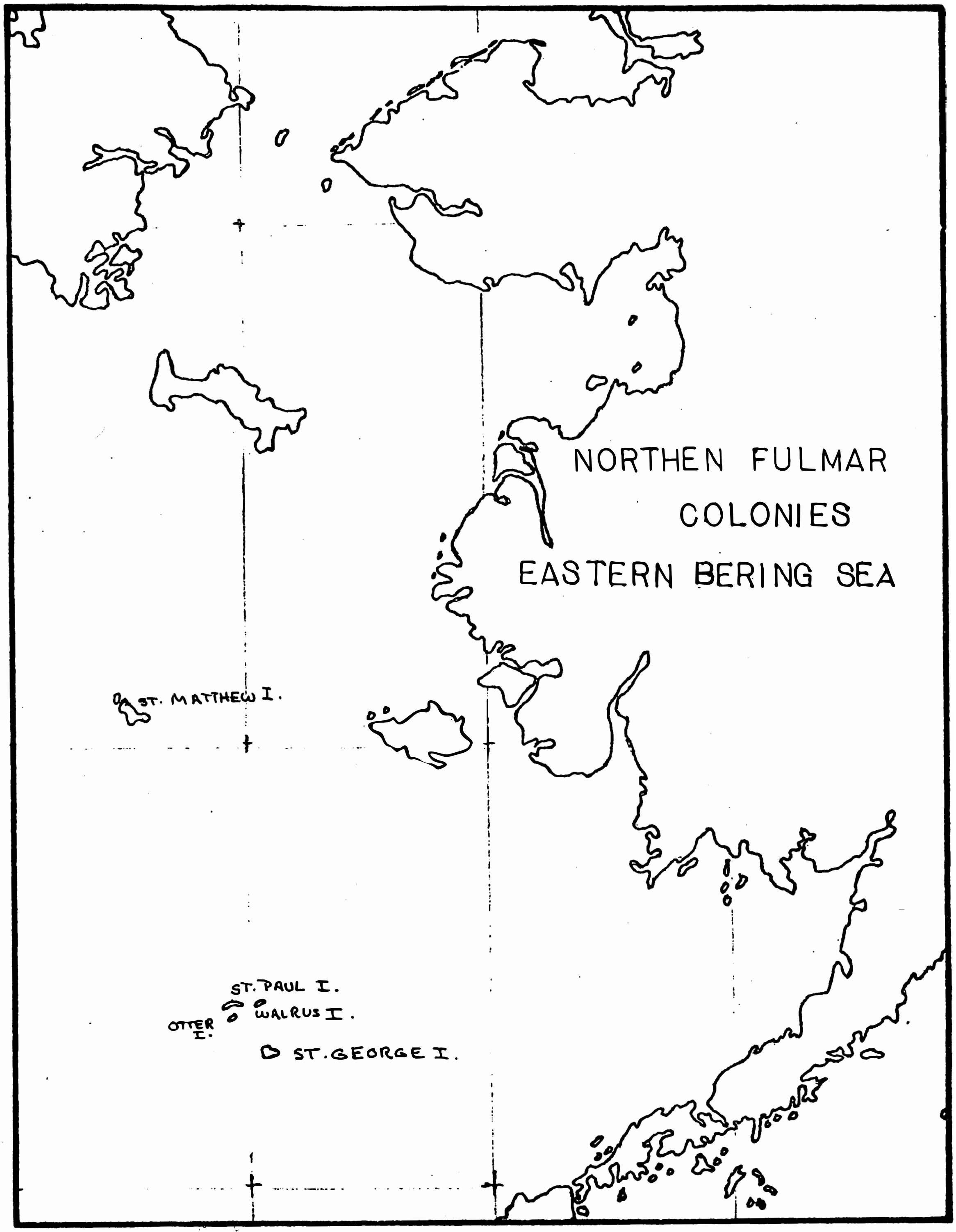

Figure 2. The locations of Northern Fulmar colonies in the eastern Bering Sea.

the eastern Bering Sea. The largest colony in the North Pacific proper, ca. 500,000 birds, is in the Semidi Islands in the Gulf of Alaska (Hatch, personal communication).

Fulmars arrive at the Pribilof colonies in early May and leave in early September (Table 2, Figure 3). Numbers at sea remain fairly stable in spring and summer (Table 3), but are particularly hard to correlate with colony of origin. Fulmars range widely at sea, and breeding birds may have incubation shifts of two weeks (Hatch, personal communication). This means that while one parent is incubating the egg or chick, its mate is at sea. Thus, breeding birds could easily range several hundred kilometers or more from their colony. Presumably the birds at sea within a few to several kilometers of a given colony are from that colony, but it is possible that birds from other colonies are also mixed in.

Using Shuntov's (1972) at-sea density figure, we have estimated the pelagic population of fulmars in the eastern Bering Sea in summer at about 2.8 million (Table 3). By assuming that pre-beeeding birds comprise 10% of the total population and that they all occur at sea, and by assuming that breeding birds occur equally at sea and on the colonies, we have calulated that the total population of fulmars in the eastern Bering Sea is about 5.1 million birds. Our gut feeling is that this figure is probably conservative, but it seems unlikely that it could be low by as much as an order of magnitude.

Fulmars obtain their food at or very near the surface (Table 4), and eat a variety of prey (Table 5). Their bills are fairly large, so they feed relatively high in the food web. As attested by the huge flocks of fulmars seen feeding on offal from fishing and factory ships in the eastern Bering Sea (unpublished data, USFWS) they readily take advantage of chance occurrences. The ecological implication of feeding on large, and dependable supplies of offal will be disucssed below.

Shearwaters: Two congeneric species of shearwaters occur in the eastern Bering Sea; the Sooty Shearwater (*Puffinus griseus*) and the Short-tailed Shearwater (*P. tenuirostris*). Both species breed in the southern hemisphere during the boreal winter, migrate to the northern hemisphere in the spring, forage heavily in summer throughout much of the Subarctic Pacific Region, and migrate to the southern hemisphere again in the boreal autumn (Sanger and King in press; Shuntov 1972). A small proportion of the Sooty Shearwater population occurs in the Atlantic, but the entire world population of Short-tails occurs in the Pacific Ocean.

The Short-tailed Shearwater population occurs much farther north than the Sooty population, and is the dominant of the two species in the Bering Sea. There is apparently a zone of overlap in their distribution in the southern Bering Sea (Shuntov 1972), but most of the Sooty population occurs in the North Pacific proper. Like the two murres, these two shearwaters are very difficult to distinguish in the field.

Shearwaters are completely absent from the Bering Sea in winter, yet they are the most abundant form of marine bird at sea in summer,

Table 2. General breeding chronology of northern fulmars, glaucous-winged gulls, black-legged kittiwakes, and crested, least, and parakeet auklets in the eastern Bering Sea.

SPECIES	ARRIVAL ON COLONY	NEST BUILDING	EGG LAYING	HATCHING & BROODING OF CHICKS	FLEDGING	DEPARTURE FROM COLONY
Northern Fulmar	early May, S 6 May, HY	May, S	late May-early June (Start), S	last wk Jul-1st wk Aug, H		1 Sep, H (last sighting made)
Glaucous-winged Gull	already there 28 Apr, P 22 Apr, G	May, G	3 Jun, P (start) 1 Jun, G	0% hatching success (fox predation)	7-31 to 8-20	9-13 G
Black-legged Kittiwake	Apr 29, P	mid June, D 1 Jun, P	25 June-19 Aug, H late Jun-late Jul, D 10 Jun-2 Jul, P	23 Jul-16 Sep, H all Aug, D 9-27 Jul, P	31 Aug-25 Sep, D 18 Aug 2 Sep, P	9 Sep, P (last sighting made)
Crested Auklet						not seen after mid-August, H
Least Auklet			early Jun-10 Aug, H	10 Jul-1 Sep, H	mid-end Aug, H	
Parakeet Auklet	19-24 May, SB 6-12 May, P		20 Jun, 7 Jul, SB	30 Jul-2 Aug, SB ca. 14 Jul, P	29 Aug-7 Sep, SB	11 Aug, P

References: B, Bedard 1969b; SB, Sealy & Bedard 1973; S, Shuntov 1972; D, Drury 1976; HY, Hickey 1976; H, Hunt 1976; P, Petersen and Sigman 1977; G, Gill et al 1977.

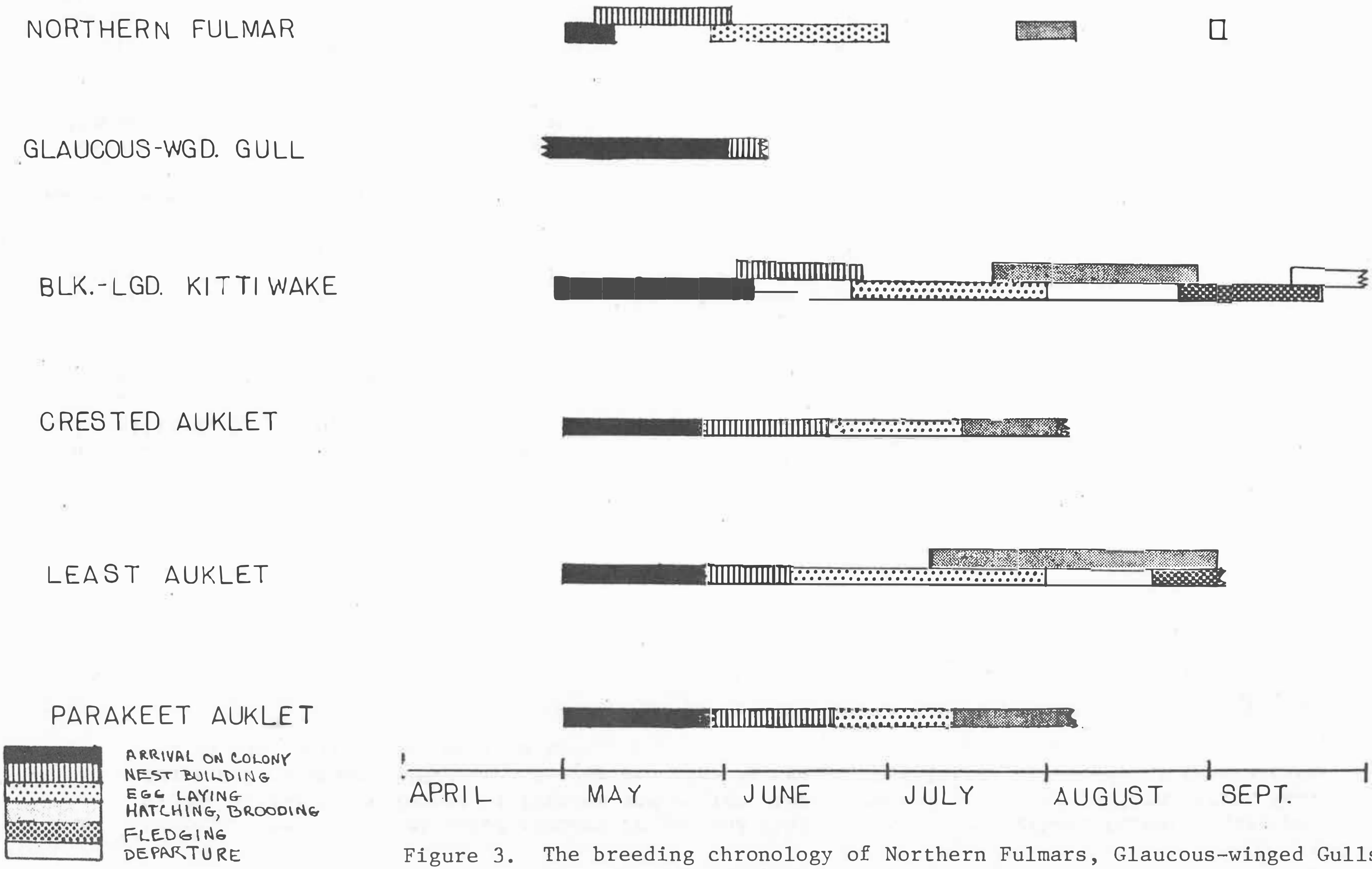

Figure 3. The breeding chronology of Northern Fulmars, Glaucous-winged Gulls, Black-legged Kittiwakes, and Crested, Least and Parakeet Auklets in the eastern Bering Sea.

Table 3. Seasonal changes in estimated numbers at sea and their biomass for northern fulmars, glaucous-winged gulls, black-legged kittiwakes and alcids other than murres in the eastern Bering Sea. Adapted from Shuntov 1972, and Sanger and King in press. Population sizes assume the eastern Bering Sea shelf is one million km^2.

SEASON	NORTHERN FULMAR	GLAUCOUS-WINGED GULL	BLACK-LEGGED KITTIWAKE	ALCIDS (except murres)
$\bar{X}$ Bird Weight	634g	1,175g	444g	
Dec - March[1]				
Density (birds/ 100 km^2)	20	170	20	40
Numbers (millions)	0.06	0.51	0.06	0.12
Biomass (M tons x 10^3)	0.038	0.599	0.027	
April - May				
Density	180	80	120	
Numbers	2.34	1.04	1.56	
Biomass	1.484	1.222	0.693	
June - August				
Density	216	18	54	180
Numbers	2.81	0.23	0.70	2.34
Biomass	1.782	0.270	0.311	
Sept - Nov				
Density	108	120	120	132
Numbers	1.40	1.56	1.56	1.72
Biomass	0.888	1.833	0.693	

[1] Ice cover varies in winter: assume 75% of shelf covered.

Table 4. Summary of feeding behavior of Northern Fulmars, Glaucous-winged Gulls, Black-legged Kittiwakes, and Parakeet, Least, and Crested Auklets.

SPECIES	BEHAVIOR
Northern Fulmar	Major: Surface seizing. Moderate: Scavenging, surface filtering. Minor: Dipping, pursuit diving.
Glaucous-winged Gull	Moderate: Surface seizing, dipping, piracy, scavenging, plunging. Minor: Pattering.
Black-legged Kittiwake	Major: Dipping, pattering. Moderate: Piracy, surface seizing, scavenging, plunging. Minor: Pursuit diving. Also, "hawk" over water, dip to surface, hover, dive like terns into water, with wings bent back.
Parakeet Auklet	Major: Pursuit diving. Forage at sea in late afternoon. Diurnal.
Least Auklet	Major: Pursuit diving. Forage at sea in early morning, and early afternoon.
Crested Auklet	Major: Pursuit diving. Forage at sea in early morning, and early afternoon.

References: Ashmole 1971; Hunt 1976; Drury 1976; Sealy 1973.

Table 5. Frequency of occurence of prey items in northern fulmars, glaucous-winged gulls and black-legged kittiwakes. Figures are in percent occurrence.

PREY ITEM	NORTHERN FULMAR	GLAUCOUS-WINGED GULL	BLACK-LEGGED KITTIWAKE
Mollusca			
Cephalopoda	Moderate$_A$ 100.0$_H$	Minor$_A$	Minor$_A$ 9.0$_H$
Shellfish		Major$_{PM}$	Trace$_{PM}$
Crustacea	Major$_A$		Moderate$_A$
Barnacle		Moderate$_A$	Minor$_{PM}$
Copepod (*Calanus*)			
Amphipod			Trace$_Z$ 14.0$_H$
Euphausiacea			4.0$_H$
Mysid			
Decapoda		Major$_{PM}$	17.0$_H$
Polychaeta			Minor$_Z$
Echinodermata		Major$_{PM}$	
Other Invertebrates	Minor$_A$	Moderate$_A$	Minor$_A$
Fish	Minor$_A$	Moderate$_A$	62.0$_H$ Major$_{A,\ Z}$
Ammodytes			100.0$_D$ Major$_Z$
Boreogadus			Major$_Z$
Carrion etc.	Minor$_A$	Moderate$_A$ Major$_{PM}$	Minor$_{A,\ PM}$
Debris			6.0$_H$
Plastic Particles			3.0$_H$

References: A-Ashmole 1971; H-Hunt 1975; D-Drury 1975; S-Stejneger 1885; PM-Preble & McAtee 1923; Z-Swartz 1966; B-Bedard 1969a.

outnumbering even the murres. The migration of shearwaters into the Bering Sea is dramatic. During May 1976, an OCSEAP Fish and Wildlife Service observer stationed at Unimak Pass during a two-week period observed that shearwaters migrating northward through the pass increased from none to an average of 5,000 per hour. This explosive influx of shearwaters into the Bering Sea is reflected also by the data of Shuntov (1972), Table 6. When the more comprehensive data on the pelagic distribution and abundance of shearwaters recently obtained by Juan Guzman (OCSEAP RU# 239), and the U.S. Fish and Wildlife Service in OCSEAP studies has been completely analyzed, the picture of shearwater numbers in the eastern Bering Sea will be far more complete. Table 6 also suggests that the fall exodus of shearwaters from the Bering Sea is more leisurely, and a few birds (probably immatures) linger as late as November. The important point bearing on modeling efforts is that very little is known about what governs shearwater distribution within the Bering Sea once they get there. They may concentrate over the shelf break, but large concentrations have also been noted over the shelf itself (Shuntov 1961). They also have a decidedly patchy distribution, unrelated to distance from shore (Figure 4).

Using Shuntov's (1972) at-sea density figure for Short-tailed Shearwaters, we have estimated their population for the eastern Bering in summer at about 7 million birds. It does not seen unreasonable to assume that Sooty Shearwaters, even though they range only in the southern part of the Bering Sea, could number 3 million there. Thus, we estimate the total shearwater populations in the eastern Bering Sea at 10 million birds.

Shearwaters dive and readily swim under water in pursuit of their food, but they apparently stay within the upper 5 meters or so (Table 7). Data on their feeding habits in the Bering Sea is very sparse (Table 8), but they suggest that Short-tailed Shearwaters feed heavily on euphausiids. Judging from preliminary data from the Gulf of Alaska (unpublished data, USFWS), Sooty Shearwaters feed more heavily on fish, whose sizes are considerably larger than euphausiids. Stomach sample material for Sooty Shearwaters from the eastern Bering Sea are needed.

There is no published information on feeding rates of shearwaters, but inferential evidence from USFWS OCSEAP marine bird feeding studies suggests that shearwaters could consume as much as 20% of their body weight per day. Analyses of shearwater stomach samples are incomplete, but the maximum weights of the contents from partly full stomachs has ranged up to 125 grams. For a 700-gram bird, this is 18% of the body weight. It is probable that a shearwater could easily hold 150 grams of food, and it is not unreasonable to assume that they fill up with food on an average of once per day. Thus, a food consumption rate of 20% per day for shearwaters seems possible. Further, without exception, shearwaters examined thus far which were collected in summer have had very heavy fat deposits, suggesting that their food has been plentiful regardless of their stomach contents at the time of collection.

Gulls: Although Glaucous-winged Gulls and Black-legged Kittiwakes are both in the family Laridae (gulls), they are dissimilar in many ways. The Glaucous-winged Gull is about 2.5 times larger than the Black-

Table 6. Seasonal changes in estimated numbers at sea and their biomass for short-tailed shearwaters and murres in the eastern Bering Sea. Adapted from Shuntov (1972) and Sanger and King (in press). Population sizes assume the eastern Bering Sea shelf is one million km^2.

SEASON	SAMPLE SIZE[1]	Murres (Uria spp.) ($\overline{X}$ weight = 0.9 kg)			Short-tailed Shearwater ($\overline{X}$ weight = 0.7 kg)		
		Density birds/100km^2	Numbers millions	Biomass M tons x 10^3	Density birds/100km^2	Numbers Millions	Biomass M tons x 10^3
December - March[2]	170	680	1.7[2]	1.53	---	---	---
April-May	460	460	4.5	4.1	720	7.2	5.0
June-August	280	270	2.7	2.4	702	7.0	4.9
September-November	130	240	2.0	1.8	240	2.4	1.7

[1] Number of transects of 30 or 60 minutes (V.P. Shuntov, personal communication).

[2] Ice cover limits range in winter; assume 3/4 of shelf covered.

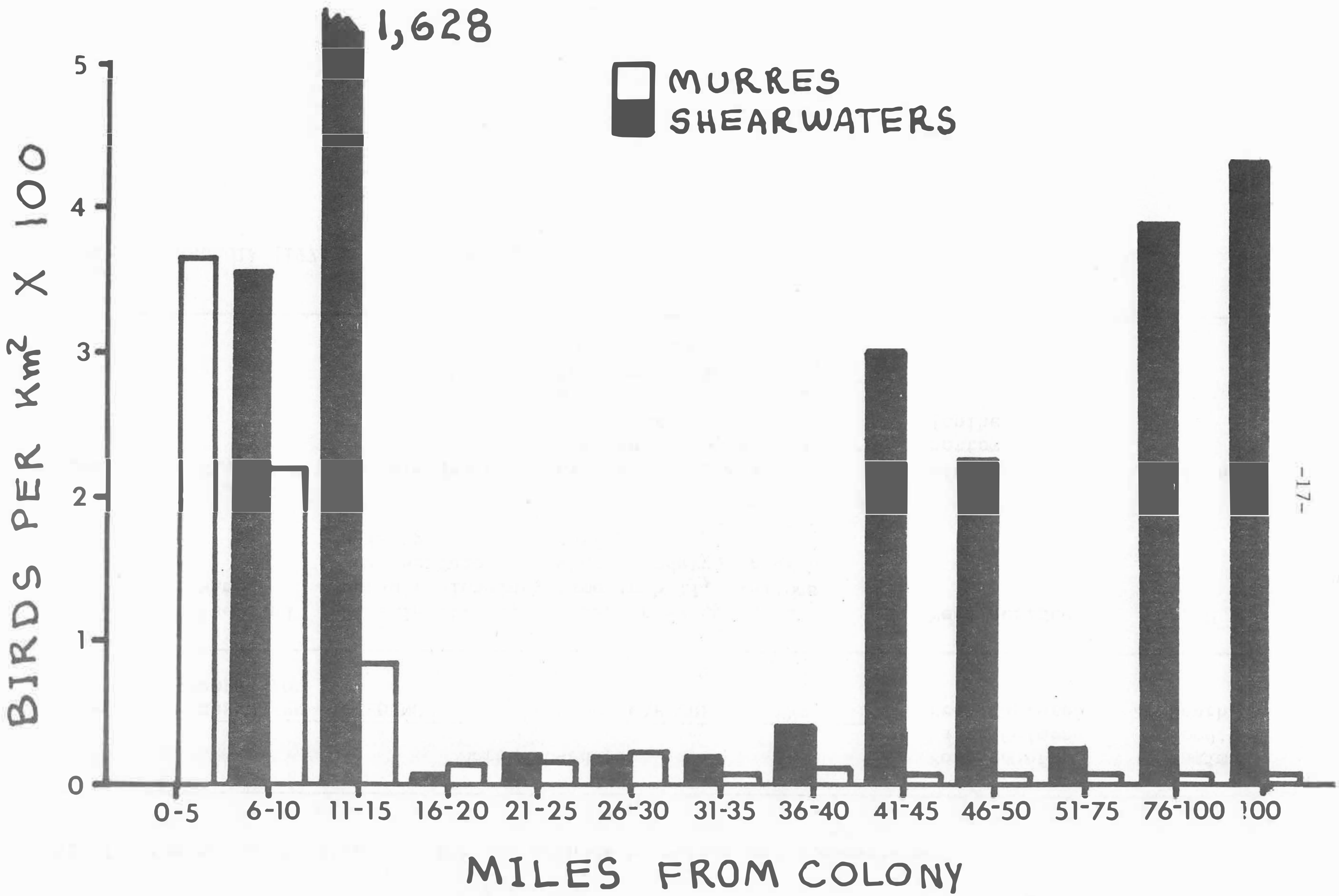

Figure 4. Relative densities of murres and Short-tailed Shearwaters in relation to distance offshore from the Cape Newenham murre colony, northern Bristol Bay, 15 July 1973. Unpublished data, U.S. Fish and Wildlife Service, Anchorage, Alaska.

Table 7. Summary of feeding behavior and methods by murres and shearwaters.

SPECIES	Method Used For: UNDERWATER PROPULSION	FEEDING	FOOD CAPTURE	Portion of Water Column Prey Captured	Maximum Feeding Depth
Shearwaters	Feet and Wings	Pursuit diving, pursuit plunging, some surface seizing.	Grasps prey one at a time in bill, swallows whole, underwater or at surface.	Near surface	5 M
Murres	Wings	Pursuit diving.	Grasps prey one at a time in bill, swallows whole underwater or at surface. Adults feeding chicks carry fish to land.	mid depth to bottom (epibenthic).	40-60 M

References: Ashmole (1971); Tuck (1960).

Table 8. Feeding habits of murres (Uria spp.) and short-tailed shearwaters in the eastern Bering Sea (adapted from Ogi and Tsujita 1973).

PREY ITEM	PREY LENGTHS, cm	% COMPOSITION (weight)	Equivalent DYNUMES Trophic Component
	Murres (Uria spp.), N = 163		
FISH		72	Pollock I
Pollock	10-24		
Sandlance	5-20		
Capelin	11-12		
EUPHAUSIIDS		15	Euphausiids
SQUID		8	Euphausiids
OTHER		5	Euphausiids
	Short-tailed Shearwaters, N = 29		
FISH		tr	---
Sandlance			
EUPHAUSIIDS		100	Euphausiids

legged Kittiwake (Table 3), and other ecological differences are noted below. They should be considered separately in ecosystem modeling attempts.

Figure 5 notes the distribution of Black-legged Kittiwake colonies in the eastern Bering Sea, and Table 1 lists their estimated sizes. The largest known colony in the eastern Bering Sea, about 200 thousand birds, is at Cape Peirce; a similar or greater number may occur at nearby Cape Newenham; more work is needed in this area. About 100 thousand nest on St. George Island in the Pribilofs.

Populations of Glaucous-winged Gulls are much harder to estimate because they generally do not nest in dense colonies. The largest known colony in the eastern Bering Sea, about 12.4 thousand birds, exists on several small islands in Nelson Lagoon on the Alaska Peninsula (Table 1). Other large colonies exist on the Seal Islands (6 thousand birds), also on the Alaska Peninsula, and at Cape Peirce (5.6 thousand birds), but the species is generally ubiquitous in much smaller numbers in its nesting habits.

Seasonal fluctuations in densities of both gulls at sea are presented in Figure 6. The pattern shown for Glaucous-winged Gulls appears to be correlated with their breeding chronology (Table 2). Their highest densities occur at sea in winter (1.7 birds/km^2). The species ranges pelagically as far south as southern California in winter (Sanger 1972b), so the high density in winter in the Bering Sea is somewhat puzzling. Apparently birds breeding there overwinter there as well. There is possibly even an influx of birds from the North Pacific into the Bering Sea in winter. The decrease in densities in spring (Figure 6) probably reflects the birds' beginning to orient toward their breeding colonies. In summer, the species is very strongly oriented to land; only 0.2 birds/km^2 occur at sea. These are likely immatures. The implication here is that the large majority of the population feeds on land or very close to it. The increased density in fall reflects the return of the population to pelagic areas. Pelagic observations within 35 km of the Pribilofs in 1974 (Sanger, unpublished data) showed no Glaucous-wings Gulls in early August, they began appearing at sea by the third week, and were seen commonly by the first week in September.

Black-legged Kittiwakes exhibit very low densities in winter, particularly when compared to the Glaucous-winged Gulls. Most of the population migrates to the North Pacific proper, where they are highly pelagic as far south as southern California (Sanger and King in press). The sharp increase in densities in spring reflects the species' return to the Bering Sea prior to breeding, but they tend to remain in pelagic areas. They are apparently strongly oriented to their colonies in summer, regardless of age. The mean summer density of 0.5 birds/km2 may reflect a population of immatures, or possibly a certain number of adults who forage from the colonies out to the pelagic areas. Shuntov (1972) does not distinguish the age composition of his data on Black-legged Kittiwakes. The high density in fall again reflects their return to pelagic areas, prior to their migration into the North Pacific.

By extrapolating the highest observed densities in Figure 6 for the entire eastern Bering Sea shelf (estimated at one million km^2), the

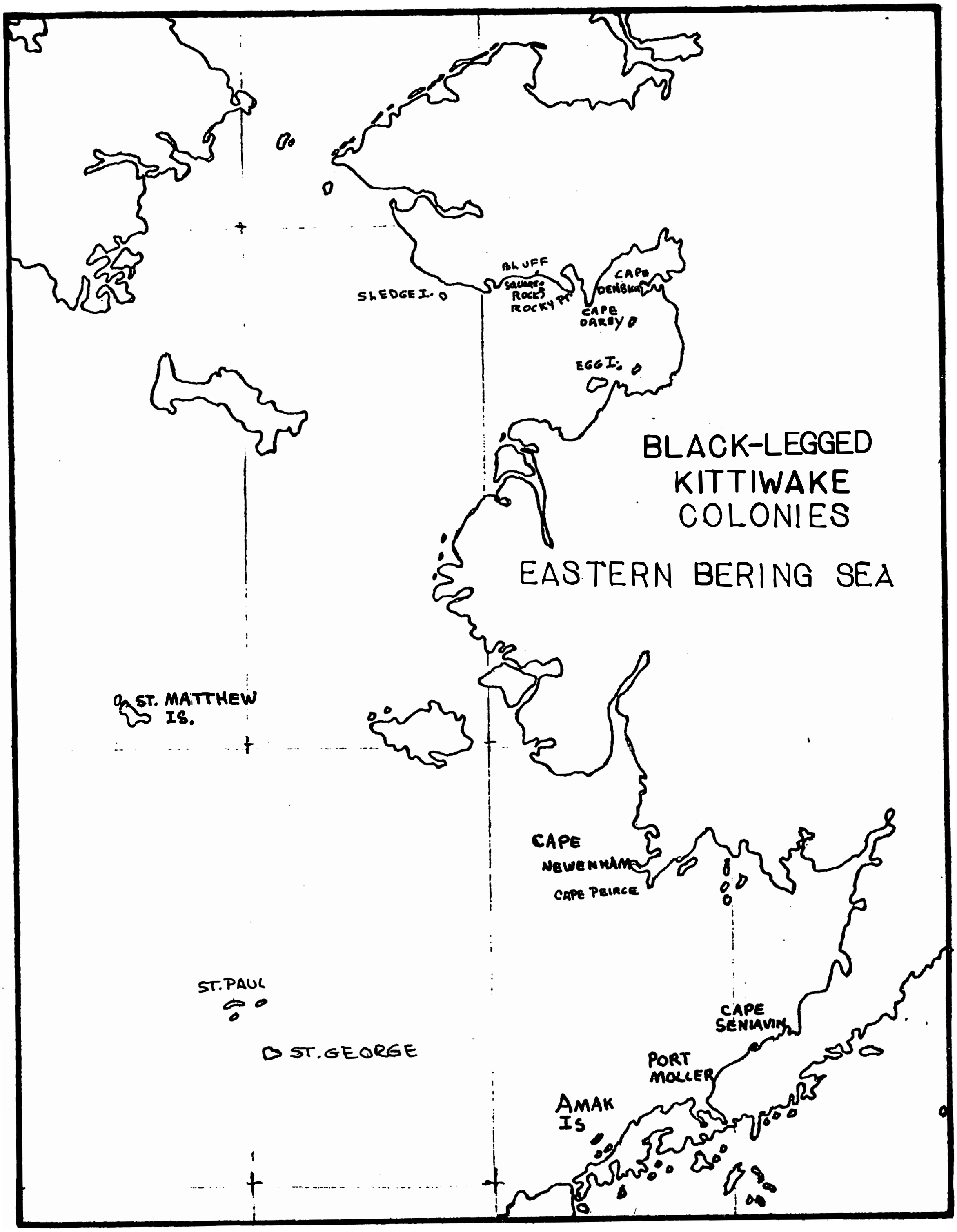

Figure 5. The locations of Black-legged Kittiwake colonies in the eastern Bering Sea.

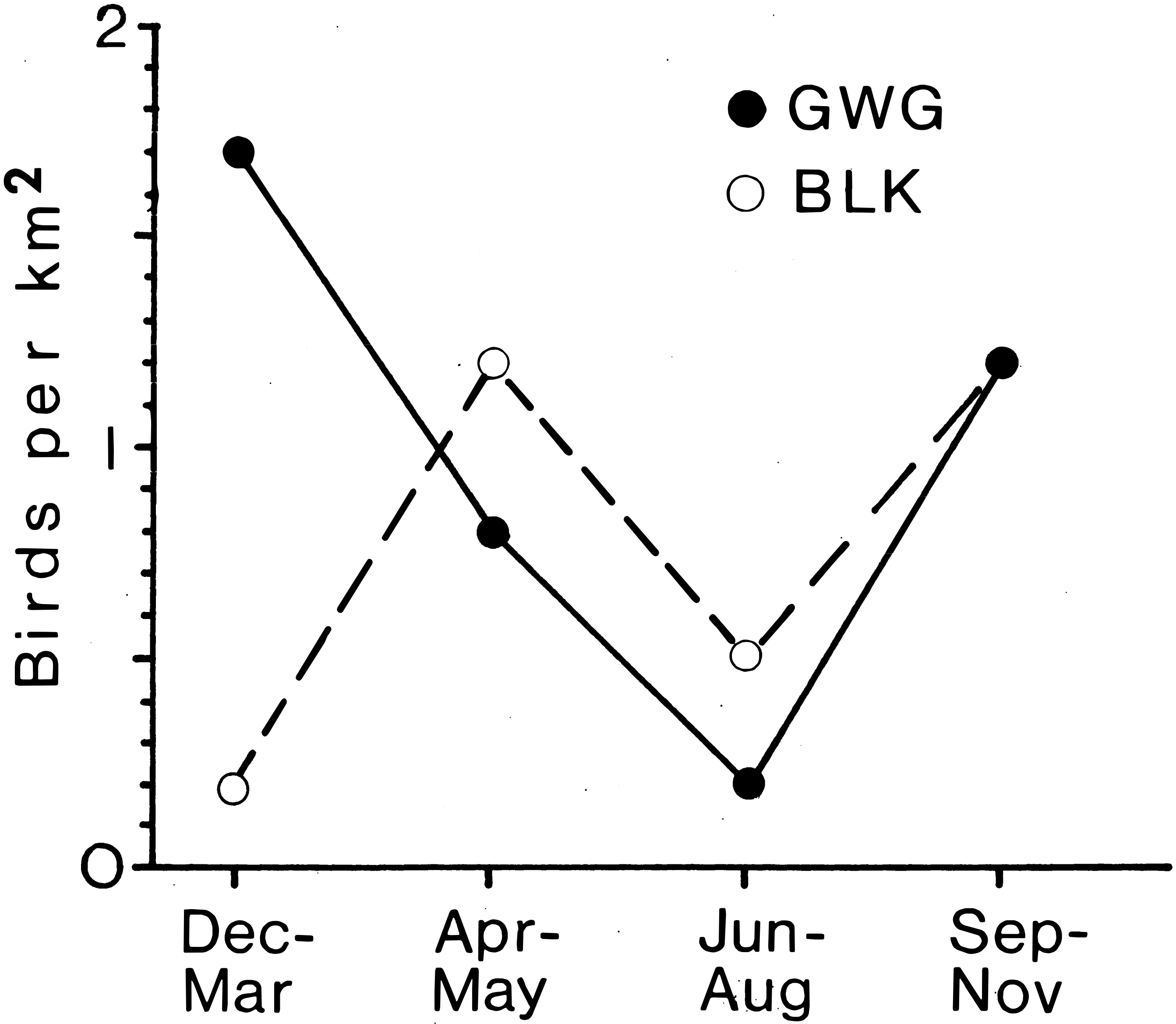

Figure 6. The seasonal abundance of Glaucous-winged Gulls and Black-legged Kittiwakes over the shelf and slope of the eastern Bering Sea. Adapted from Shuntov (1972).

winter population of Glaucous-winged Gulls is estimated at 170 thousand birds. Intuitively, this seems too low for a total eastern Bering Sea population, but there is no hard data to refute it. The spring kittiwake density extrapolates to a population of 120 thousand birds; at least 339 thousand breed in the eastern Bering Sea (Table 1). This figure again seems low for a total eastern Bering Sea population. One may assume that an equal number of kittiwakes breeding in the eastern Aleutians "use" the eastern Bering Sea. The total number of kittiwakes interacting with the ecosystem of the eastern Bering Sea thus may crudely be guesstimated at about 750 thousand birds.

Table 4 summarizes the feeding behavior of these two gulls. The important points bearing on ecosystem modeling are: 1. Both species feed at or near the surface; 2. Both species are scavengers to some extent; 3. Black-legged Kittiwakes tend to feed relatively farther offshore in summer than the Glaucous-winged Gulls, therefore making them more likely to interact with the foreign fishing fleets then; 4. The same holds true for the Glaucous-wings in winter; and 5. Both species are likely to interact as scavengers with the fleets in the fall.

Murres: Two circumpolar species of murres are present in the Bering Sea, the Common Murre (*Uria aalge*) and the Thick-billed Murre (*U. lomvia*). With body weights of nearly a kilogram, they are the largest members of the marine bird family Alcidae in the Bering Sea. In the eastern Bering Sea, they are highly sympatric on many breeding colonies. Their ranges at sea also overlap, although the Thick-billed generally occurs farther offshore than the Common Murre, particularly in winter. The two species are difficult to distinguish at sea, even by trained observers. Hence, pelagic population data for the two species is usually lumped.

Table 9 lists the names and best available size information for the known colonies of Common and Thick-billed Murres in the eastern Bering Sea. Figure 7 locates these colonies geographically. This information is the best available, but the size estimates need considerable refinement. Work on some intensively studied colonies has shown that murres have marked occupancy cycles on the colonies, and if a particular survey of a colony happened to coincide with when most of the birds were at sea, the colony size would be underestimated. Current intensive studies on a few selected colonies (Pribilofs, Cape Peirce) will help delineate this phenomenon much better, but more work is needed.

The timing of events associated with breeding of murres, i.e., foraging, is linked closely with their presence or absence on their breeding colonies, and therefore with their distribution and density at sea. Table 10 outlines a generalized breeding chronology for murres in the southern Bering Sea, based on the observations of Matthew Dick (personal communication) at the Cape Peirce Common Murre colony in 1973. In general, the timing of arrival on the colonies is closely associated with the breakup of sea ice, so breeding occurs progressively later with increasing latitude. It seems probable that the more northern populations follow the ice edge as it retreats northward, and "drop behind" as the latitude of their particular colony is reached by the retreating ice pack.

Table 9. Estimated sizes* of colonies of murres in the eastern Bering Sea. X = species present as a breeder; P = species present but not breeding.

LOCATION	BREEDING STATUS		DOMINANT SPECIES		Estimated Colony Size, Thousands of Birds
	Common	Thick-billed	Common	Thick billed	
Stuart Island	?	?	?	?	0.1
King Island	X	X	X		10's
Sledge Island	X	X	X		3
Topkok Head	X	X			?
Square Rock	X		X		5
Bluff Head	X	X	X		102
Cape Denbigh		X			10
Besbror Island	X	X			?
Egg Island		P	X		2.5
Stobli Rocks		P	X		?
Cape Kagh-Kasalik		P	X		?
Southwest Headlands	X	P	X		?
Nunivak Island	X		X		?
St. Matthew Island	X	X			10's
Hall Island	X	X			10's
Cape Newenham	X				1,000
Cape Peirce-Shaiak Is.	X		X		500
Hagemeister Island			X		?
High Island	X				10's
Crooked Island	X		X		?
Twins Island	X		X		750 (?)
Amak Island	X				?
St. George Island	X	X		X	)
St. Paul Island	X	X		X	)
Otter Island	X	X		X	) 2,000 (?)
Walrus Island	X	X		X	)

*Preliminary estimates, adapted from Drury 1976; Hickey 1976; Petersen and Sigman 1977; and, files of the U.S. Fish and Wildlife Service, Office of Biological Services, Anchorage, Alaska.

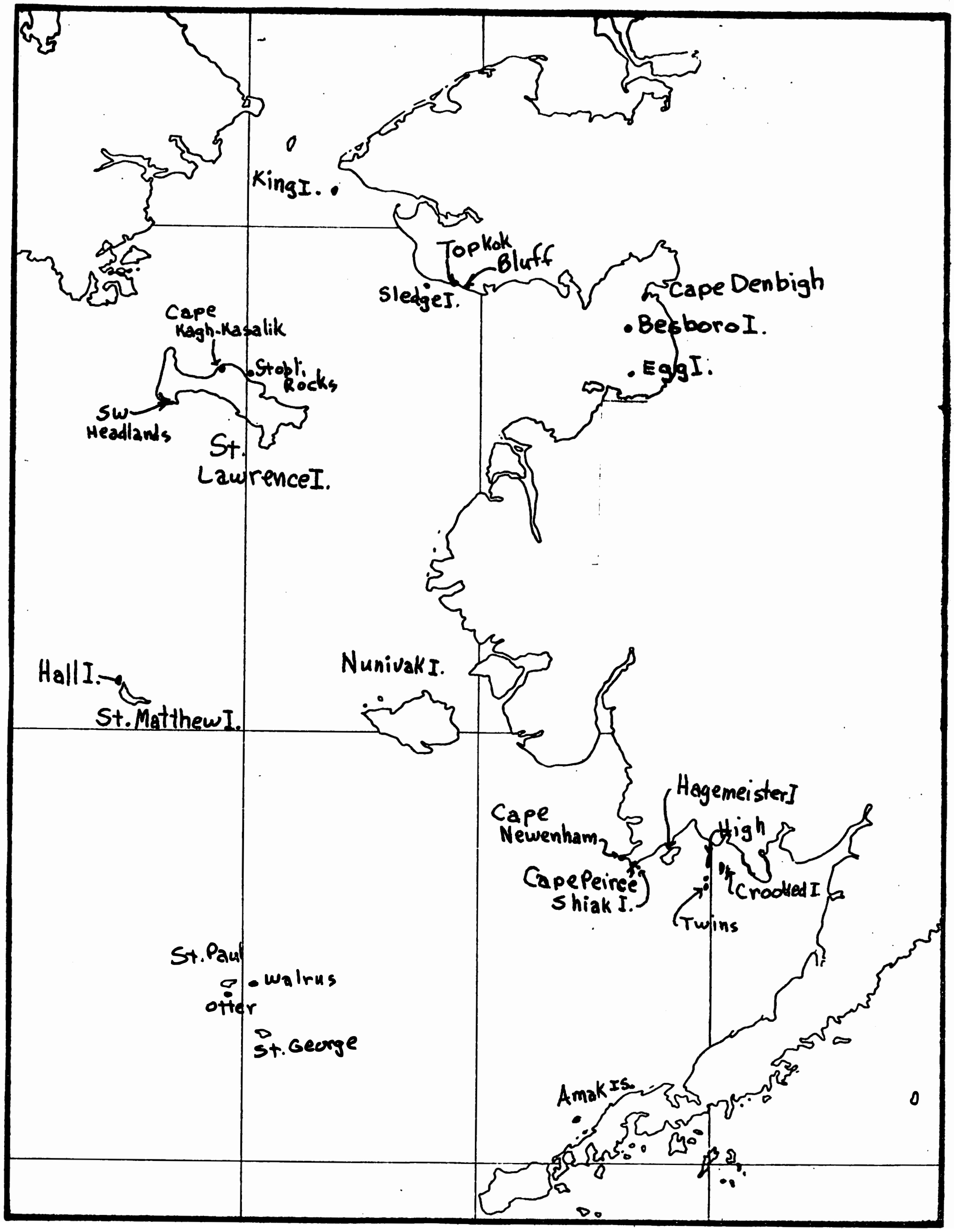

Figure 7. The locations of murre colonies in the eastern Bering Sea.

Table 10. Generalized breeding chronology for murres in the south-eastern Bering Sea. Breeding is pregressively later with increasing latitude, occurring 3-4 weeks later near Nome.

Approximate Dates	Events
Late April	Birds begin concentrating near colonies; a few aggregate on the colonies.
May	Numbers of birds and their duration on the colonies increases.
Early June	Copulation and egg laying commences. Birds concentrated on and very near the colonies probably comprise 60-80% of the populations.
Early July to mid-August	Eggs begin hatching. Chicks on colonies fed by adult birds
Late July to early September	"Sea going" of chicks.

Source: M. Dick, unpublished 1973 data.

Figure 4 demonstrates the pronounced orientation of murres to breeding colonies at the height of the breeding season, and also demonstrates how unrelated to land and how patchy that shearwater distribution can be. However, as far as ecosystem studies are concerned, the mere presence of birds in an area does not necessarily coincide with their feeding there.

Two factors overwhelmingly influence murre distribution in the eastern Bering sea: the location of breeding colonies in spring and summer, and the location of seasonal pack ice in winter. Table 6 represents average pelagic densities, and the only data reflecting either factor in these data is the decrease in bird density from spring to summer. With most of the population engaged in breeding, one would expect murre densities at sea to decrease.

Information on pelagic population sizes is scanty, a fact which is complicated by the lack of reliable information on relative proportions of the populations occurring at sea and on the breeding colonies during the breeding season. Immatures probably do not return to land until at least their second year. Shuntov's (1972) pelagic density value for spring (4.5 birds/km2; Table 6), extrapolates to a pelagic population of 4.5 million birds for the eastern Bering Sea, Tuck (1960) pelagic estimated total North Pacific populations of murres at 20 million. If this is accurate, 4.5 to 5 million seems a not unreasonable figure for total populations in the eastern Bering Sea. Some breeders from the eastern Aleutians likely forage on the western part of the eastern Bering Sea shelf.

Table 7 summarizes the feeding behavior and methods of murres. The important points concerning ecosystem studies is that murres are capable of exploiting the entire water column over much of the eastern Bering Sea shelf. Murres likely get much of their food from mid-depths to the bottom.

Data on feeding habits of murres in the eastern Bering Sea are very scanty (Table 8), but they suggest that murres feed heavily on fish. This view should be regarded as quite preliminary, and probably is not the case universally throughout the eastern Bering Sea. Anatomical, morphological, and behavioral studies on captive Common and Thick-billed Murres by Spring (1971) suggest that the Common Murre is a fish specialist, but the Thick-billed Murre is better adapted to feed on a wider variety of prey. Wiens and Scott (1976) showed that Common Murres feed mostly on fish off the Oregon coast, but euphausiids and other planktonic crustaceans sometimes account for as much as 27% of their diet. Preliminary data from U.S. Fish and Wildlife Service OCSEAP studies bear out Spring's (1971) theory that Thick-billed Murres can eat a wider variety of prey than Common Murres; squid, shrimp, and other crustaceans have frequently occurred in Thick-billed Murre stomachs, as well as fish. Because this preliminary information reflects a large diversity of prey, we suggest that the list of model components (Laevastu and Favorite 1976) will have to be expanded if it is to realistically reflect the feeding habits of the marine bird community in the eastern Bering Sea.

Auklets: The auklets are the smallest members of the seabird family Alcidae. Two species, the Least Auklet (Aethia pusilla) and the Crested Auklet (A. cristatella) are abundant in the eastern Bering Sea. A third, the Parakeet Auklet (Cyclorhynchus psittacula) is a ubiquitous nester, but apparently less abundant than the prior two species. Due to their small size (e.g., at about 90 g., the Least Auklet is less than a tenth the size of a murre), they probably have little direct affect on the ecosystem. Including them as components in a model of the ecosystem would give a more accurate view of the ecosystem, however, and provide a more comprehensive portrayal of the marine bird community. The excellent studies of Bedard (1969 a & b) and Sealy and Bedard (1973) have provided very useful data on the feeding ecology and breeding biology of these species. Through these studies we have a much better idea of their roles in the ecosystem than the larger species, which have a more direct, if not more important influence on the ecosystem.

Locations of the breeding colonies of these auklets are noted in Figures 8, 9, and 10. The Crested and Least Auklets breed only in the Pribilofs, and on St. Matthew, St. Lawrence, and King Islands, while the Parakeet Auklet is a ubiquitous nester, occurring in many small colonies (Bedard 1969a). Estimated colony sizes of these species are shown in Table 1, and their breeding chronology is summarized in Table 2.

Little is known about the distribution of these auklets at sea. At St. Lawrence Island, all three species forage to at least 25 km offshore (Bedard 1969a). In the Aleutians, Murie (1959) noted Crested Auklets foraging to at least 16 km offshore. During pelagic observations within 8 and 35 km of the Pribilofs in 1974 (Sanger, unpublished), no Least Auklets or Parakeet Auklets were seen at sea, and only scattered Crested Auklets were seen between mid-August and early September. Mark Phillips (Unpublished USFWS observations) saw fair numbers of Least Auklets near the edge of the ice in the southern Bering Sea in April 1976.

Little is known about the total populations of these species. Bedard (1969b) estimated nearly a million Least Auklets on St. Lawrence. Recent population data of this species on the Pribilofs is still being analyzed, but there apparently are at least 200 to 400 thousand there (Hickey 1976). Considering birds from the eastern Aleutians (Murie 1959), one may guess that the total populations of Least Auklets in the eastern Bering Sea could be as high as 2 million birds.

Crested Auklets apparently are not as abundant as the former species in the Bering Sea. There are an estimated 600 thousand at St. Lawrence (Bedard 1969b). Considering those from the Pribilofs and the eastern Aleutians, there could be as many as 1 to 1.5 million in the eastern Bering Sea. Parakeet Auklets do not occur in the dense concentrations of the other species but they breed in many more locations (Figure 8). It seems reasonable to guess that there could be as many as 500 thousand in the eastern Bering Sea.

The feeding behavior of the three auklets is summarized in Table 4. All feed by subsurface pursuit diving (Ashmole 1971). Bedard (1969a) collected his birds in water depths ranging down to 50 meters. At least

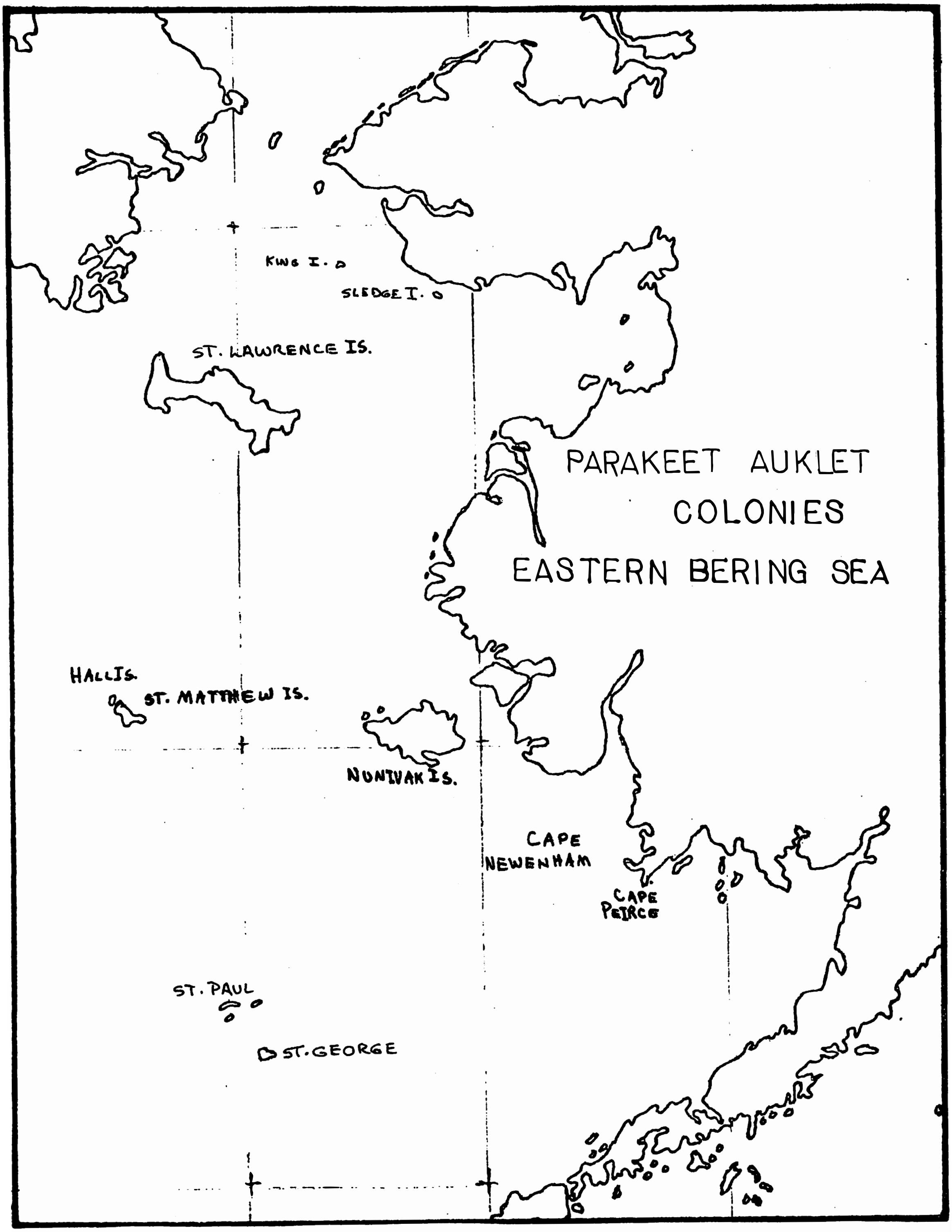

Figure 8. The locations of Parakeet Auklet colonies in the eastern Bering Sea.

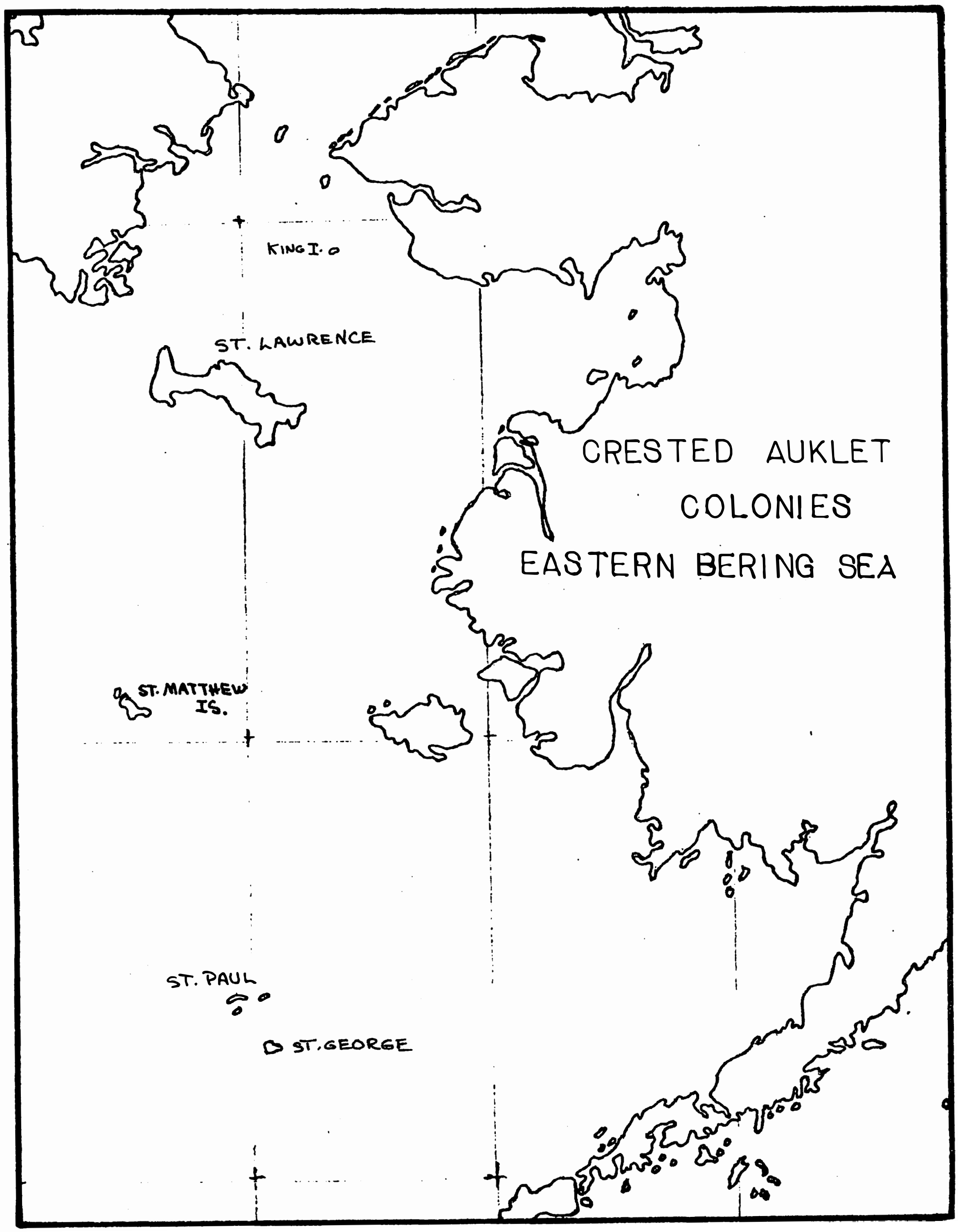

Figure 9. The locations of Crested Auklet colonies in the eastern Bering Sea.

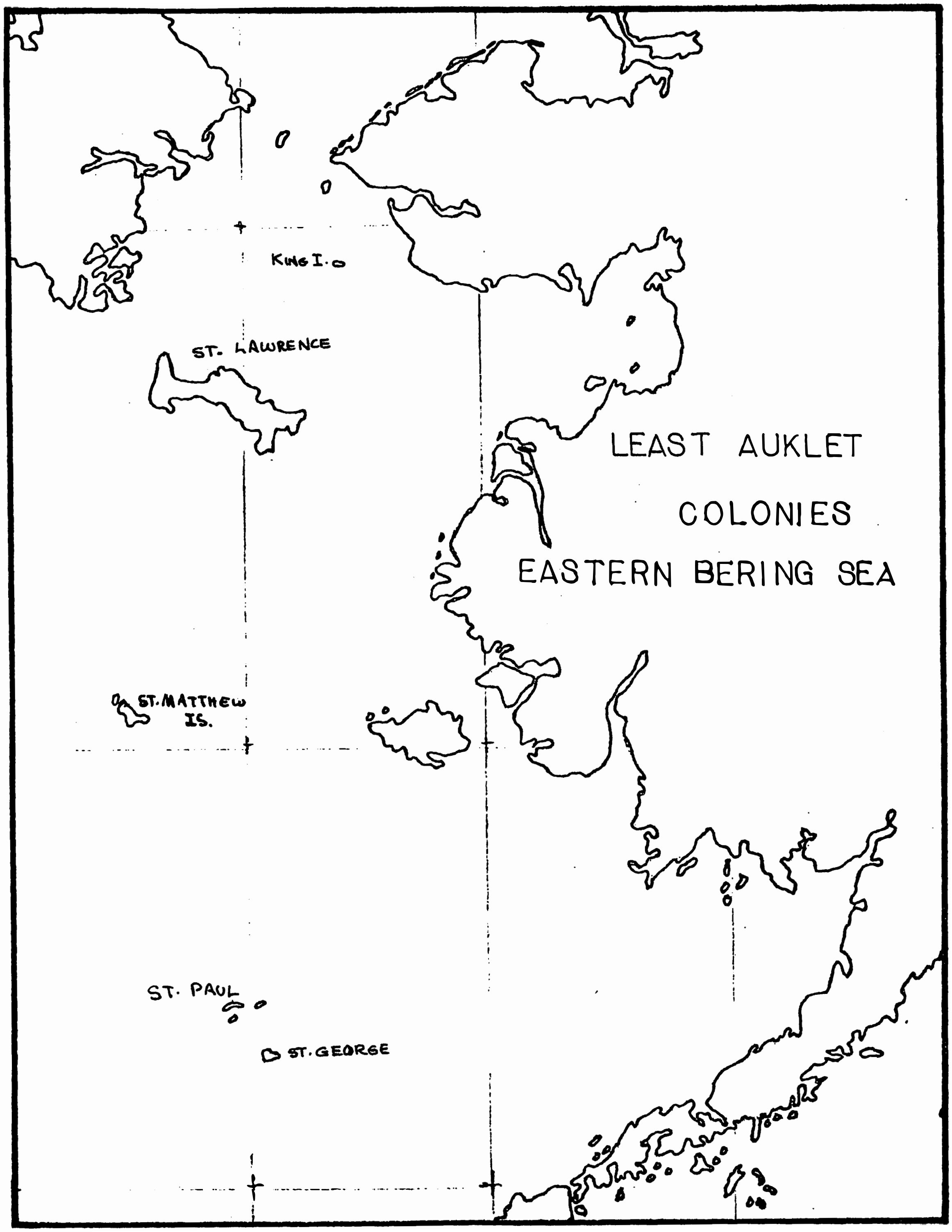

Figure 10. The locations of Least Auklet colonies in the eastern Bering Sea.

the Parakeet Auklet likely dives all the way to the bottom for their food, which includes epibenthic fauna. All three species are planktivores and eat a variety of prey species (Table 11).

Least Auklets tend to eat relatively more Calanus copepods than any other species, particularly after their eggs have hatched. Most of their prey are less than 7 mm in length. In contrast, Crested Auklets tend to eat relatively more Thysanoessa euphausiids. Most of their prey was in the 7-15 mm size category before egg hatching, but after hatching they tend to be less specialized in prey size, consuming prey from less than 7 mm to over 15 mm (Figure 11).

Parakeet Auklets have the most diverse diet of the three species (Figure 11, Table 11). The large hyperiid amphipod Parathemisto libellula is important in their diet. The presence of mysids and gammarid amphipods suggests that they forage near the bottom at least part of the time. Figure 12 depicts schematically the complex food web of the Parakeet Auklet, and points out the danger of making an ecosystem model too simple if it is to reflect real conditions.

It is important to stress the changes in feeding habits the auklets undergo as the breeding season progresses, as noted by Bedard (1969a). He believes, for example, that the feeding of Least Auklets on Calanus copepods coincides with the crustaceans sudden occurrence at depths shallow enough for the birds to reach (Ostvedt 1955). He further theorizes that the sudden availability of a particular food item may trigger egg laying by the birds. He generalizes the sequence of feeding by the two Aethia as follows: "early summer dependence on benthic prey items; mid-summer dependence on many types of semibenthic and pelagic organisms such as caridean (shrimp) larvae, small hyperiids, mysids, and macrocopepods; and, during the chick-rearing period, reversal to near-monophagy (copepods and euphausids)."

GENERAL DISCUSSION AND RECOMMENDATIONS FOR FURTHER WORK

Field and Laboratory Studies

The most pressing need in field studies is for more seasonal food samples from all species of marine birds, from key areas of the eastern Bering Sea. As noted above, we know enough about the dynamics of the birds in the ecosystem to know that future collections of the major species will have to be much more comprehensive than past ones. It needs to be stressed that a mere knowledge of which prey species that birds are taking will not be sufficient. An ecological and trophic characterization of the prey is needed. Moreover, we need to know which organisms the birds are not eating, and hence the need for integrated nekton/zooplankton/bird feeding studies.

Real-time studies during the breeding season are needed over a long enough time period to bracket the timing and duration (i.e., the cycles) of bird movements between the colonies and the foraging areas. They

Table 11. Frequency of occurrence of prey items in parakeet, least and crested auklets. Figures are in percent occurrence; those with parenthesis from the chick stage and those without are before hatching.

PREY	PARAKEET AUKLET	LEAST AUKLET	CRESTED AUKLET
Mollusca			
Cephalopoda	Minor $_{A,B}$	Major$_S$	Major$_S$
Shellfish	35.9$_B$ (pteropod)		
Crustacea	Major$_A$	Major$_A$	Major$_A$
Barnacle			
Copepod (Calanus)	Minor$_B$ (42.2)	44.0$_H$ Minor$_A$ Major$_B$ 40.5 (90.5)	Major$_B$ 2.4(35.7)
Amphipoda			
Hyperiid (Parathemisto)	Major $_B$ 60.8 (17.5)$_B$	Minor$_B$ 6.6 (2.4)	80.0$_H$ Major $_M$ Minor$_B$ 17.0
Gammarid	(1.1)$_B$	Minor $_B$ 9.7 (0.6)	48.0(2.4)$_B$
Euphausiacea	5.4$_H$	17.0$_H$	
Thysanoessa	Major$_B$ (23.9)	Minor$_B$ 0.6(2.7)	Major$_B$ 7.7(56.0)
Mysid	Minor$_B$ (9.2)	Trace$_B$ 2.1 (0.2)	Major$_B$ 24.5(0.7)
Decapoda		6.0$_H$ 0.5$_B$	
Carid Shrimp	(2.2)$_B$	Major$_B$ 33.3	0.8(4.4)$_B$
Polychaeta	Minor$_B$		Major$_S$
Echinodermata			
Other Invertebrates	Moderate$_A$ 2.2(0.6)$_B$	Minor+ 2.2(0.6)$_B$	Minor+$_A$ 1.1$_B$
Fish	Minor$_{A,B}$ 55.0$_H$(3.1)$_B$	10.0$_H$ 1.1(2.4)$_B$	Trace$_B$ (0.2) 20.0$_H$
Ammodytes			
Boreogadus			
Cottid	Minor$_B$		
Debris	14.0$_H$	15.0$_H$	
Plastic Particles	14.0$_H$		

References: A-Ashmole 1971; H-Hunt 1975; D-Drury 1975; S-Steneger 1885; PM-Preble & McAtee1923; Z-Swartz 1966; B-Bedard 1969 a.

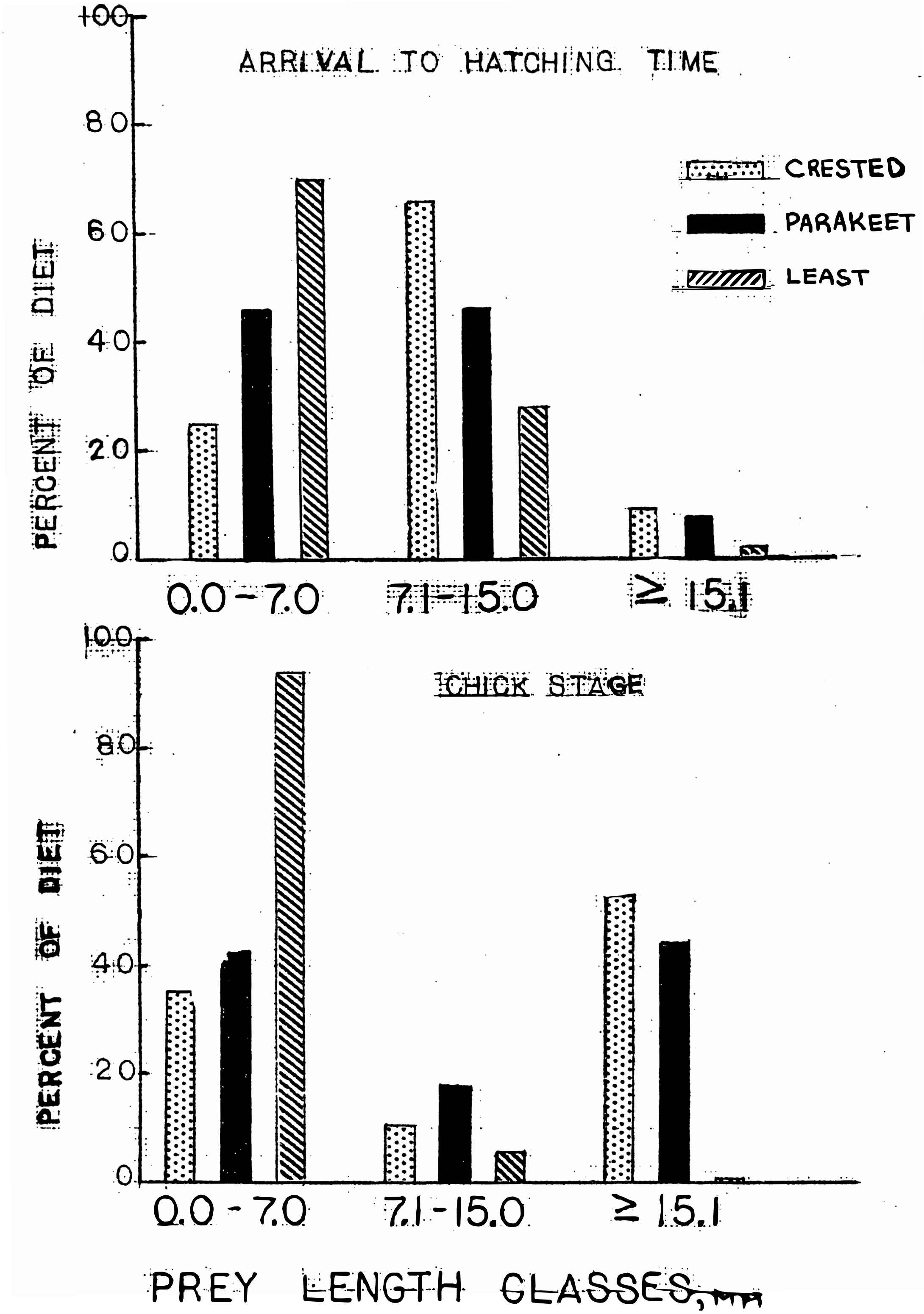

Figure 11. Prey length classes of Crested, Parakeet and Least Auklets during the pre-hatching and chick stages of the breeding cycle on St. Lawrence Island. Adapted from Bedard (1969a).

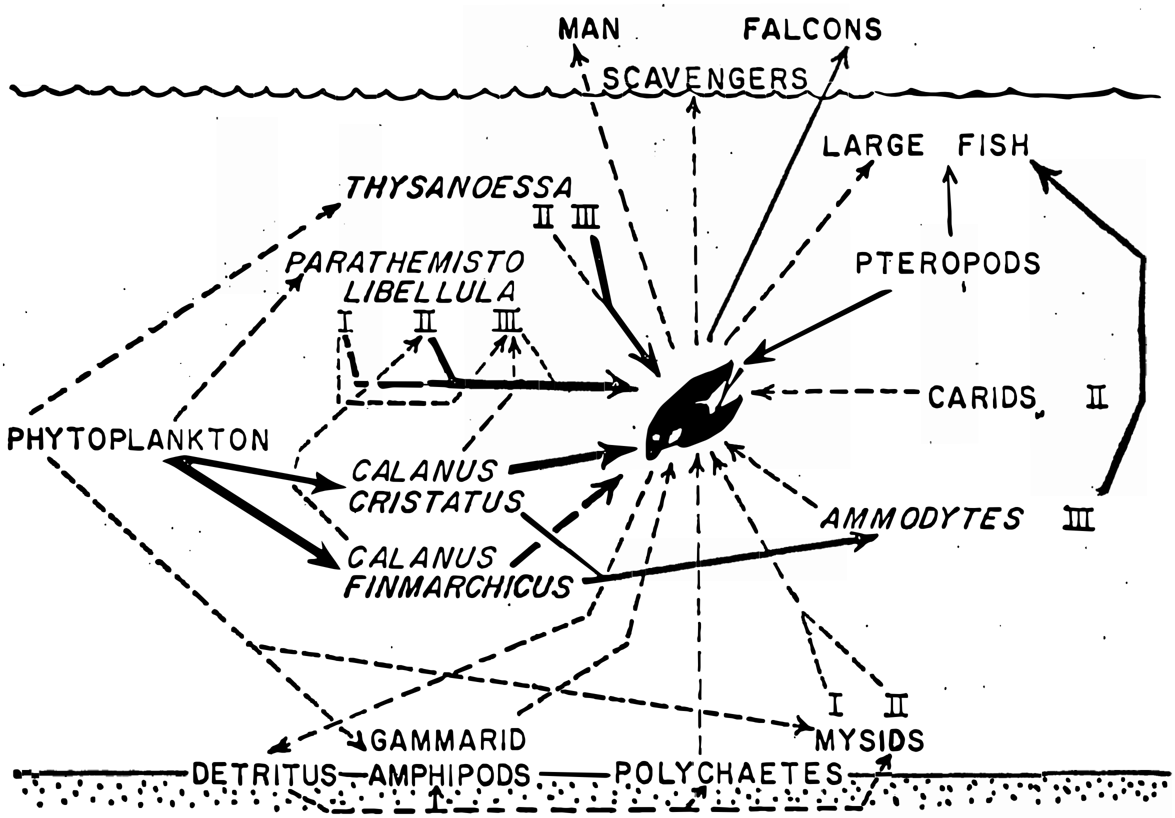

Figure 12. Schematic food web of the Parakeet Auklet in the eastern Bering Sea. Arrow size indicates relative importance of prey. From Ainley and Sanger (in press).

should be designed to locate foraging and non-feeding areas within the expected range seaward from the colonies. They should collect food samples from the birds by several means, and simultaneously sample the nekton and zooplankton. They should include the following:

1. Research from a vessel large enough to keep working in rough weather. There is a cost benefit ratio between vessel size and its operating expense, but a deep-draft vessel of at least 100' would be preferable to a smaller one. Higher operating costs of a larger vessel could be offset by integrating various other studies as outlined in this section.

2. Quantitative, real-time observations for birds along track lines radiating out to some minimum distance from the colony, probably at least 60-80 miles.

3. Birds collected for food samples by shotgun, gillnets, floating mist nets, as appropriate for night-time or daylight hours, concentrating on but not being limited to feeding flocks.

4. Simultaneous real-time observations and collections on the colonies, including seawatches, photographing, and otherwise counting birds on the cliffs. The effectiveness of this would be maximized by maintaining radio contact between the shipboard and the shore phases of the study.

5. With the close coordination of biological oceanographers, real-time collections of the nekton, zooplankton, and if feasible, the benthic epifauna. This phase would be most intensive at night, and would most profitably be done in the immediate vicinity of the floating mistnets and gillnets sampling the birds. Weather permitting, the real-time aspect of the mistnet and gillnet collections (for both fish and birds) would be accomplished by patroling the nets with a skiff at intervals during the night and removing any animals caught. The real-time aspect of the zooplankton collections would be accomplished by hauling a Tucker net (or other feasible opening-closing net) at similar intervals, at selected depth in the water column.

6. The whole operation would last long enough to determine the timing and duration of bird movements to and from the colony for all major species. A <u>minimum</u> of 10 days to two weeks would probably be needed for working near a given colony, repeated at all stages of the breeding cycle (pre-laying, incubation, chick stage, post fledging).

Ideally, these studies should be conducted at and near all major colonies. When "major bird colonies in the eastern Bering Sea" is mentioned, the Pribilof Islands usually come to the mind. However, the importance of the Pribilofs must be related to other major colonies, both in terms of total numbers of birds and the amount of work done there already. The Pribilofs probably have the greatest concentration of birds in the area (2 to 3 million), but other colonies in the southeastern Bering Sea harbor numbers of birds which approach those in the Pribilofs, and which collectively exceed those of the Pribilofs. Chief of these is the Cape Newenham-Cape Peirce-Hagemeister Island area at the northwest corner of Bristol Bay. Geographically, this area is only slightly larger than the Pribilofs, and the best conservative estimates number the bird populations at over two million.

Another important area is the eastern Aleutians between Umak Island and Unimak Pass, at the southern end of the Golden Triangle. We conservatively guesstimate populations in this broad area at 1 to 1.5 million birds. Finally, St. Matthew and Nunivak Islands have large colonies which are just barely known. Nunivak is believed, for example, to have the largest colony of Horned Puffins known (ca. 60 thousand). The point is, there are areas in the southern Bering Sea besides the Pribilofs that need attention, particularly since the Pribilofs have already had recent intensive study.

A major data gap is the virtual lack of knowledge about feeding rates of marine birds, and nutritional values of their various prey. Bedard's (1969a) study briefly touched on this subject. He conducted feeding experiments wherein he provided captive young auklets a super-abundant supply of live gammarid amphipods. Despite the fact that the birds readily fed on the amphipods, they consistently lost weight and died within a few days. Gammarids have a high ash content, which apparently was inhibiting the assimilation of the protein and fat by the birds. The point is, it is misleading to simply lump all prey as "biomass" and assume they are nutritionally equal. Feeding experiments could be conducted on captive birds to test the nutritional value of various prey species, and to get an idea of feeding rates of the birds.

We still need to know much more about shearwaters in the southern Bering Sea, particularly the relative proportions of the two species and their comparative feeding habits. Knowing these things is critical to any ecosystem process study, because shearwaters are collectively the most abundant form of marine bird and have the greatest biomass of all marine birds in the Bering Sea. Preliminary indications are that Sooty Shearwaters feed at least one trophic level higher than Short-tails, and that the former specializes on fish and the latter on nektonic crustaceans. It would be ecologically quite misleading to lump them. The study outlined here would also be able to monitor the densities, movements, and feeding habits of shearwaters. This information would also be important in determining if the presence of the shearwaters in the area influences the breeding birds in any way; if there is enough overlap in feeding niches of the shearwaters and the colony birds, the presence of shearwaters within the normal foraging areas could conceivably adversely affect productivity on the cliffs.

Similarly, we need to know much more about the ecological differences between the two murre species. Particularly since preliminary indications are that they feed on different prey, we need to know how to more precisely fit each species into an ecosystem model.

The Tufted Puffin is of fairly large size (ca. 800 g) and occurs in large numbers in the eastern Bering Sea, particularly the southern part. This species should also be included in future ecosystem modeling attempts.

Ecosystem Modeling

Marine birds are as ecologically diverse a fauna as exists in the Bering Sea. They occur and forage in a wide variety of habitats, ranging from the littoral out to the pelagic, and from the surface down through the water column to the epibenic. They consume a diverse array of prey species, of different sizes, from copepods of a few millimeters to fishes of at least 20 centimeters. As discussed below, a few species have probably benefited greatly from the offal and "ecological imbalancing" created by the recent intensive pollock (*Therogra chalcogramma*).

The pollock fishery has probably had two major influences on the marine bird community:

1. The catch of enormous numbers of pollock over the last several years has made available a large forage resource that otherwise would have been eaten by the pollock. Studies on adult pollock in the eastern Bering Sea (Donald S. Day, personal communications) showed that pollock prey heavily on *Thysanoessa* euphausiids and the large hyperiid amphipod *Parathemisto libellula*. One may presume that juvenile pollock prey heavily on *Calanus* copepods. As noted in the above sections, all these species are more or less important in the diets of marine birds. Thus, many species of marine birds in the eastern Bering Sea would seem to have benefited by the increased availability of prey provided by the decrease in the pollock stocks from the fishery.

2. The scavenging species, Northern Fulmars, Glaucous-winged Gulls and Black-legged Kittiwakes, would seem to have benefited greatly by the large quantities of offal produced by the fisheries motherships. The fulmars and kittiwakes in particular, which remain fairly pelagic during their breeding season, would benefit by the offal if the motherships happened to be operating near the colonies.

The strong implication is that if an ecosystem model is to portray marine birds with greater accuracy than a present attempt (Laevastu & Favorite 1976), an expanded list of modeling components is necessary. Generally, it appears that more complexity (i.e., trophic levels) is needed at lower trophic levels in the food web. We suggest that the following changes or additions be made:

Meroplankton. At present, ichthyoplankton is considered as an integral part of a zooplankton component. Due to the sharp seasonal nature of all meroplankton (including ichthyoplankton), it should be considered as a separate component. Meroplankton such as shrimp larvae have been shown to be important to some birds (Bedard 1969a).

Copepods. The life histories, general ecology, and trophic levels of copepods are sufficiently different from euphausiids that they should be separate. There is no direct evidence from the Bering Sea, but it is highly probable that adult euphausiids prey heavily on smaller copepods. Thus, they would be a trophic level apart. As noted in preceding sections of this report, different species of bird preferentially eat copepods or euphausiids (Ogi and Tsujita 1973; Bedard 1969a).

Euphausiids. For the reasons noted in the preceding two paragraphs, euphausiids should be considered as a separate component of the model. Although the component as presently conceived includes all euphausiid species, it should be considered to include the large (up to at least 5-6 cm) amphipod *Parathemisto libellula*, which is an important prey of several bird species, and pollock.

Small Pelagic Fish. It is assumed that herring is just an example of this group, but it should be kept in mind that the group includes capelin (*Mallotus villosus*) and sand lance (*Ammodytes*). These species have sh wn preliminary indication of being more important to marine birds than herring.

Epibenthic Macroplankton. The present component listed simply as "benthos" needs refinement. Particularly since much of the secondary production of the eastern Bering Sea appears to depend on the benthic community, that part of the ecosystem should be portrayed as accurately as possible. Since many species of marine birds consume benthic forms such as clams, gammarid amphipods, mysids and juvenile shrimp, it is a distinct enough component to consider separately.

Fisheries Offal. Offal seems important enough to birds that it should be included in future ecosystem modeling attempts. Any offal which sinks to the sea bottom would likely be consumed by gammarid amphipods, which are important in the diet of baleen whales (Rice and Wolman 1971).

Finally, it seems to us worthwhile to at least begin thinking about plugging primary productivity into the ecosystem model. Considering the base of the food web may give insight to the timing of events at higher trophic levels. The timing, intensity, and duration of under- and in-ice productivity, water column productivity and "lagoon productivity" should be considered. The latter includes epibenthic algae, eel grass, and of possible great importance to the offshore parts of the system, the contribution of eel grass detritus.

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