SHOREBIRD LITTORAL ZONE ECOLOGY

OF THE ALASKAN BEAUFORT COAST

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I. SUMMARY

We have studied shorebird distribution, habitat relationships, trophic dependencies and behavior at several Beaufort coast sites since 1975. Our objective is to assess the degree and nature of dependence of shorebird species on arctic habitats which are potentially susceptible to perturbation from offshore oil development activities. With other researchers we have identified several sensitive sites along the Beaufort coast where shorebird use of coastal habitats is very high. We have ranked types of coastal habitats on the basis of bird use and possible effects of oil development. We have categorized the common shorebird species in terms of relative sensitivity to habitat disturbances associated with oil development and have defined seasonal habitat use patterns of all species to determine sensitive periods within the year.

During June and early July shorebird activity is centered on the tundra where shorebirds nest. In July and August a major shift in habitat use occurs, beginning with post-breeding adults and augmented increasingly by fledged juveniles moving to shorelines to forage in littoral habitats prior to southward migration. Species vary in timing and magnitude of this habitat shift, but the phenomenon is widespread across species, with many species reaching littoral zone densities far in excess of those on tundra during early summer. Within the littoral zone, species differ also in their relative use of different types of littoral habitat. On a finer scale, species exhibit microhabitat foraging preferences within littoral habitats. All these differences affect the likelihood that oil development activities or oil spill accidents will affect species populations. Specific results are detailed below.

Littoral zone movements of most shorebird species at Barrow represent more than just local breeding birds. Annual variation in post-breeding densities of most species is correlated with annual variation in temperatures during the post–breeding period but not with variation in temperatures during the nesting period. Birds which share post-breeding habitats fluctuate similarly in post–breeding densities. Annual variation in post-breeding littoral zone densities is probably determined by conditions within the littoral zone; development perturbations will affect groups of species similarly.

Measured densities of migrating birds are very sensitive to variation in turnover rates of individuals at a census site. Turnover rates of Red Phalaropes at Barrow in 1976 were rapid, suggesting that large populations of birds might be affected by a local oil spill.

The common Barrow shorebirds can be classed in four groups on the basis of seasonal patterns of tundra vs. littoral zone habitat use. Species such as Red Phalarope and Ruddy Turnstone are heavily dependent on the littoral zone while Golden Plovers are almost restricted to tundra habitats; other species show intermediate patterns.

Based on six measured habitat variables our littoral transects can be separated in principal component habitat space into groups corresponding to gravel beaches, littoral flats and slough edges. Birds respond to these differences in habitat type, with groups of species occurring in the same transect groups in each year. Species density distributions in habitat space are often quite distinctive, but different species sometimes show similar shifts in habitat use between years, probably in response to changes in environmental conditions. Groups of species emerge with similar habitat preferences within the littoral zone and with similar micro-habitat preferences within habitats. These groups of species may be affected similarly by particular environmental disturbances.

Types of available littoral habitats were comparable at Barrow and Prudhoe Bay but Barrow has larger areas of gravel spit shorelines, which attract high densities of phalaropes. At Fish Creek Delta in Harrison Bay this habitat is absent, but mudflat and saltmarsh habitats, heavily used by other species, are more extensive than at Barrow and Prudhoe Bay. Red Phalaropes are much more common than Northern Phalaropes in migration at Barrow, but they are less common in Harrison Bay probably as a result of a longitudinal gradient in relative abundance as well as a gradient in habitat preference of the two species.

Shorebird concentration areas occur in areas of gravel spits and barrier islands (Icy Cape, Peard Bay, Point Barrow, Plover Islands, Jones Islands) and in areas with extensive littoral flats, saltmarshes and slough edges (Icy Cape, Barrow, Fish Creek Delta, Coleville Delta, Cape Halkett).

Species differ also in fat accumulation schedules prior to southward migration. Fat levels of Red Phalaropes and Dunlin both increase during August. Fat levels of Ruddy Turnstones and Sanderlings prior to departure are even higher than in the latter species. Semipalmated Sandpiper juveniles depart much earlier, with less fat.

Littoral zone diets of most shorebird species correspond to the habitats in which they forage rather than to strong species differences in diet preference; diets of many species overlap broadly while foraging in the same habitat type. On littoral flats, in saltmarshes and along the edges of sloughs and lagoons, shorebirds prey mainly on chironomid fly larvae, with adult chironomid flies and oligochaetes taken during some periods. Along marine shores the prey base for many species is the mix of marine zooplankton and under-ice amphipods which is highly variable in density and species composition between years and within one season. Diets of shorebirds have a strong seasonal component as species shift from tundra to littoral habitats and as prey availability within habitats changes.

Juvenile Red Phalaropes foraging along the shores of Barrow Spit altered their diets and their foraging behavior in relation to onshore wind direction, apparently in response to changes in relative abundance of marine zooplankton and

under-ice amphipods. This response suggests that spits and islands may be favored foraging areas because they present more options with respect to onshore - offshore winds when compared with mainland shores.

At Prudhoe Bay, the dust shadow produced on tundra beside gravel roads reduced densities of nesting shorebirds and passerine. A tundra area where natural drainage has been altered by construction showed a reduction in shorebird breeding densities but an increase in densities of late summer migrants. An artificial gravel pier at Prudhoe Bay was used less than adjacent mainland shores by passerine and several species of shorebirds, but densities of Northern Phalaropes were extremely high. Artificial piers and islands will probably attract zooplankton foragers to areas where oil spills may be more likely.

In choice experiments, juvenile Red Phalaropes made no initial distinction between foraging on clear water or on water containing an oil film. However, on subsequent choices they avoided foraging on oiled surfaces; they also foraged longer on clear surfaces. In a related aquarium experiment, phalaropes increased time spent in escape behavior in response to thin oil films on water. If their fate is not sealed by initial contact with oil on water, phalaropes may learn to avoid it quickly enough to reduce mortality rates.

II. INTRODUCTION

Along the Beaufort and Chukchi coasts of arctic Alaska tundra habitats merge with saltmarsh, sloughs and arctic beaches. In these habitats shorebirds (Charadriiformes: Charadrii; sandpipers, plovers and their close relatives) of many species are present throughout summer months. In contrast to areas farther south, shorebirds comprise a major segment of the avifauna of the coast of arctic Alaska (Bailey, 1948; Gabrielson and Lincoln, 1959; Pitelka, 1974). The twenty-seven species listed in Table 1 occur regularly in the arctic during summer months, migrating to spend their winters in temperate and tropical regions of both northern and southern hemispheres. As a group they are an international resource, with individual species dependent in varying degrees on summer conditions along the Alaskan arctic coast.

Prior to 1975 most of the detailed studies of shorebird ecology in arctic Alaska had been done near Barrow where researchers concentrated on conditions and activities on the tundra primarily during the short arctic breeding season (Holmes, 1966a, 1966b, 1970, 1971; Holmes and Pitelka, 1968; MacLean, 1969, 1974; Norton, 1972, 1973; Pitelka 1959, 1974; Pitelka et al., 1974). It had been noted at Barrow and elsewhere in the arctic that densities of several species of shorebirds increased near the shoreline as summer progressed resulting in a net increase in use of littoral habitats (Holmes, 1966a; Bengtson, 1970). This movement begins with non-breeders and is augmented progressively by a shoreward movement of local and also inland birds, especially after the young have fledged. However, the importance of this habitat shift in the breeding cycle of arctic shorebirds had not been adequately evaluated.

Since 1975 we have attempted to provide detailed and quantitative information necessary to assess the dependence of shorebirds and other species on littoral habitats along the Alaskan arctic coast. Development of petroleum resources along the outer continental shelf will produce some unknown degree of disturbance to these habitats. To the extent that shorebirds and other birds depend upon shoreline and near-shore habitats any disturbances may affect their populations. Our approach to evaluating the significance of the littoral zone to shorebirds has been to gather and analyze basic ecological data dealing with seasonal occurrence of shorebirds in different habitats; trophic relationships of shorebirds feeding in littoral habitats; and variability in these aspects both over time and over space. These efforts have been supplemented with behavioral data, experimental work and observations of bird use in habitats already subjected to development alterations. Our objectives are to define the seasonal relationships between each common species and the habitats available; to identify the species and habitats most sensitive to disturbance as well as the regions along the Beaufort coast that should be considered most important to shorebird populations; to predict the probable impact of

Table 1. Shorebird species occurring regularly along the Beaufort and Chukchi coasts of Alaska (from Connors et al., 1979).

Regular Breeders
Semipalmated Plover, *Charadrius semipalmatus*
American Golden Plover, *Pluvialis dominica*
Black-bellied Plover, *Pluvialis squatarola*
Ruddy Turnstone, *Arenaria interpres*
Black Turnstone, *Arenaria malanocephala*
Common Snipe, *Capella gallinago*
Whimbrel, *Numenius phaeopus*
Red Knot, *Calidris canutus*
Pectoral Sandpiper, *Calidris melanotos*
White-rumped Sandpiper, *Calidris fuscicollis*
Baird's Sandpiper, *Calidris bairdii*
Dunlin, *Calidris alpina*
Semipalmated Sandpiper, *Calidris pusilla*
Western Sandpiper, *Calidris mauri*
Stilt Sandpiper, *Micropalama himantopus*
Buff-breasted Sandpiper, *Tryngites subruficollis*
Long-billed Dowitcher, *Limnodromus scolopaceus*
Bar-tailed Godwit, *Limosa lapponica*
Red Phalarope, *Phalaropus fulicarius*
Northern Phalarope, *Lobipes lobatus*

Additional Migrants
Killdeer, *Charadrius vociferus*
Sharp-tailed Sandpiper, *Calidris acuminata*
Least Sandpiper, *Calidris minutilla*
Rufous-necked Sandpiper, *Calidris ruficollis*
Curlew Sandpiper, *Calidris ferruginea*
Sanderling, *Calidris alba*
Hudsonian Godwit, *Limosa haemastica*

potential disturbances and to suggest alternatives or guidelines that will be useful in managing the development of the Beaufort coast.

Annual reports presenting results of these studies have been published by OCSEAP each year (Connors and Risebrough, 1976; 1977; 1978; 1979; 1980). In this final report dealing with the Beaufort coast we will attempt to summarize and synthesize results presented in those reports and to present the results of further analyses performed on the multi-year data set. In the interest of brevity and clarity, we will not present all details of subjects discussed previously but will repeat any information necessary to understanding topics discussed in this report.

III. METHODS

Study Areas

Our principle approach to the study of shorebird habitat use in the littoral zone required initially a definition of the littoral zone appropriate for the Beaufort Coast. Definitions for shorelines in more southerly regions have been established (see Ricketts et al., 1968) but the Alaskan Beaufort Coast presents some special problems. The mean tidal range at Barrow is only 29 centimeters; however, during periods of open water, storms may produce tides of 1 meter or more above normal, inundating large areas of low lying coastal habitats. Vegetation, patterns of bird use and susceptibility to petroleum pollution carried by storm waters differ markedly within this zone compared to tundra just beyond it. For these reasons, we considered the arctic littoral zone as extending from the lowest tide level up to the limits of the area likely to be flooded by storms at least once every few years. The imprecision of this operational definition results from our inability to establish the area frequency contours necessary for a more precise definition. In practice this littoral zone can readily be recognized by the brackish water in flood pools, by the presence of salt tolerant vegetation, and by the distribution of storm drift material.

We established permanent marked transects at our three principal study sites: Barrow (71° 17'N, 156° 46'W) where we censused transects for four consecutive summers from 1975 through 1978; Prudhoe Bay, (70° 15'N, 148° 20'W) where we censused transects during the summer of 1978; and Fish Creek Delta (70° 25'N, 151° 22'W) in Harrison Bay where we worked during 1980 (Figure 1). At Barrow, our main study site, we established transects in a wide variety of littoral and near littoral habitats (Table 2 and Figure 2). These included gravel spit beaches varying in wave exposure, gravel mainland beach, tundra-backed beach, ocean estuary, open lagoon estuary, closed brackish lagoon and a variety of mudflat and salt marsh habitats varying in amount of water cover, salinity of pools, type and density of vegetation, substrate grain size and proximity to ocean, lagoon or sloughs. On the basis of habitat measurements and bird use we have grouped transects into three main categories, designated as gravel beaches (G), lagoon and slough edges (E), and littoral flats (F). We established a similar systems of transects at Prudhoe Bay designed primarily to test the effects of habitat disturbances by sampling disturbed and undisturbed habitats, and in Fish Creek Delta to measure shorebird densities on the extensive littoral flats and slough edges of that area.

We supplemented our regular transect census information with observations and density measurements made in brief visits to several other sites: Icy Cape, Wainwright, and Peard Bay west of Barrow; Lonely, near Pitt Point, Oliktok, east of the Colville River, and a site west of Harrison Bay near Cape Halkett, all along the Beaufort Coast (Figure 1).

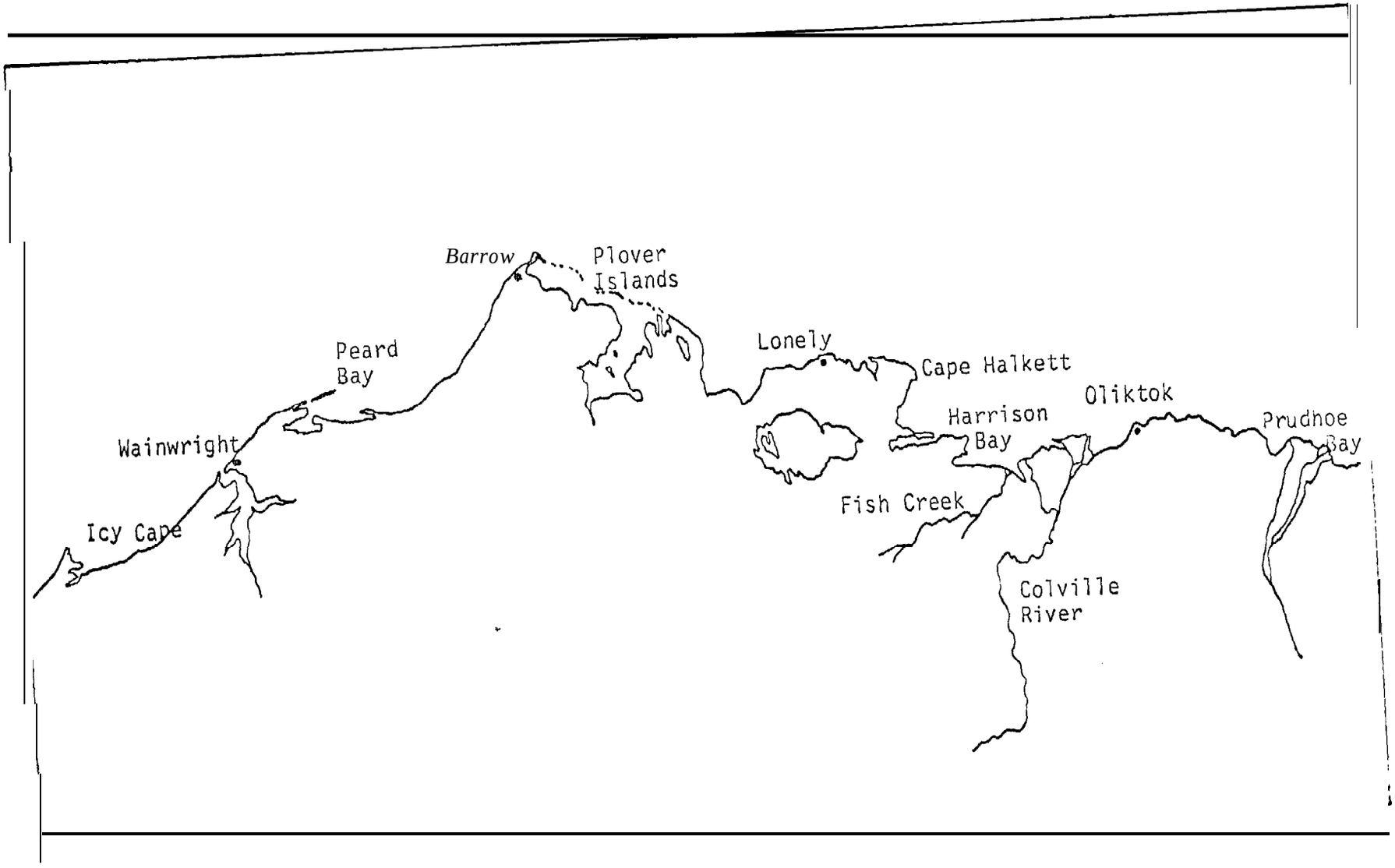


Figure 1. *Beaufort and* Chukchi *coast* study *area,*

Table 2. Littoral zone transects studied at Barrow 1975-1978.

Transect Code	Years Censused	Length (m)	Width (m)	Habitat
BAP	3	1000	50	G
BBD	3	2900	50	G
BBS	4	1000	50	G
BBV	1	1000	50	G
BCB	3	1000	50	G
BCN	3	1000	50	G
BCS	4	1000	50	G
BDM	3	1000	50	G
BDC	1	1000	50	G
BPP	3	1000	50	G
BPS	3	1000	50	G
BRW	3	1000	50	G
BTW	3	1000	50	G
BWS	4	1000	50	G
BBP	4	300	100	F
BGF	4	500	100	F
BNL	4	500	100	F
BNT	3	500	100	F
BVL1	2	500	50	F
BVL2	2	500	100	F
BCM	2	1000	50	E
BME	3	500	50	E
BMW	3	500	50	E
BNB	4	1000	50	E
BNE	4	500	50	E
BVE	2	500	50	E

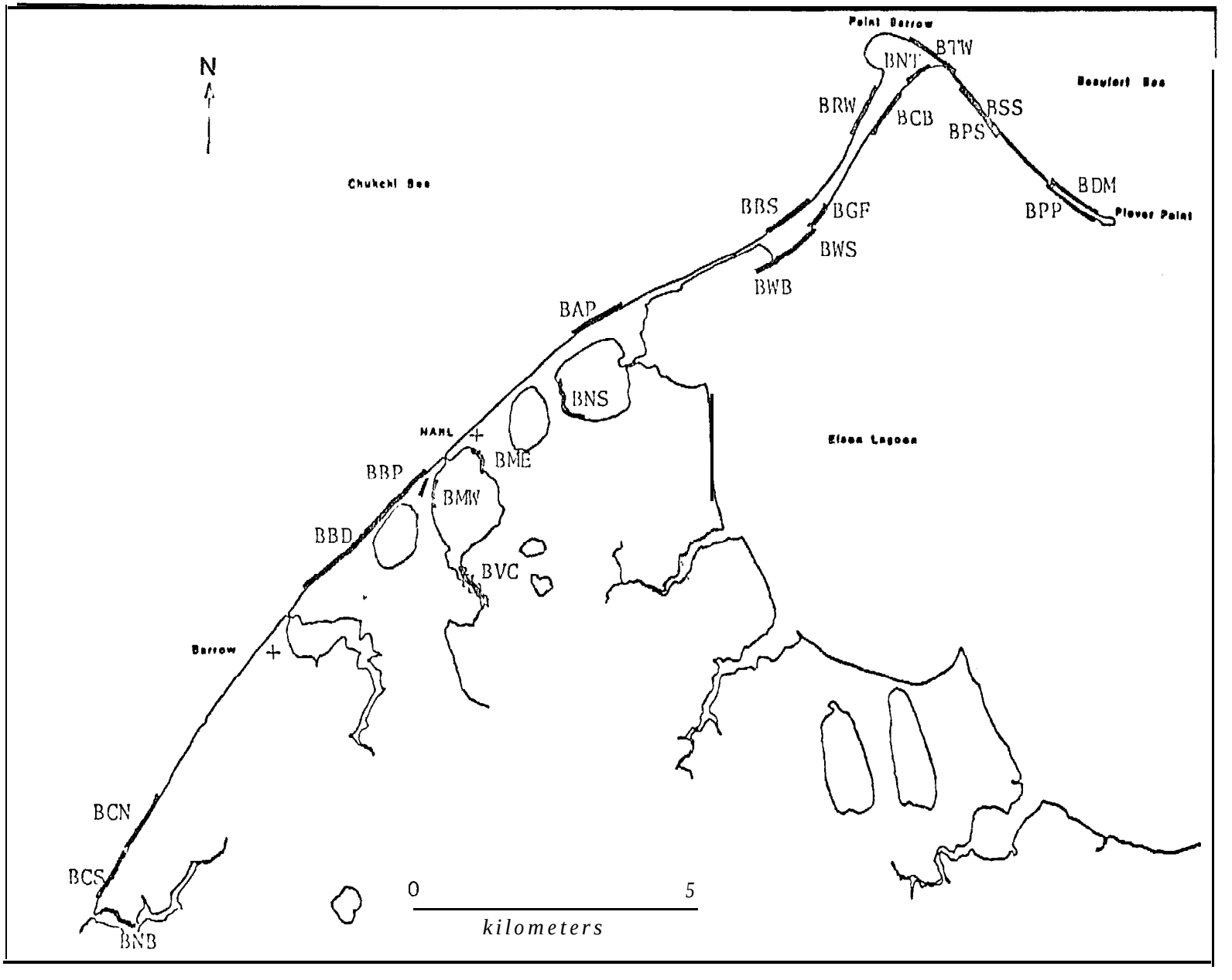


Figure 2. *Location of transects at Barrow.*

Airplane flights between these sites and our principal study sites gave us more extensive but less detailed information on the distribution and availability of habitats and on concentration areas of shorebirds along the coast.

Transect censusing

Permanent transects were marked with stakes at 50 meter intervals. In relatively uniform habitats such as mudflat, saltmarsh or tundra, transects were straight and 100 meters in width with 50 meter stakes running along the center line of a double row of 50 x 50 meter square plots. At Barrow transect distances varied from 300 meters to 1000 meters (Table 2). Shoreline transects, such as along lagoon edges or ocean beaches, consisted of a single row of 50 meter x 50 meter square plots following the shoreline. These transects varied from 500 meters to 2900 meters.

We censused transects once every five days and have averaged data from all years pertaining to five day periods throughout the summer. Barrow study seasons differed in different years: 16 June - 3 September 1975, 6 June - 18 September 1976, 16 July - 18 September 1977, and 11 July - 29 August 1978. We censused in all four years during the nine periods of heaviest littoral zone activity for most shorebird species, 19 July through 29 August. In discussions of inter-year variability, only these 9 periods are considered, but for full season data, average densities are computed based on the appropriate number of density estimates. The number of transects censused in different years also varied, primarily as a result of logistic considerations. Number of years each transect was censused is given in Table 2. Our census objective was to determine an instantaneous density on each 50 meter by 50 meter plot by locating, identifying and counting each individual. Some factors affecting censusing are discussed in Results.

At Prudhoe Bay we censused transects continuously in 5 day intervals from 1 June to 10 September, 1978. Transect locations and sizes are shown in Figure 3 and Table 3. At Fish Creek Delta in Harrison Bay our censuses ran from 26 July to 29 August, 1980. All transects at that site were 1000 m long by 100 m wide (Figure 4).

Table 3. Transects studied at Prudhoe Bay in 1978.

Transect Code	Length(m)	Width(m)	Transect Code	Length(m)	Width(m)
PAB	1000	50	PPI	250	50
PBB	500	100	PP2	250	50
PBS	500	100	PP3	250	50
PDW	1000	50	PP4	250	50
PEB	1000	100	PPB	500	100
PED	400	50	PPM	1000	50
PF1	700	100	P Pu	350	50
PF 2	800	100	Ps 1	500	50
PG 1	500	100	Ps 2	500	50
PG 2	500	100	PRB	400	100
PG 3	500	100	PSB	1000	100
PG 4	500	100	PSR	500	100
PGI	1000	50	Pss	1000	100
PIS	500	100	Pw 1	1000	50
PMF	300	100	Pw 2	1000	50
PNO	150	100	Pw 3	1000	50
Pos	150	100	Pw 4	1000	50

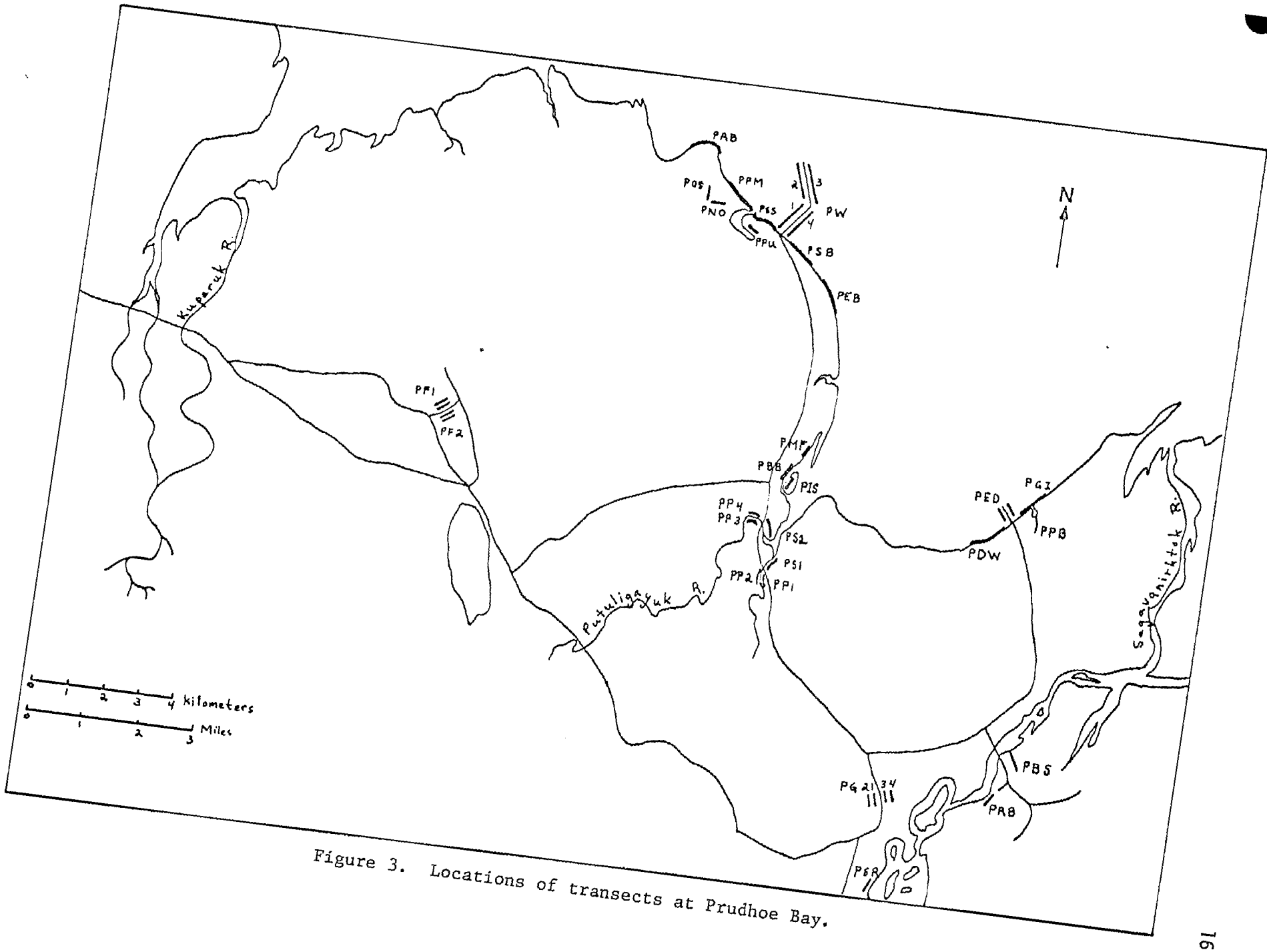


Figure 3. Locations of transects at Prudhoe Bay.

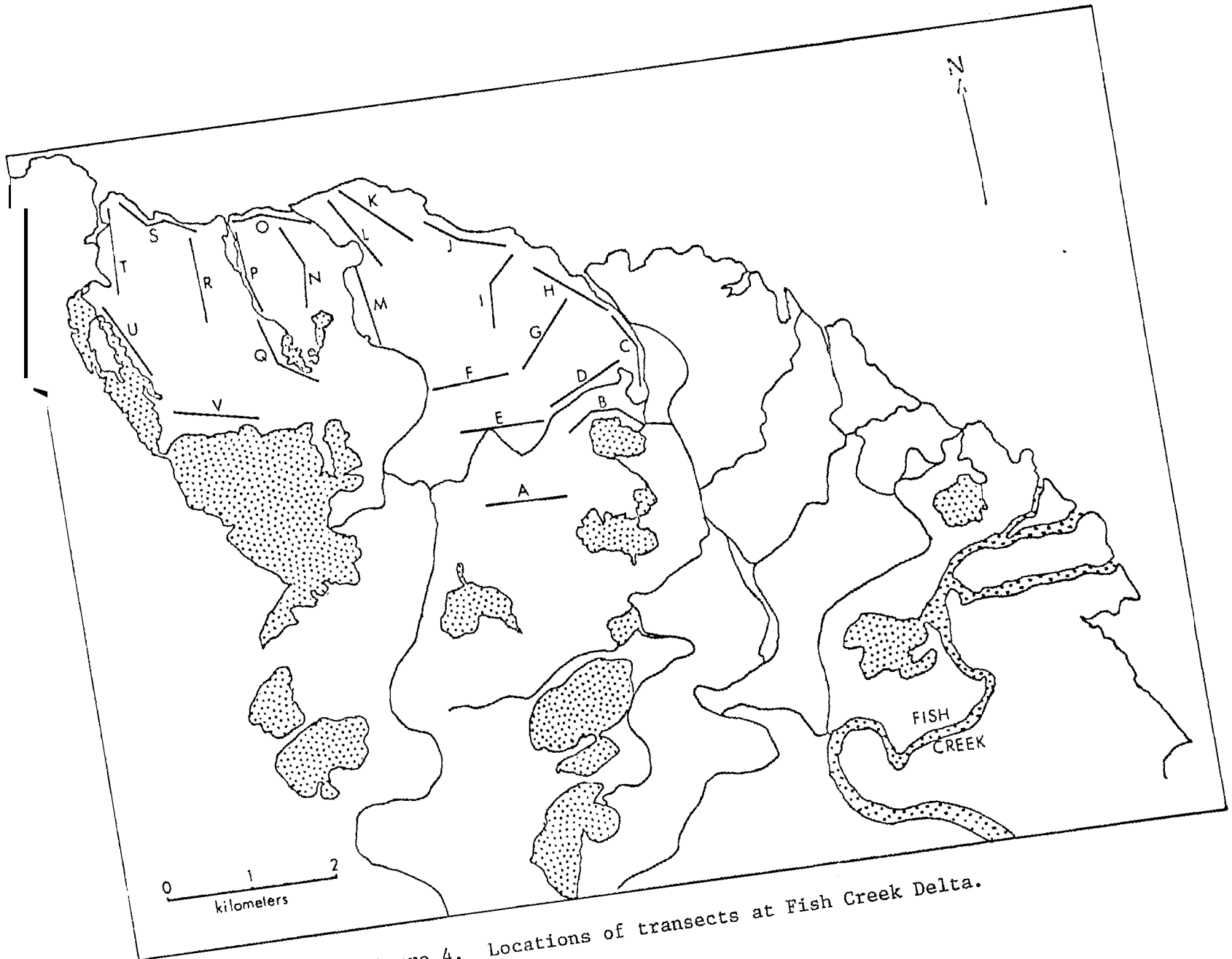


Figure 4. Locations of transects at Fish Creek Delta.

Habitat characterization

We present general descriptions of the shorebird habitats studied in Results below. To characterize our transect habitats quantitatively for further analysis we described the littoral zone transects by measuring six variables for each 50 meter plot:

1. Distance from shore (DSHORE): distance from center of 50 meter plot to nearest major shoreline (e.g. ocean, lagoon, river).
2. Width of normal flood zone (NORFLZ): distance from mean water level to highest level inundated during most years. Determined by recent drift material and by vegetation.
3. Width of maximum flood zone (MAXFLZ): distance from mean water level to highest water level as indicated, by farthest inland driftwood line.
4. Water cover (WATCOV): percent of plot covered by water.
5. Substrate (SUBSTR): particle size gradient classified as mud (1), fine sand (2), coarse sand (3), fine gravel (4), coarse gravel (5).
6. Vegetation cover (VEGCOV): percent of exposed area covered by plants.

These six components were used in principal component analyses (Morrison, 1976) and as our results will show they were sufficient to identify the principal distinctions between groups of littoral habitats. We also recorded three additional categorical variables for each plot: major land form, habitat form and major plant taxa on the plot (Connors and Risebrough, 1978). We evaluated these in our subjective classifications of littoral habitats into three basic types; the results agreed with the quantitative analyses based on the first six variables (see Results). These categorical variables also contribute to a useful description of habitats, conveying a more easily communicated picture of the habitats than is possible with the quantitative analysis.

Habitat descriptions were performed during August to represent the conditions experienced by shorebirds during the period of heaviest use each year. Only one variable, percent water cover, is sensitive to the date of measurement; all other variables remain fairly constant throughout the summer.

Foraging microhabitat measurements

During late summer of 1976 at Barrow, we recorded six variables describing microhabitat in the immediate vicinity of points where shorebirds foraged in the littoral zone. The variables were: distance from foraging point to water line, depth of water at foraging point, grain size at foraging point, distance to nearest algae from foraging point, distance to nearest vascular plant from foraging point and depth of penetration of the bird's bill into the substrate. We measured a total of 1210 foraging points on 9 common shorebird species (Connors and Risebrough, 1977). We used factor analysis {Wallace and Bader, 1967) to extract coordinates

which combined the measured variables to represent the major environmental gradients which describe the differences in species foraging microhabitats. The space defined by these new coordinates can be thought of as microhabitat space with different areas representing different types of microhabitat. The locations of each species' foraging points within this microhabitat space then define the differences in foraging preferences among the species.

Trophic studies

We collected 136 individuals of 13 species over the years 1975 - 1978 at Barrow and a few nearby sites (Table 13). All were collected by shotgun with immediate injection of a formalin solution into the stomach and esophagus to preserve ingested prey items. These organs were subsequently removed in the laboratory where prey items were identified and counted. We also recorded the fat condition of each bird using a scale which combines the OCSEAP seabird fat code with a traditional museum fat description as follows: Code 1, no fat; Code 2, little fat; Code 3, moderate fat; Code 4, heavy fat; Code 5, excessive fat. Prey identified in bird stomachs were compared with densities and distributions of prey sampled in the foraging substrate (with cores and sieves) or in shallow water using a floating plankton net. The rectangular net (30 cm wide by 14 cm high at opening) was towed parallel to shore along beaches to sample zooplankton available to foraging phalaropes (Connors and Risebrough, 1977).

Phalarope oil film experiments

To test the responses of phalaropes to thin oil films on water, we first constructed a cylindrical pen of hardware cloth (1.9 cm mesh), 1.5 m diameter, 1.4 m height, wrapped with black plastic to a height of .6 m to isolate birds from visual distractions. Within this pen, we placed a continuous ring of 8 identical shallow galvanized metal pans, each 40 cm inner diameter, 9 cm depth. A central plywood disc or table (80 cm in diameter) rested on all 8 pans, but left most of each pan uncovered. A bird standing on the center table had a choice of entering any of the pans which formed a symmetrical ring around the circumference of the table. During the experiments, all pans contained seawater to a depth of 7 cm, and equal densities of live brine shrimp, *Artemia franciscana*, (1.3 ml drained brine shrimp per pan, equal to approximately 150 prey items).

Juvenile Red Phalaropes were acclimated to the experimental setup for 2 to 3 hours with water containing prey, but no oil. This acclimation period was necessary because the initial response of wild birds introduced to the cage often entailed fluttering escape attempts which resulted in the birds falling into pans. We wished to observe choices by the birds, not accidents.

For choice experiments, we placed a thin film of oil on 4 pans alternating with 4 clear pans around the circumference of the table. All pans contained equal amounts of water and

prey. Oiled pans contained 10 ml of a 1:1 mixture of Prudhoe crude oil and diesel fuel (JPR-5). This formed an irregular surface film of small patches and spots of a medium brown semitransparent film, covering approximately 60% of the surface. To our eyes, the oiled and clear pans appeared distinctly different. Moving prey could be readily seen in both clear and oiled pans, but they were more visible in clear pans.

To initiate an experiment, the bird was placed under a small box in the center of the table. The box was hoisted smoothly to the top of the cage by remote control, releasing the bird in the center of the table to choose a foraging pan. Two observers sat inside a nearby laboratory above the cage, recording movements, behavior, and sequence and duration of choices for a trial period of 15 minutes per bird. The behavior of most birds, entailing a period of inspection of several pans from the table edge before entering any pan, leads us to conclude that the birds were in some way choosing foraging pans based on the results of that initial inspection. The inspection period often lasted several minutes and included visual inspection of many or all pans. Choices were scored when a bird entered a pan directly from the table, and duration of foraging periods was timed until the bird left the pan. Until the end of the 15 minute trial period, subsequent entries were scored as sequential choices.

In a second experiment, phalaropes previously acclimated to swimming and foraging in a 15 gallon glass aquarium (rectangular, 30 cm x 60 cm x 8 cm depth of seawater) were placed singly in the aquarium containing .9 ml of drained brine shrimp (approximately 100 prey). Behavior of each bird was timed for 60 seconds in the absence of oil and in the presence of very thin films (1.1 m and 2.8 m) of the 1:1 mixture of crude oil and diesel fuel.

IV. RESULTS AND DISCUSSION

The census data and habitat descriptions can be combined and analyzed to focus on several separate questions relevant to shorebird littoral zone ecology. In this section we address these topics sequentially, presenting initial results and analyses and 'discussing our interpretations and conclusions regarding each topic. We begin with some cautionary and explanatory remarks regarding our methodology, followed by brief descriptions of the principal types of habitats of interest along the Beaufort coast. We present an overview of the seasonality of habitat use by arctic shorebirds, and then discuss annual variation in shorebird numbers, habitat differences and shorebird habitat use patterns, geographic variation, shorebird diets, fat accumulation schedules, effects of habitat disturbances on shorebird densities, and responses of phalaropes to spilled oil. From these results we identify sensitive areas, habitats, species and times with respect to petroleum development. Finally, we present accounts of species distribution and littoral zone ecology in Appendix.

FACTORS AFFECTING CENSUS RESULTS

Habitat density averaging

In dealing with large numbers of transects in a variety of habitats, a decision must be made concerning the hierarchy of averaging steps in combining habitats to determine a final overall density. In our calculations the basic data were densities in birds per hectare for each species on each transect treated separately. On the basis of our habitat analysis we classified all littoral transects into three habitat groups, discussed below. At step two we calculated the average density for each habitat type as the mean of the densities for each transect within that habitat group. We then calculated an overall average density as the mean of the three habitat type densities. Finally we averaged these densities for all years censused (usually four years) to achieve our final mean density for each census period.

We considered two alternative methods of averaging. The simplest procedure would be to calculate directly the overall density by dividing the total number of birds of a species found on all transects by the total area of all transects censused. This value would be weighted by the amounts of different habitat types studied. It might be the method of choice if a study is of primarily local significance and if transects can be placed in proportion to the amounts of habitat types available locally.

The second alternative, computing the habitat densities separately by dividing total birds on transects of one habitat type by total area of transects of that habitat type, is more general for a study focusing on habitat densities but it is sensitive to variation in the sizes of individual transects. If all transects are of identical size, both this

method and the method we chose achieve identical results. However, compared to the first alternative, these two procedures are sensitive to the choice of habitat divisions. For example, we might have considered only two habitat types rather than three, combining transects on littoral flats and lagoon edges. The effect on the final calculated average density for species with strong habitat preferences could be significant. For species which forage only on gravel transects, the final average density would be increased 50% relative to the density calculated with three habitat types. For species which forage only in littoral flat or lagoon edge habitats, or in equal densities in both, the final calculated average density would be reduced 25% from those calculated with three habitat types. At the other extreme, species with equal densities in all three habitat types would have final average densities identical by both methods. As shown below, the actual habitat use patterns of most species occur between these extremes; Figures 21 and 22 allow an estimate of the effect just described. We chose our habitat density averaging method to give us results which relate closely to habitat differences in the littoral zone but which consider all transects as equal estimates of the density at a particular site irrespective of transect size.

Turnover rate

The densities of transient populations calculated from censuses at any site are determined by two factors, the total numbers of birds passing through the site and the amount of time each individual bird stays at the site. This second factor is relatively unimportant when censusing stable populations, for example territorial breeding birds of many species, because individuals remain at the site for a long time; the number censused at one time is a good estimate of the total number of individuals present throughout the breeding season. When migrational movements are studied, however, turnover rate becomes an important factor in interpreting measured densities. At a site where birds are continually passing through, changes in turnover rate can greatly affect measured densities even though the number of individuals passing the area remains the same. To illustrate this affect, let us assume a total of 100 birds of a species are moving through our census area. We will census every day from long before to long after the birds pass through. Assume further that the arrival of the 100 birds is regular, with 10 new birds arriving on each day for 10 subsequent days. Table 4 shows the effect on peak number or density and cumulative number or density to be produced by varying the length of time each individual stays. A ten-fold increase in length of stay will produce a ten-fold increase in peak densities and in cumulative densities with no change in the number of birds passing through. Clearly, in the absence of information on turnover rates, density measurements of migrating birds cannot give reliable population estimates. This problem is central to the question of estimating popu-

Table 4. Effects of turnover rate on peak numbers and cumulative numbers recorded. Assume daily censusing at study site where 10 migrant birds arrive each day for 10 consecutive days:

Length of stay, each individual	Peak numbers censused	Cumulative number censused
1 day	10	100
2 days	20	200
10 days	100	1000
20 days	100	2000

lation *effects of environmental disturbances. For example, our measured densities of migrating Red* Phalaropes *at Barrow permit us to estimate minimum numbers of birds potentially affected by an* oil *spill, but without some estimate of turnover rate they do not provide estimates of actual populations affected.*

The simple example above is artifical, *chosen for demonstrative purposes. For most species in migration, arrival, departure and interval dates are probably modally distributed rather than regularly distributed but environmental factors such as storms or changes in food supplies may increase the degree of synchrony, especially in southward departure date. As a result, turnover rates for different individuals may differ depending on date of arrival. Variation of turnover rate was in fact suggested in an experiment we performed on Red* Phalaropes *in 1976 (Connors and* Risebrough, *1977). Forty-seven juvenile* phalaropes *were trapped and released in six groups on different dates from 8 to 23 August 1976. Each group was* marked *with paint in a different color pattern for easy recognition in the field. Subsequently we searched for marked individuals throughout the entire Barrow spit area on* 11 *different times between* 11 *and 25 August. We resighted eight individuals, all in the early part of the experiment. The pattern of resightings in relation to the proportion of total birds* marked *suggested that from* 11 *August through at least 15 August most birds remained in the area for at least four days. After 15 August, however, we had no resightings, implying a* much *quicker turnover rate in* phalaropes *in the Barrow spit area. A much more extensive refighting effort would have been necessary to closely determine turnover rates during these different periods. However, our tentative interpretation of these results is consistent with the* overall *census results which show a steadily increasing population of Red* Phalaropes *from August 5th through August 15th and a fluctuating population after August 15th, apparently as groups of birds left and new birds continued to arrive. The importance of this high turnover rate in most of August and*

early September to assessment of oil-related impacts is clear. A local habitat disturbance such as an oil spill, which might remain in a local area for 1 month or more, has the potential to affect several times as many phalaropes as are present at any one time on the area. Wave after wave of migrating Red Phalaropes from undisturbed areas might be affected as they pass through the disturbed area.

Species differences in response to observers

Although we censused all birds that occurred on our transects, we report here the results primarily for shorebirds and passerine and secondarily for gulls and terns. Our reason for omitting many other species, in particular the loons and waterfowl, relates to our choice of transect and census method. The size and type of transect was chosen specifically to allow identification of all shorebirds on each plot. This required censusing at a scale and distance which is inappropriate for many larger species which react to an observer at greater distances. Thus our data on densities of waterfowl censused in this manner would be misleading. Similarly a method of choice for measuring densities of Yellow-billed Loons, for example, might require aerial surveys which would be of little or no use for measuring shorebird densities.

HABITAT DESCRIPTIONS

Our habitat analyses based on six measured variables present objective reasons for grouping our transects in several habitat types. A general description of each of these habitats follows.

Gravel beach

Most shorelines of arctic spits and barrier islands consist of gravel beaches. These are ice-scoured and subject to gravel movement during open water storms. There are no benthic infauna of any major importance to shorebirds. Upper levels of these beaches are sparsely vegetated with salt tolerant plants such as *Honckenya peploides* and *Elymus arenarius*. Gravel beaches may be backed by high ridges of deposited beach gravel or by tundra shores, especially where gravel beaches occur along the mainland.

Littoral flats and saltmarsh

These habitats are grouped together because in most cases they vary only in the degree of vegetative cover. They are usually very flat, slightly above mean sea level and protected from wave action. They are maintained by periodic flooding with salt water during high storm tides. Substrates sometimes consist of gravel but usually this is mixed with or replaced by finer grain sizes. These habitats are stable and harbor populations of benthic invertebrates. Common and characteristic plants in these habitats include: *Puccinellia phryganodes*, *Carex subspathacea*, *Carex ursina*, and in less frequently flooded areas, *Stellaria humifusa*, *Cochlearia officinalis* and *Dupontia fischeri*.

Slough and small lagoon edges

This category includes the borders and fringes of all brackish and estuarine areas but excludes the large open water lagoons such as Elson Lagoon. Sloughs may vary from small streams entering the ocean to lagoons of one kilometer or more in diameter with openings to salt water at least during storm conditions. Borders of sloughs and lagoons vary widely, from gravel shores, especially near the mouths of lagoons, to tundra banks, sometimes with a narrow mud margin, and to broad areas of mudflat and even saltmarsh. Thus this category and the previous one merge in many instances and bird use in these cases is similar.

Mainland shores

Beaches along the mainland may be exposed or partially protected by barrier islands. Beach types vary from gravel to fine sand and may be broad and flat or narrow backed by a tundra cliff. Narrow tundra backed beaches have lower densities of bird use than any of the other littoral habitats described. At Barrow we had only one transect in this habitat which was abandoned after two years for logistics reasons. Our observations of habitats of this kind at other sites in the Beaufort and northern Chukchi corroborate our conclusion that it is the least used of all littoral zone habitats by arctic shorebirds. Mainland beaches do support moderate densities of shorebirds in some areas however, especially if they are near sloughs, lagoons or gravel spits.

Tundra

The final general category considered in our studies consists of all non-littoral habitats, classed as tundra. This varies from well-drained uplands to very wet lowlands. We distinguish lowland coastal tundra from littoral habitats such as saltmarshes on the basis of saltwater influence. Littoral habitats are at least occasionally inundated by saltwater and always differ from tundra habitats in the absence of tundra vegetation or the presence of salt tolerant plants.

SEASONALITY OF HABITAT USE: AN OVERVIEW

The transect census data yield a phenology of habitat use. Figure 6 shows the general pattern of shorebird seasonality at Barrow, contrasting densities measured on tundra and littoral transects. Tundra data in this and subsequent sections are drawn from Myers and Pitelka (1980) and Connors et al. (1979). During the nesting period in June and July, activity centers on the tundra. When birds initially arrive in late May and early June, most shoreline areas are frozen and inaccessible. As snow melt progresses during this period, birds establish territories on newly exposed tundra. Eggs are incubated during June and early July with hatching in late June through mid-July. The main prey base for shorebirds during this interval consists of freshwater zooplankton and insect larvae and adults (Holmes and Pitelka, 1968). For several species (Red Phalarope, Pectoral Sandpiper) the nesting participation by one sex ends

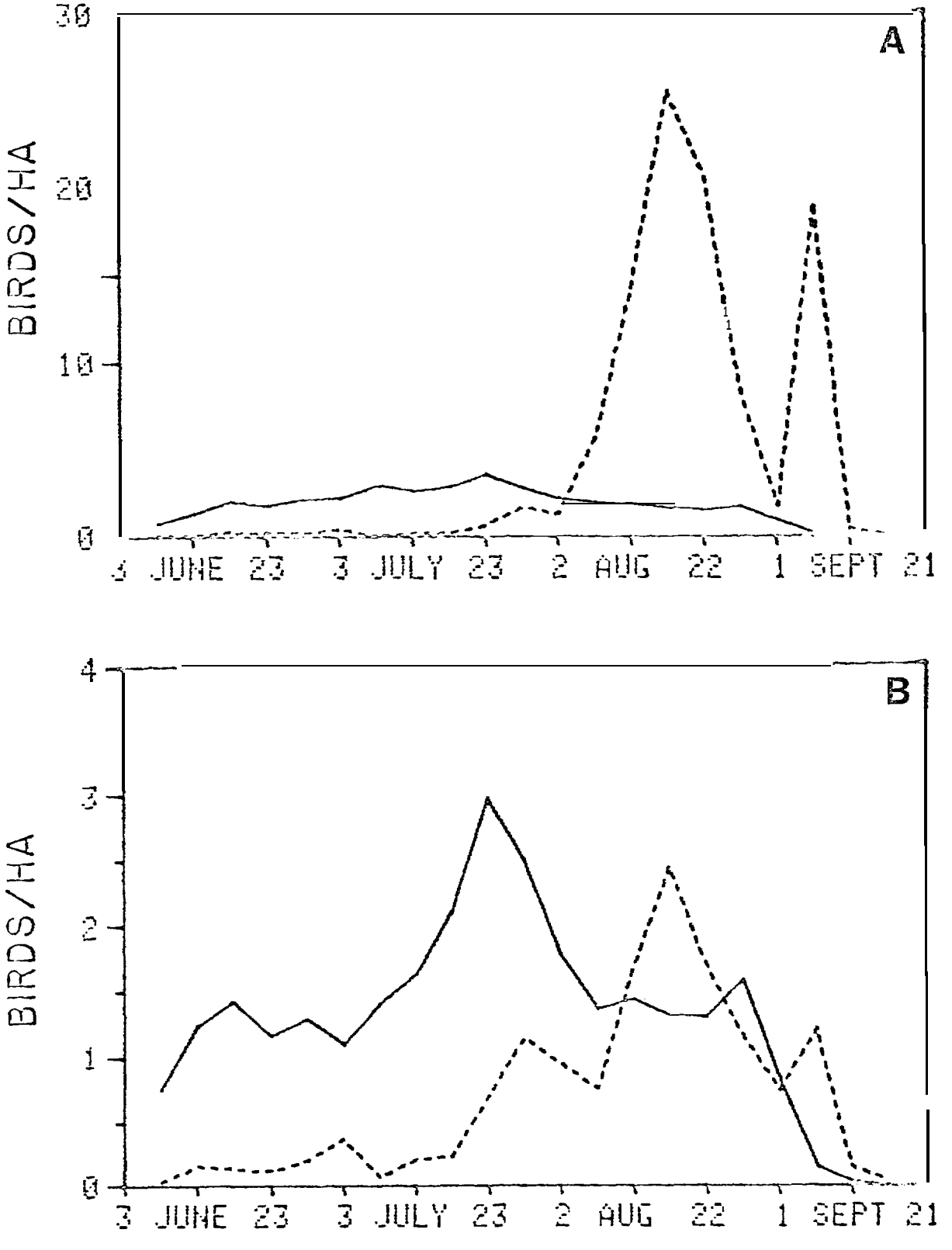


Figure 6. Seasonal habitat use, tundra (solid line) vs. littoral (dashed line) . (A) all shorebirds combined (B) all shorebirds except Red Phalaropes.

before young are fledged. These released adults, together with other non-breeding or failed-breeding adults, occur increasingly on mudflats, lagoon edges and ocean shorelines as meltoff in these areas proceeds. As juveniles fledge in late July and August, large numbers of remaining adults and young occur along shorelines, shifting to a diet of oligochaetes and insect larvae on mudflats, and a wide variety of marine zooplankton along the shore. By mid-August the littoral zone has become a major foraging area for many species. Birds of different species and different age or sex classes depart Barrow to begin their southward migration at different times throughout the summer but by mid-September few birds remain.

The marked shift in habitat use from tundra to littoral use as the season progresses, displayed in Figure 6, is a composite of many individual species patterns. Species differ in the timing of population movements as well as the relative magnitude of use of different habitats. As Figure 6B indicates, the shift to littoral habitats in late summer is most pronounced for Red Phalaropes but is also a feature of the habitat use patterns of most other species. In the Appendix we discuss the seasonal habitat use patterns and the overall seasonality of littoral zone use for each of the common species individually.

ANNUAL VARIATION IN SHOREBIRD DENSITIES

Arctic ecosystems are commonly characterized as subject to extremely high variation in environmental and biological components but the data to examine annual variation are scarce. In this study we have maintained a schedule of frequent and regular censuses on fixed littoral zone transects at Barrow for at least the post–breeding season in four consecutive years, 1975-1978. Shorebird densities recorded by the same methodology on similar tundra transects are available from Myers and Pitelka (1980) for five years (1975-1979) at Barrow, and three years (1977-1979) inland at Atkasook (100 km south of Barrow). These data, together with daily meteorological records from Barrow, provide a unique opportunity to examine patterns of annual variation in numbers of shorebirds using the littoral zone at one site on the arctic coast. This combined data set consists of approximately three thousand separate transect censuses over the five year period.

To concentrate on annual variation we will consider littoral zone densities only during the late summer period of heavy use, censused consistently in all four years of the study. Our approach involves the use of Pearson correlation analysis to look for relationships among groups of species in different periods at different locations and with environmental variables. We wish to consider the question of whether the late summer shoreline movement among shorebirds represents just the local birds shifting habitats or is instead a widespread phenomenon drawing birds from farther away.

Comparisons among study sites

Table 5 gives mean densities and coefficients of variation of breeding pairs on tundra and of post–breeding migrants in the littoral zone for eight common shorebirds at Barrow. Both data sets are for the same four years 1975-1978. The amount of annual variability by species is weakly correlated between these two habitat periods. Species which vary widely in breeding densities tend to vary widely in post–breeding shoreline densities also. Furthermore the magnitude of variation is comparable in both habitat perids. Three species showed wider variation in breeding densities and five species showed wider variation in post–breeding densities. This does not necessarily imply a close relationship between shoreline densities and local breeding densities but may rather indicate consistent species differences in population dynamics over wider geographic areas.

Another indication of species differences in population dynamics is given by our correlation analyses of the relative abundances of different species between years at each of our sites. We find that breeding densities are correlated between years at Atkasook and at Barrow and post-breeding littoral densities are correlated between years at Barrow. The median dates of post-breeding movements in the littoral zone are also correlated between years. These correlations are not surprising however since they indicate nothing more than that some species are consistently more common than other species.

The degree of annual variation within a single species is shown in Figures 7 and 8A for Semipalmated Sandpiper densities on early summer tundra transects and on late summer littoral transects. In three out of four years the peak density recorded on the tundra occurred in early July as an early movement of post-breeding adults. On littoral transects the peak densities occurred in each year near the end of July as large numbers of premigratory juveniles foraged on mudflats, in saltmarshes and on the edges of lagoons.

To investigate the causes of this annual variation we looked for patterns in correlations between density measurements at different sites. Annual variation in post-breeding densities in the littoral zone was not correlated with variation in breeding densities at either the local Barrow tundra site or at Atkasook. This correlation might not be expected even if the post–breeding movement consisted primarily of local birds because breeding densities do not tell us all we need to know about productivity in each year; since the post-breeding littoral zone movement is composed primarily of juveniles of most species, annual variation in productivity might override annual variation in breeding density among local birds. However, coupled with our observations of shoreline movements of species which are particularly common at Barrow or at other sites along the coast, we conclude that annual variation in post-breeding

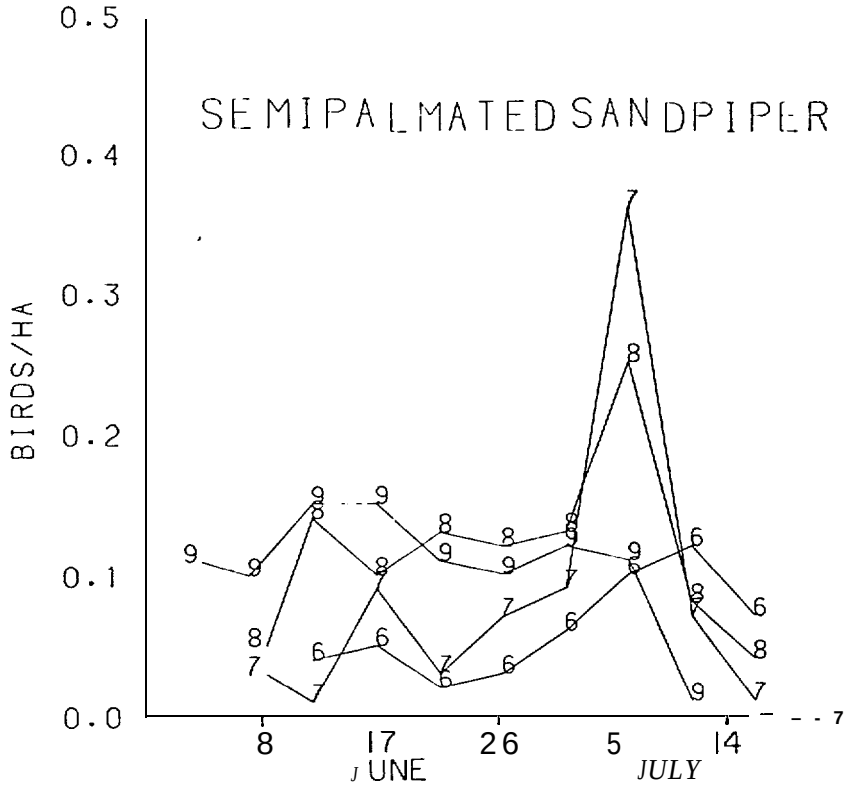


Figure 7. Annual variation in Semipalmated *Sandpiper breeding season densities on tundra transects, 1976-1979.*

migrant densities at Barrow reflects more than just local breeding density fluctuations. Birds foraging in the littoral zone at one site may be drawn from breeding areas distant from that site.

Correlations with temperature variation

We looked for relationships between shorebird densities and temperature in the following manner: 'we calculated the cumulative temperature deviation - the cumulative amount the temperature differs above or below the mean temperature for each date – for several periods of ornithological significance. This calculation separates years of warmer than average temperature from years of colder than average temperature for each period. Testing a large number of species against several temperature periods is likely to produce at least a few apparently significant correlations. In evaluating this matrix of correlations we looked for patterns of correlations exhibited by many species with temperature during a particular calendar period. Our objective criteria for this test required first a significant sign test over all species in one temperature period (almost all species with correlation coefficients of the same sign) and agreement in similar but overlapping calendar periods, that is, an insensitivity to the exact cutoff date chosen for

Table 5. Mean densities of common Barrow shorebirds.

	Tundra Breeding Density[1]	C.V.*	Littoral Post-breeding Density[3]	C.V.
Golden Plover	.11	36	.02	74
Ruddy Turnstone	.05	42	.20	41
Semipalmated Sandpiper	.33	38	1.01	88
Pectoral Sandpiper	.33	106	.19	93
Baird's Sandpiper	.09	31	.13	29
Dunlin	.38	17	.89	53
Long-billed Dowitcher	.02	82	.27	97
Red Phalarope	.21	61	5.48	77

[1] Four-year mean of breeding adults (Myers and Pitelka, 1980).

[2] C.V. = coefficient of variation over four years.

[3] Four-year mean of mean densities on littoral transects during period 16 July – 29 August.

Table 6. Shorebird densities and temperature trends at Barrow: patterns across species.

Higher Temperatures During	Tundra Breeding Densities	Littoral Post-Breeding Densities	Post-Breeding Movement Median Date
Pre-breeding	--	- .	- -
Breeding	- -	- -	- -
Post-breeding	- -	Higher	Earlier

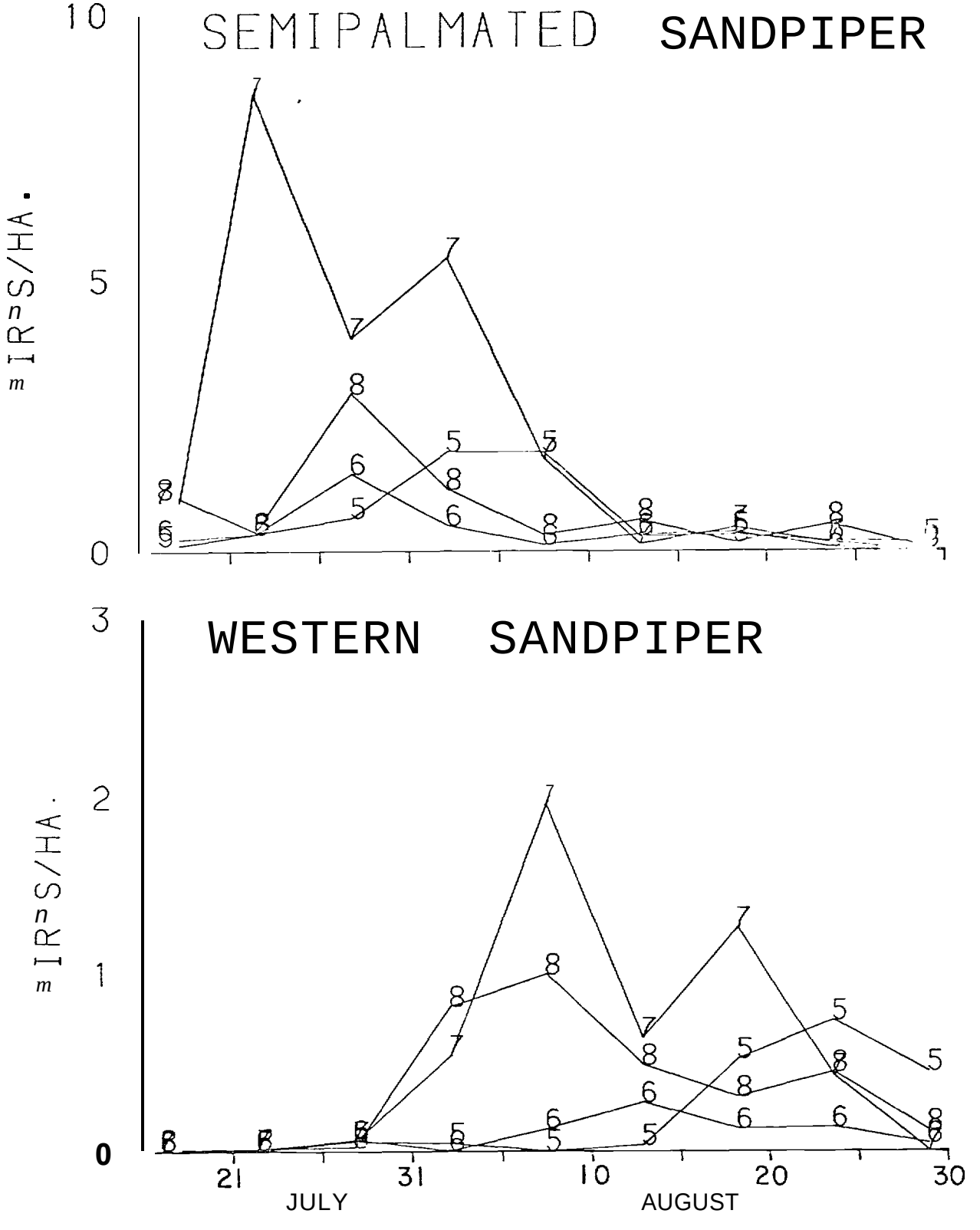


Figure 8. Annual variation in sandpiper post-breeding densities on littoral transects, 1975-1978.

our periods; and second, some individual species correlations which are significant at $p<.05$, with agreement in similar periods. Table 6 shows the only observed patterns of correlations between densities and temperature. We found no general correlation between early summer temperatures, which may determine the pattern of snow melt, and shorebird densities during any period. However, the magnitude and timing of post-breeding shoreline movements are correlated with post-breeding temperatures; in years of warmer than average late summer temperatures littoral zone densities are higher and migration peaks are earlier. It is surprising that post-breeding migrant densities are influenced more by late summer temperatures than by local breeding season temperatures, and this suggests that birds respond to conditions within the littoral zone during late summer. The numbers of birds available to use the littoral zone must already be determined before this period (by breeding densities and productivity), but the numbers which actually move to the littoral zone, the geographic distribution of birds along the coast within the littoral zone, or the turnover rates of individuals migrating within the littoral zone might be involved in this effect. The significance of changes in turnover rate on population estimates was discussed earlier.

Species comparisons

Comparisons of annual variation among species also suggest that conditions in the late summer littoral zone affect the densities of migrant birds. Figure 8 shows annual variation in littoral post-breeding densities for two ecologically similar species, Semipalmated and Western Sandpipers. The correspondence of these two sets of data is remarkable in magnitude, shape and timing in spite of huge annual fluctuations. It also suggests that these fluctuations are not random; there must be some environmental variation affecting both species similarly. We can compare variation in the two species graphically by expressing each year's cumulative density as a percent of the four year total, Figure 9. Similarly, Figure 10 displays a high correspondence of variation in densities of Pectoral Sandpiper and Dunlin with Semipalmated Sandpiper. These three species, with Western Sandpiper, form a group of species whose numbers fluctuate similarly from year to year. Red Phalaropes and Ruddy Turnstones comprise another group with numbers displaying a different pattern of annual variation. We conclude that these groups of species respond similarly to annual variation in some undetermined environmental factors.

We wish to test whether these species which fluctuate similarly year to year are associated through some aspect of their ecology during the breeding or post-breeding seasons, since this might provide a clue to the environmental mechanism which relates to these fluctuations. We classify all common Barrow shorebirds by breeding habitat on the basis

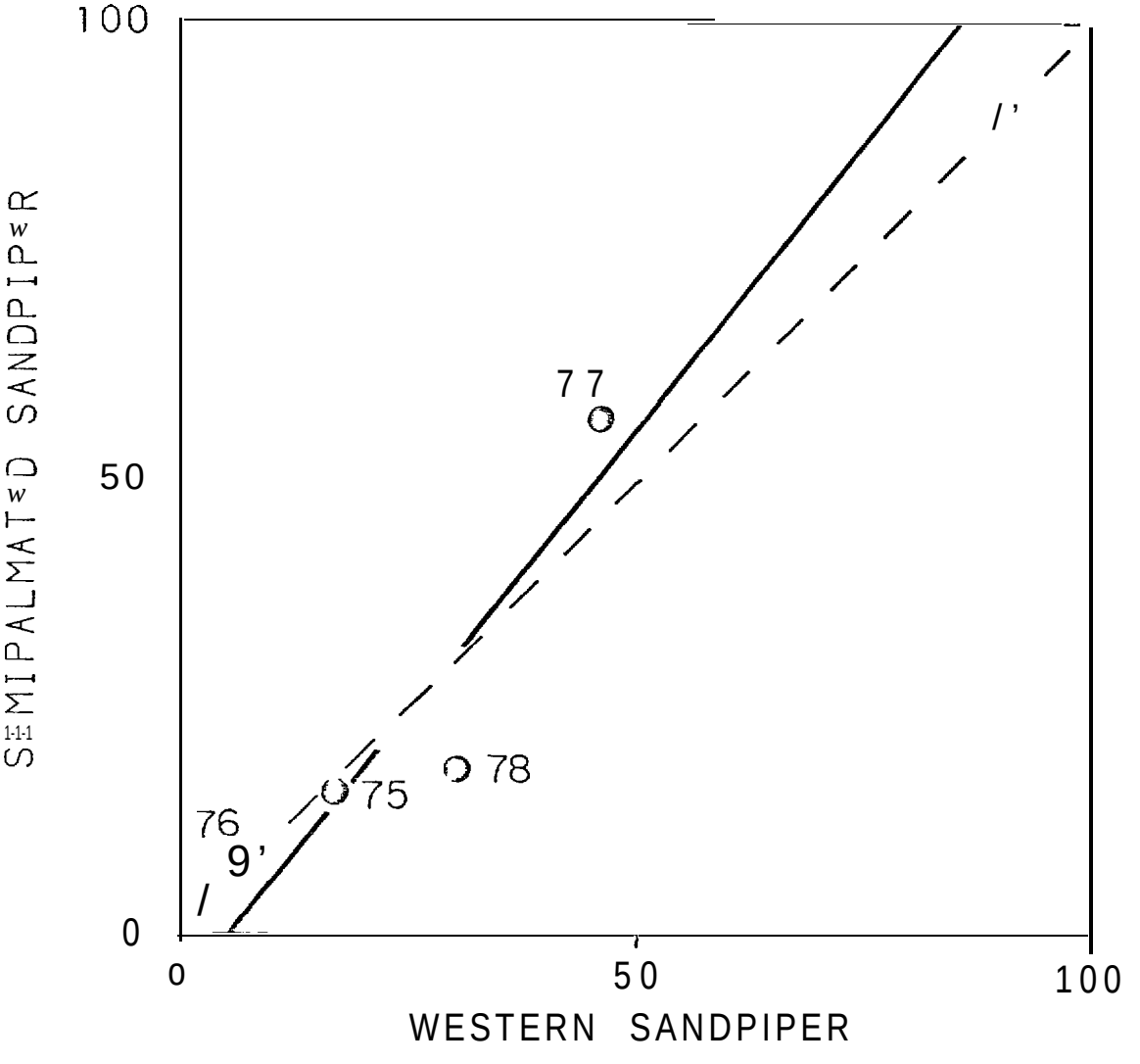


Figure 9. Per cent of 4-year cumulative density during post–breeding period on littoral zone transects, 1975–1978.

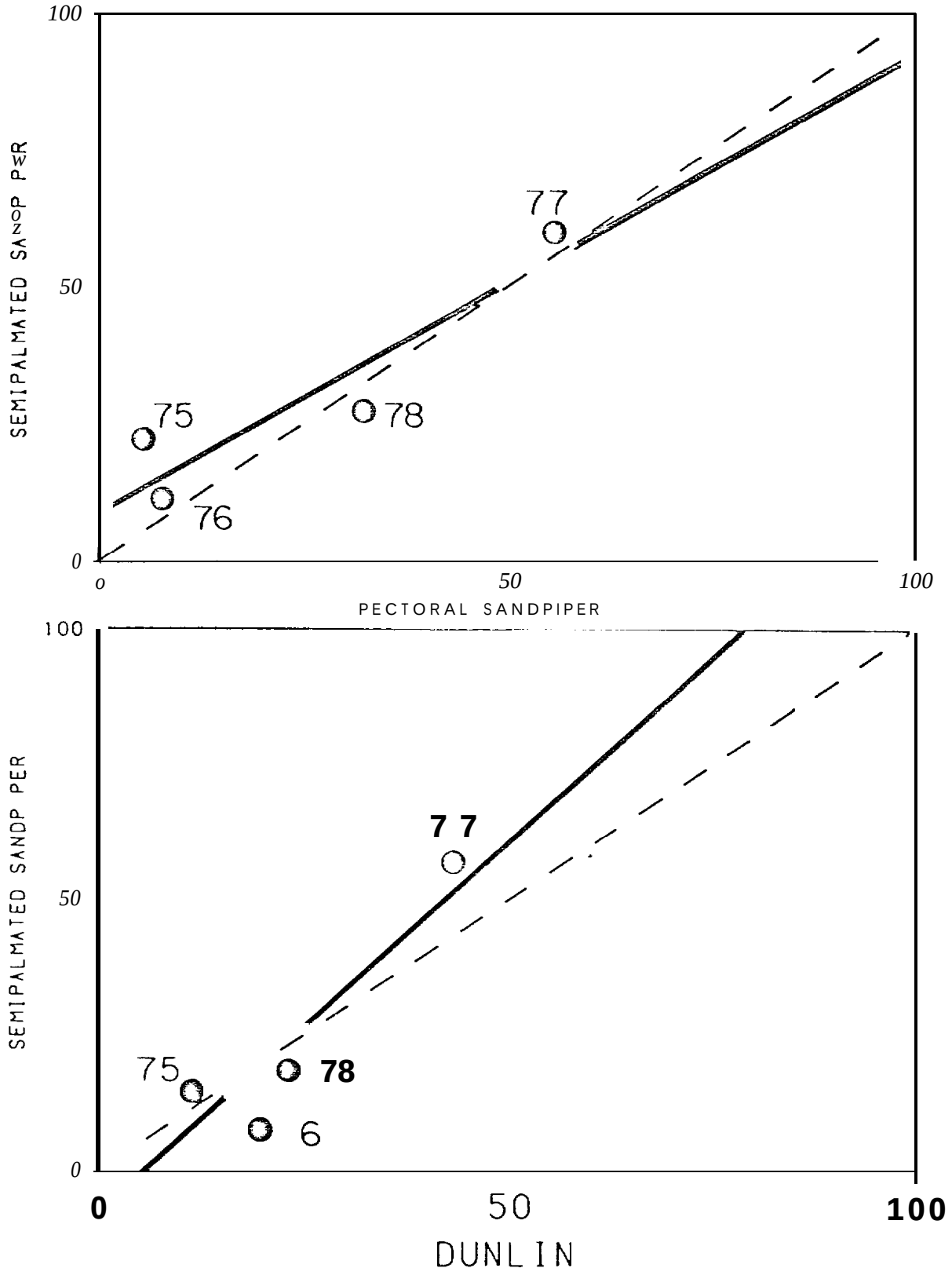


Figure 10. Per cent of 4-year cumulative density during post–breeding period on littoral transects, 1975-1978.

of habitat studies by Myers and Pitelka (1980) and again by post-breeding habitat on the basis of our results discussed below (Table 7). If we consider all pairs of species which show correlations in annual variation in post-breeding numbers (Table 8), we find that species which fluctuate similarly in the, littoral zone do not in general share the same breeding habitats (p=. 14). They do however occur together in the same post-breeding habitats (p<.005). This implies a connection of some sort through conditions in the littoral zone during the post-breeding period. We have also shown a relationship between post-breeding density and temperature during the post–breeding period which bolsters this conclusion.

What sort of affect can this be? Since it occurs after the birds have left the tundra, it is unlikely to be mediated through changes in breeding productivity, but post–fledging survival once birds reach the littoral zone may be involved. Differences in weather stress or in foraging profitability, through variable prey conditions, storm water levels or other habitat changes during or before this period may be responsible. These might affect the survival of individuals, the geographic movements of birds over local or large areas, or the length of time individuals remain in one area during migration. Environmental perturbations in these littoral habitats, such as might accompany oil development, will be expected to produce density fluctuations in species groups of migrant shorebirds, not just individual species.

Table 7. Seasonal habitat groups of common Barrow shorebirds.

Breeding Habitat Groups	
Lowland Tundra	Upland Tundra
Pectoral Sandpiper	Golden Plover
Red Phalarope	Ruddy Turnstone
Northern Phalarope	Semipalmated Sandpiper
	Western Sandpiper
	Baird's Sandpiper
	Dunlin
Post–Breeding Habitat Groups	
Gravel Beaches	Littoral Flats, Lagoon Edges
Ruddy Turnstone	Golden Plover
Sanderling	Semipalmated Sandpiper
Red Phalarope	Western Sandpiper
	Baird's Sandpiper
	Pectoral Sandpiper
	Dunlin
	Long–Billed Dowitcher
	Northern Phalarope

Table 8. Species - pair correlations of annual variation in post-breeding densities.

	Breeding	Post-Breeding
Within Habitat Groups	6	18
Between Habitat Groups	12	2
X^2 - Test	$P = .14$	$P < .005$

HABITAT STUDIES

We approached the important questions of shorebird habitat use on four different habitat levels. First, the broad division of tundra vs. littoral habitats determines some limits to exposure of each species to developments concentrated offshore or onshore. Second , we focused on activities in the littoral zone and grouped littoral transects into three general habitat categories. We evaluated the relative use of these three habitat groups for each species, since development effects within different littoral habitats will vary by species. Third, using 6 variable descriptions of each 50 *meter by 50 meter plot, we examined the responses of species to these more detailed descriptions of littoral zone habitats and were able to relate in the same habitat space transects at geographically different sites. Finally, we examined the foraging habitat preferences on a microhabitat scale for several species.*

Tundra vs. littoral habitat

Species vary widely in their relative use of these two major habitat classes during breeding aand post-breeding periods. Red Phalaropes *(Figure* 11A,B) *nest on the tundra but move to shorelines as breeding activities finish in successive waves of adult females, adult males, and finally juveniles. Peak densities in littoral habitats are many times higher than on the tundra. Other species such as American Golden Plover, (Figure 12A) are almost restricted to tundra habitats throughout the season. This difference in habitat selection should have a marked effect on the relative susceptibility of these two species to potential effects of offshore oil development.* Phalaropes *may be extremely sensitive to oil spills which would have almost no effect on Golden Plover populations. Other species show intermediate patterns.* Dunlins *(Figure* 12B) *shift from tundra to littoral habitats in late summer, but not to the same extent as* Phalaropes. *Adults remain at Barrow throughout August and early September and both juveniles and adults occur on tundra as well as littoral habitats.* Semipalmated *Sandpipers (Figure 35) show a fourth pattern utilizing some littoral habitats (slough edges and littoral flats) during the breeding season where these occur in the vicinity of tundra nesting sites. Use of littoral habitats increases with late summer but this species remains common on tundra as well.*

We have classified the common Barrow shorebirds into four categories based on seasonal differences in the relative use of these two habitat classes (Table 9). These are general patterns which tend to gloss over distinctions between species within groups but they indicate some of the major differences in seasonal habitat use patterns which result in differences in species susceptibility to oil development. As another step in this process we have calculated the relative littoral zone use, taking into account the differences in areal *extent of these habitats in the Barrow vicinity for each of the species (Figure 13;*

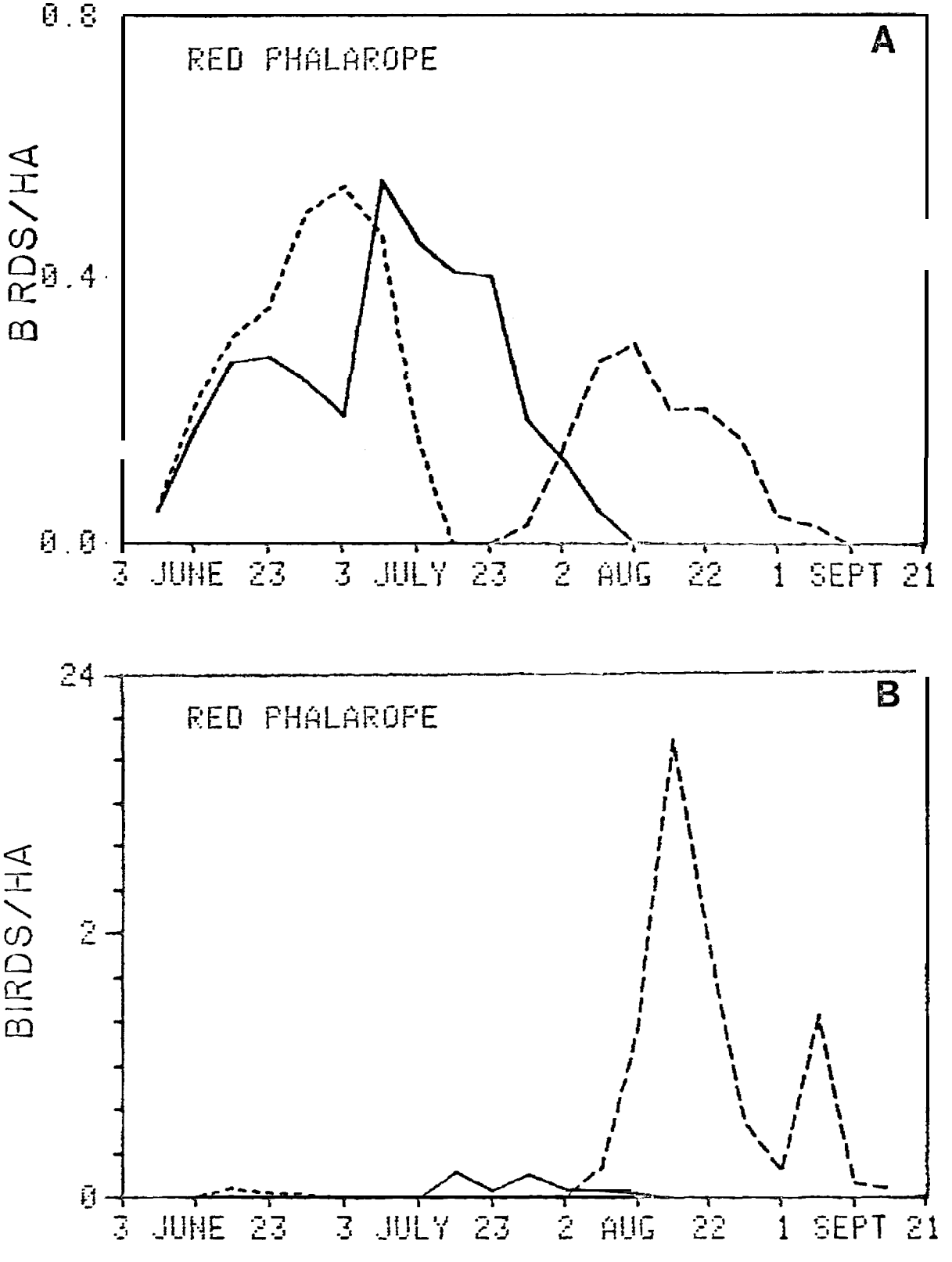


Figure 11. Red Phalarope densities on (A) tundra transects, (B) littoral transects. Short dash line, adult females; solid line, adult males; long dash line, juveniles. Note difference in scales.

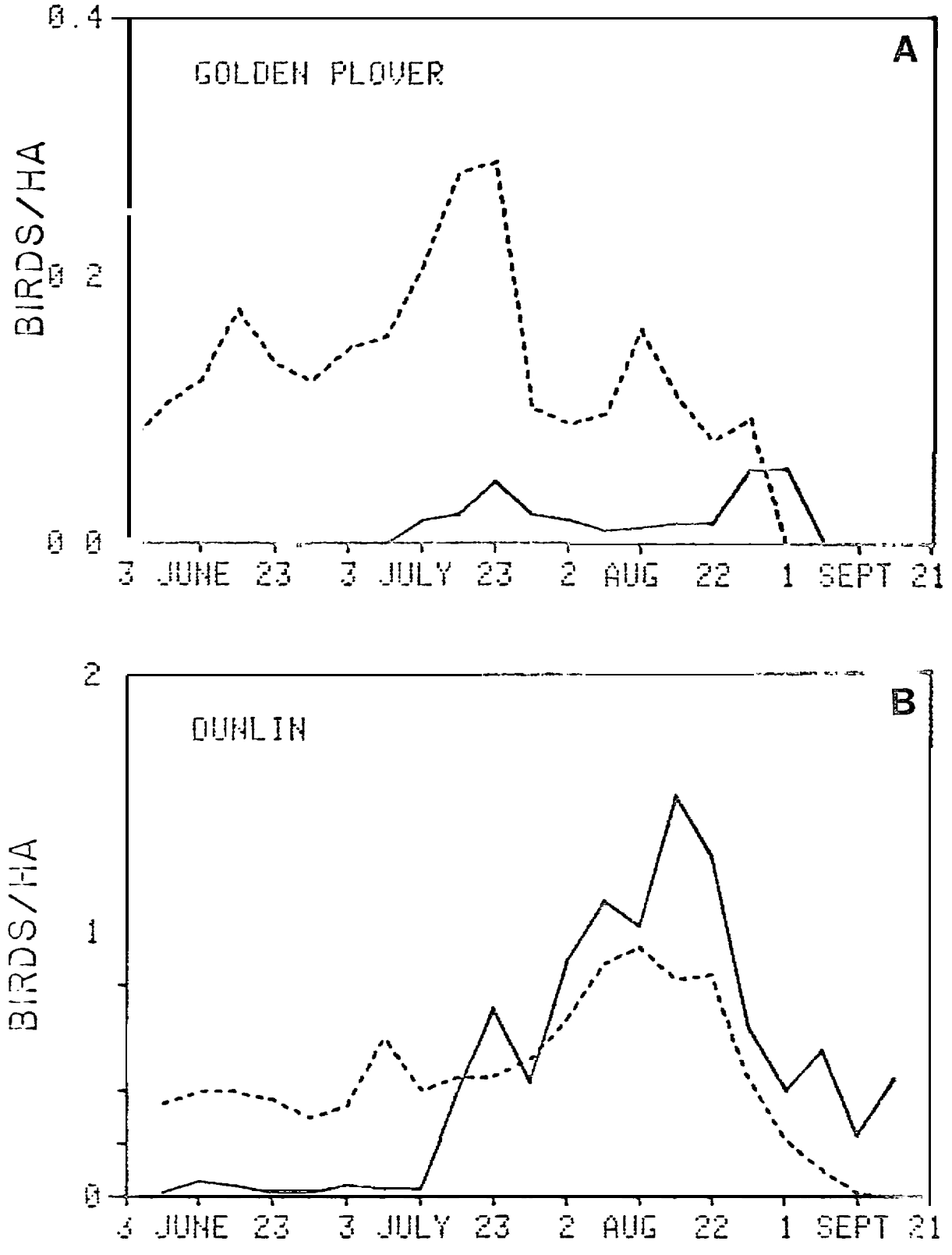


Figure 12. Densities of (A) American Golden Plover and (B) Dunlin *on tundra transects (dashed line) and littoral transects (solid line).*

Table 9. Seasonal habitat use patterns of common Barrow shorebirds. (T = Tundra; L = Littoral).

Category	Breeding	Post-breeding Adult	Post-fledging Juvenile	
I	T	T	T	Golden Plover, Pectoral Sandpiper
II	T	T+L	T+L	Dunlin, Long-billed Dowitcher
III	T+L	T+L	T+L	Western, Semipalmated, Baird's Sandpipers
IV	T	T+L	L	Red Phalarope, Ruddy Turnstone, Sanderling

Table 10. Principal component correlations for the habitat variables. Correlation coefficients and per cent of total variance associated with first and second principal components.

VARIABLE	PC I	PC II
DSHORE	.91	-.20
NORFLZ	.79	-.07
MAXFLZ	.75	-.49
WATCOV	-.76	.32
SUBSTR	-.66	-.70
VEGCOV	.67	.59
TOTAL VARIANCE	58.1	78.8

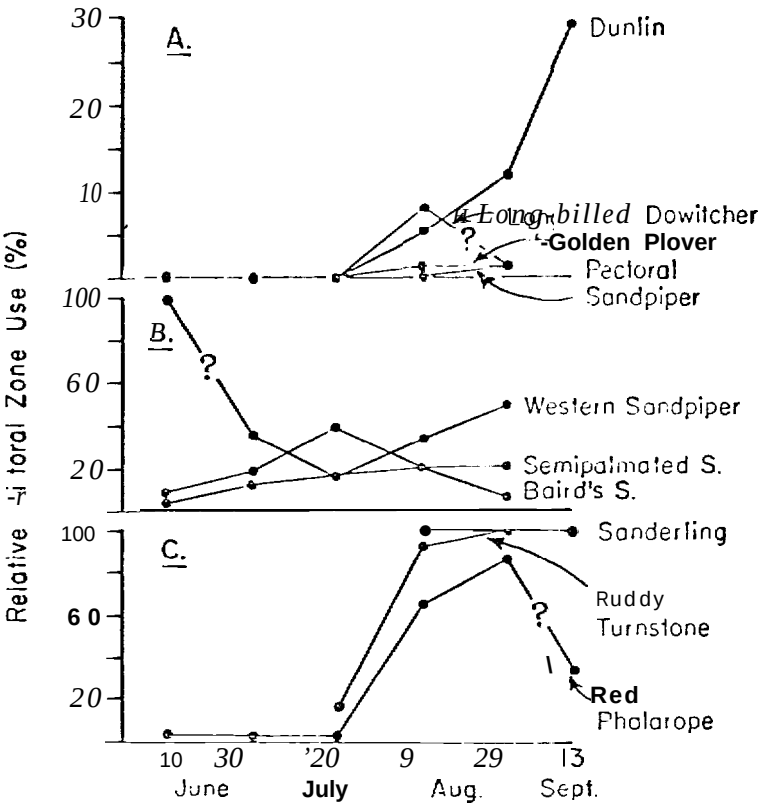


Figure 13. *Relative use of littoral habitats by shorebird species in the Barrow area. (A) includes species from categories I and II, Table 9; (B) corresponds to category III, (C) to category IV.*

Connors et al., 1979). These patterns in relative littoral zone use agree with the four categories of habitat use patterns listed in Table 9.

Littoral habitat groups

The principal components analysis based on six habitat variables assigned to each 50 meter by 50 meter square plot on each transect produced results shown in Table 10. The correlations indicate that the first principal component (PC I) should be interpreted as separating gravel beaches and lagoon and slough edges from mudflats *and* saltmarshes. *PC II further separates gravel beaches from lagoon and slough edges. This produces groupings in a newly formed habitat space which correspond to the three categories - gravel beach, slough edge and littoral flat - into which we have subjectively grouped our transects (Figure 14). Although overall agreement between the two grouping systems is high, a few transects appear misplaced. In particular, the transect BMW, denoted by an asterisk in Figure 14, is classed as a lagoon edge transect in our analyses because of its location on the shore of Middle Salt Lagoon, an almost closed lagoon*

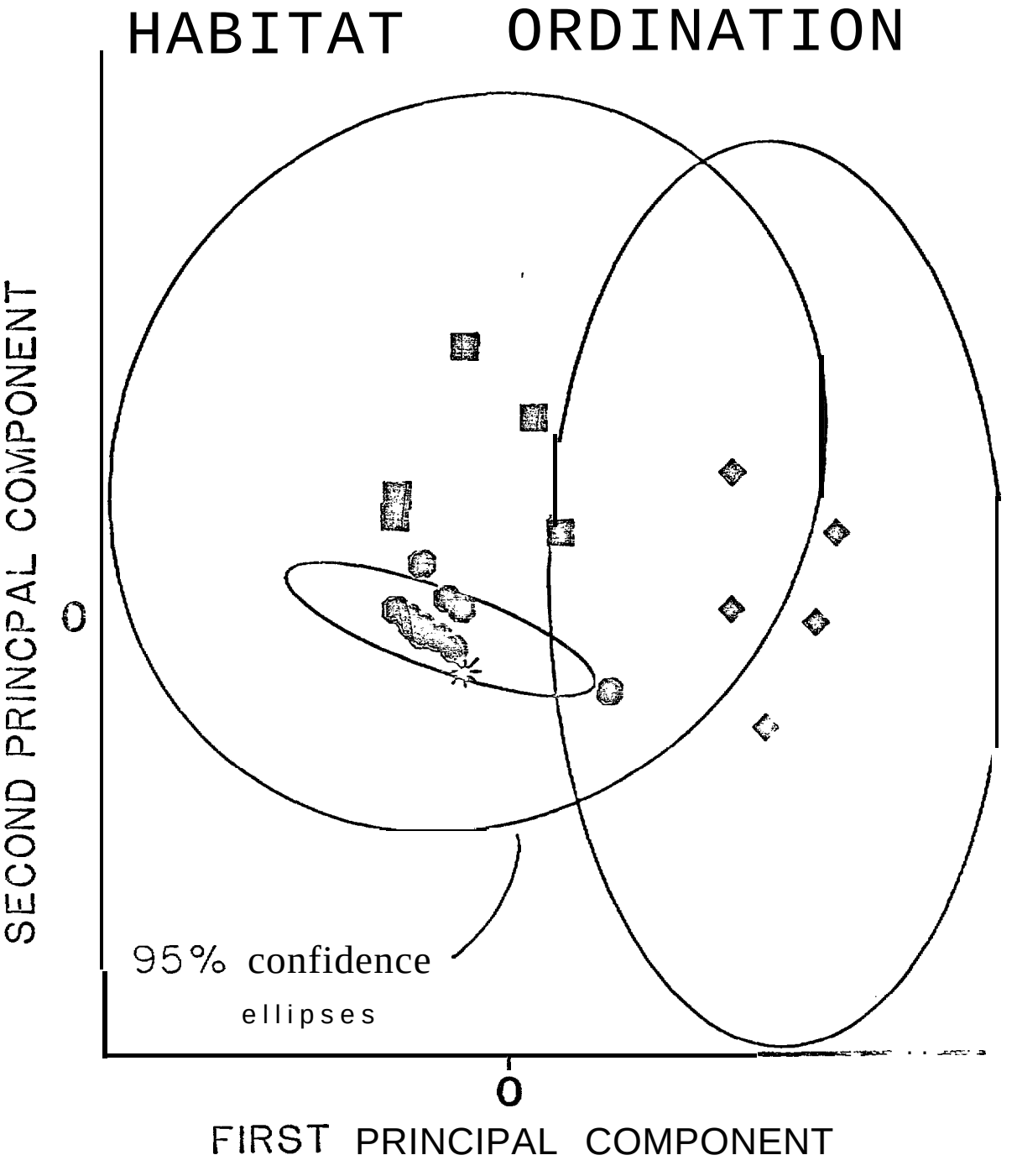


Figure 14. Locations of Barrow transects in principal component littoral habitat space. Gravel beaches (octagons), littoral flats (diamonds), and slough edges (squares). Asterisk denotes transect BMW. See text.

of 1.3 kilometer diameter at Barrow (Figure 2). In spite of this topographic feature, however, the habitat description variables do not distinguish it from a gravel beach because it is located near the mouth of the lagoon close to the inner edge of the wide gravel beach ridge. In fact, as will be noted below, several species responded to this transect and to the other middle salt lagoon transect (MSE) in a manner indicating intermediacy between gravel beaches and lagoon edges. Thus these transects show characteristics of both lagoon and marine beaches in physical description as well as in bird use.

The principal advantages of this habitat classification procedure are that it allows us to quantify aspects of habitat descriptions which otherwise remain too subjective for further analysis and that the procedure can be easily applied by field workers at other arctic sites. Assigning variables does not require extensive training. Multivariate techniques can then place newly described transects in habitat space with known transects for which bird density data are available. This permits comparison of areas studied by different researchers and may allow prediction of expected bird densities based only on habitat descriptions and geographic locality.

The essential question concerning these analyses is: do birds respond to the differences in habitats which we have described? They do, as is shown by the next two sets of analyses. Using as our data base the presence or absence of each of the thirty-one most common species on our transects (Table 11), we used a principal coordinate analysis (Gower, 1966) to separate transects in each of the four years on the basis of which species occurred on them (Figure 15). In interpreting these figures, changes in the position of transects between years is irrelevant. Concentrating on the relative positions of transects within each year, we find that in each year gravel beach transects cluster quite separately from other transects. The distinction between littoral flat and slough edge transects is less clear, however, suggesting that many of the same species utilize both groups of habitats. As mentioned above, the lagoon transect BMW (1976, 1977, 1978) is classified on the basis of species occurrence as somewhat intermediate between gravel marine shores and other lagoon edges. The details of arrangements within groups also suggest other distinctions made by the birds. Gravel beach transects along the mainland shore always cluster somewhat differently than the gravel shores along Barrow Spit (BCS in 1975; BCS, BCN, BBD in 1976 and 1977; BCS, BCN, BBD, BBV in 1978). These analyses show clearly that species occurrence varies among habitats and that groups of species apparently respond to habitat differences which are correlated with the variables we have measured. It also suggests that on the basis of species occurrence alone, the similarities between littoral flats and lagoon and slough edges are greater than between these habitat classes and gravel beaches.

Table 11. Common bird species on littoral transects during four post-breeding seasons at Barrow, Alaska.

COMMON NAME	SCIENTIFIC NAME	SPECIES CODE
Yellow-billed Loon	Gavia adamsii	YBLO
Arctic Loon	Gavia arctica	ARLO
Red-throated Loon	Gavia stellata	RTLO
Black Brant	Branta bernicla	BLBR
Pintail	Anas acuta	PINT
Oldsquaw	Clangula hyemalis	OLDS
Steller's Eider	Polysticta stelleri	STEI
King Eider	Somateria spectabilis	KIEI
Semipalmated Plover	Charadrius semipalmatus	SEPL
Golden Plover	Pluvialis dominica	GOPL
Ruddy Turnstone	Arenaria interpres	RUTU
Pectoral Sandpiper	Calidris melanotos	PESA
Baird's Sandpiper	Calidris bairdii	BASA
Dunlin	Calidris alpina	DUNL
Semipalmated Sandpiper	Calidris pusilla	SESA
Western Sandpiper	Calidris mauri	WESA
Sanderling	Calidris alba	SAND
Long-billed Dowitcher	Limnodromus scolopaceus	LBDO
Red Phalarope	Phalaropus fulicarius	REPH
Northern Phalarope	Lobipes lobatus	NOPH
Pomarine Jaeger	Stercorarius pomarinus	POJA
Parasitic Jaeger	Stercorarius parasiticus	PAJA
Long-tailed Jaeger	Stercorarius longicaudus	LTJA
Glaucous Gull	Larus hyperboreus	GLGU
Black-legged Kittiwake	Rissa tridactyla	BLKI
Sabine's Gull	Xema sabini	SAGU
Arctic Tern	Sterna paradisaea	ARTE
Black Guillemot	Cepphus grylle	BLGU
Snowy Owl	Nyctea scandiaca	SNOW
Lapland Longspur	Calcarius lapponicus	LALO
Snow Bunting	Plectrophenax nivalis	SNBU

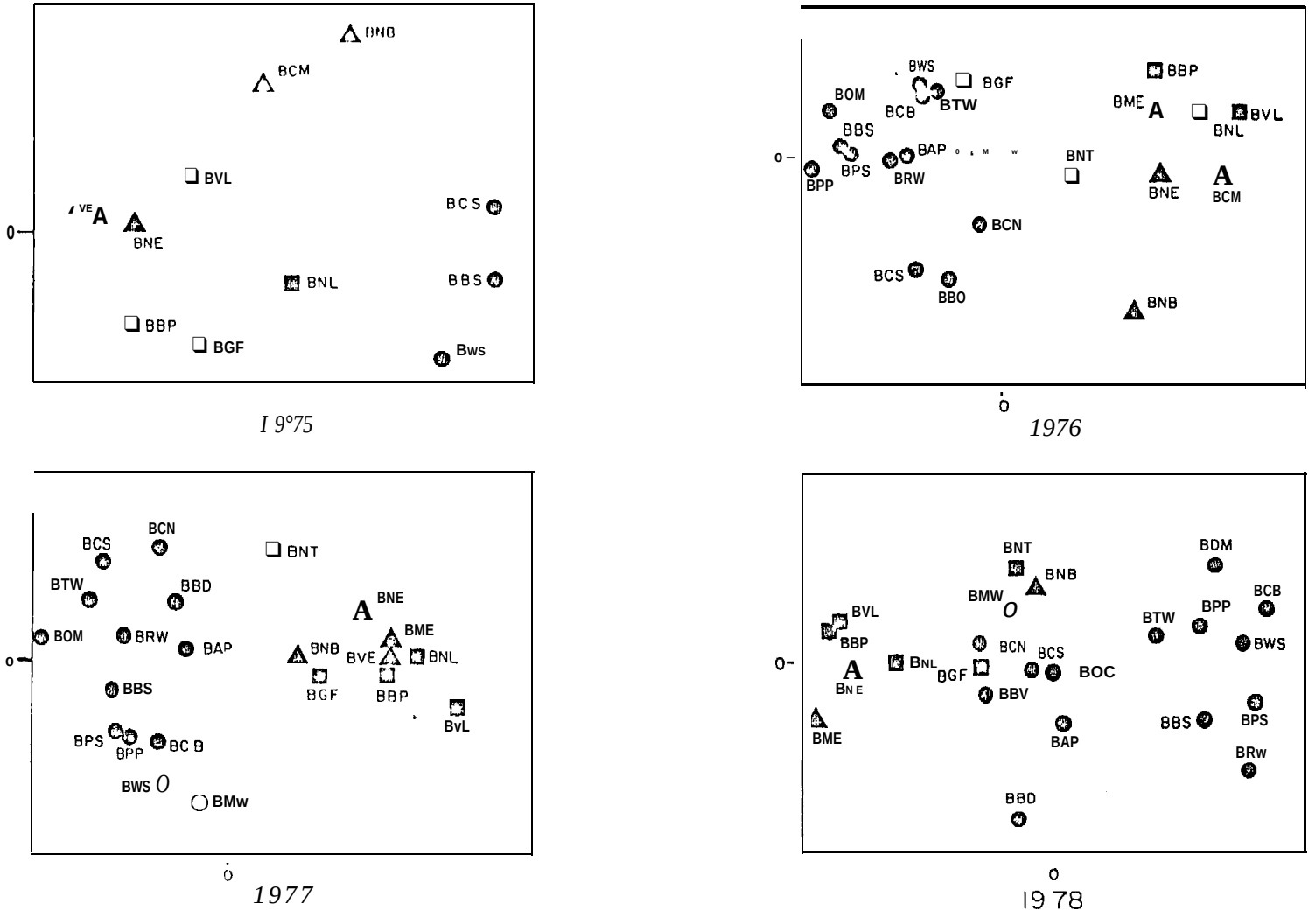


Figure 15. *Ordination of transects according to birds species occurrence. Gravel beach transects (closed circles), littoral flats (squares), slough edges (triangles) , beach-like lagoon transect (open circle). See text.*

We can also ordinate all of the species according to which transects they occur on during each year (Figure 16). These plots are more obscure but groups of species showing similar habitat use can be distinguished and these tend to be consistent from year to year. Among shorebirds, Red Phalarope and Ruddy Turnstone occur together in each of four years and these are joined by Sanderling in 1975 and 1976. The two passerines, Lapland Longspur and Snow Bunting, show very close correspondence in the three years they were censused. A cluster of sandpipers (Semipalmated, Western, Pectoral, Baird's and Dunlin) usually occur close together. Among other groups, the jaegers show a similar habitat distribution in most years, as do the loons.

Species details of habitat use

Considering the habitat space defined by our principal component analysis (Figure 14) we can assign values to cells of that space representing the relative density of use by each species for habitat represented by that cell in habitat space. We display the results for a few species in Figure 17. This gives a detailed look at the differences in distribution of use within habitat space for each species. The relative heights of peaks indicate the relative use of different areas of habitat space. Zero height can indicate total absence of the species from a cell in habitat space, or lack of a transect sampling that cell. Regions characterized by gravel beaches (G), littoral flats (F), or slough edges (E) are indicated. Semipalmated and Western Sandpipers, two ecologically similar and closely related species, display similar general patterns differing in the relative height of just a few peaks. Both species occur in very low densities on gravel beaches and much higher densities on littoral flats and slough edges. Red Phalaropes show a markedly different pattern, occurring in high densities on gravel beach transects. Dunlins show an intermediate pattern.

The next series of plots demonstrates annual variation in patterns for three species (Figures 18, 19, 20). In this case the densities are expressed as deviations from the mean density; areas of lower than average use occur as depressions in the plain of habitat space. The many details of these plots are not critical to our discussion but a few points are important. In general, we can say that there is variation from year to year within a usually consistent species pattern. In all four years Red Phalaropes (Figure 18) show a distribution of habitat use markedly different from the other two species displayed. However, variation from year to year within a species can be large. For both Semipalmated Sandpiper and Dunlin (Figures 19 and 20), 1977 appeared to be an unusual year in terms of habitat use. Both species showed patterns in that year which are distinct from the other 3 years. However, the patterns for these two species in 1977 are remarkably similar. Dunlins in 1977 occurred in habitats more similar to those used by Semipalmated Sandpipers in 1977 than to those used by Dunlins in other years. This suggests

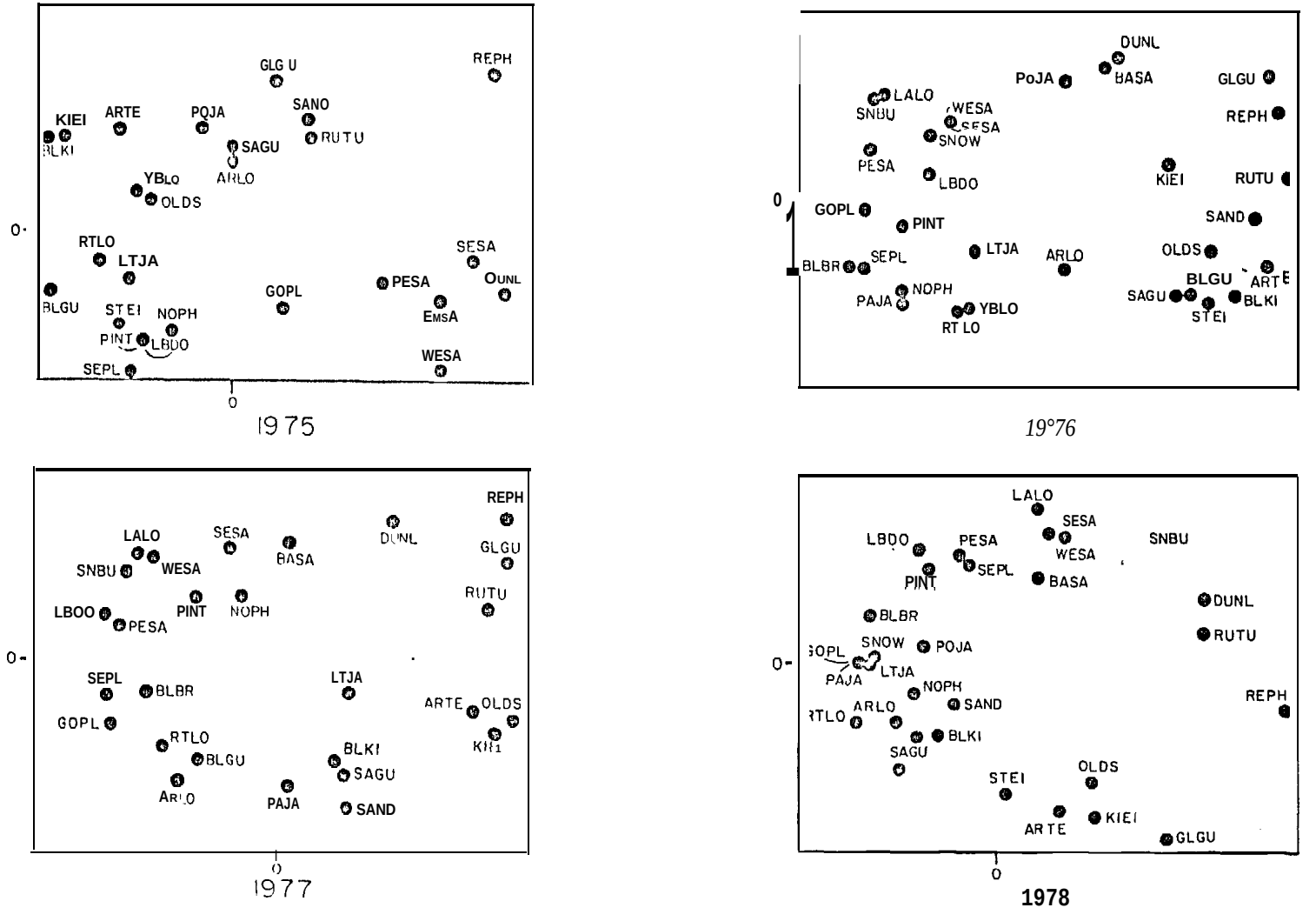


Figure 16. Ordination of species (Table 11) according to transect occurrence. See text.

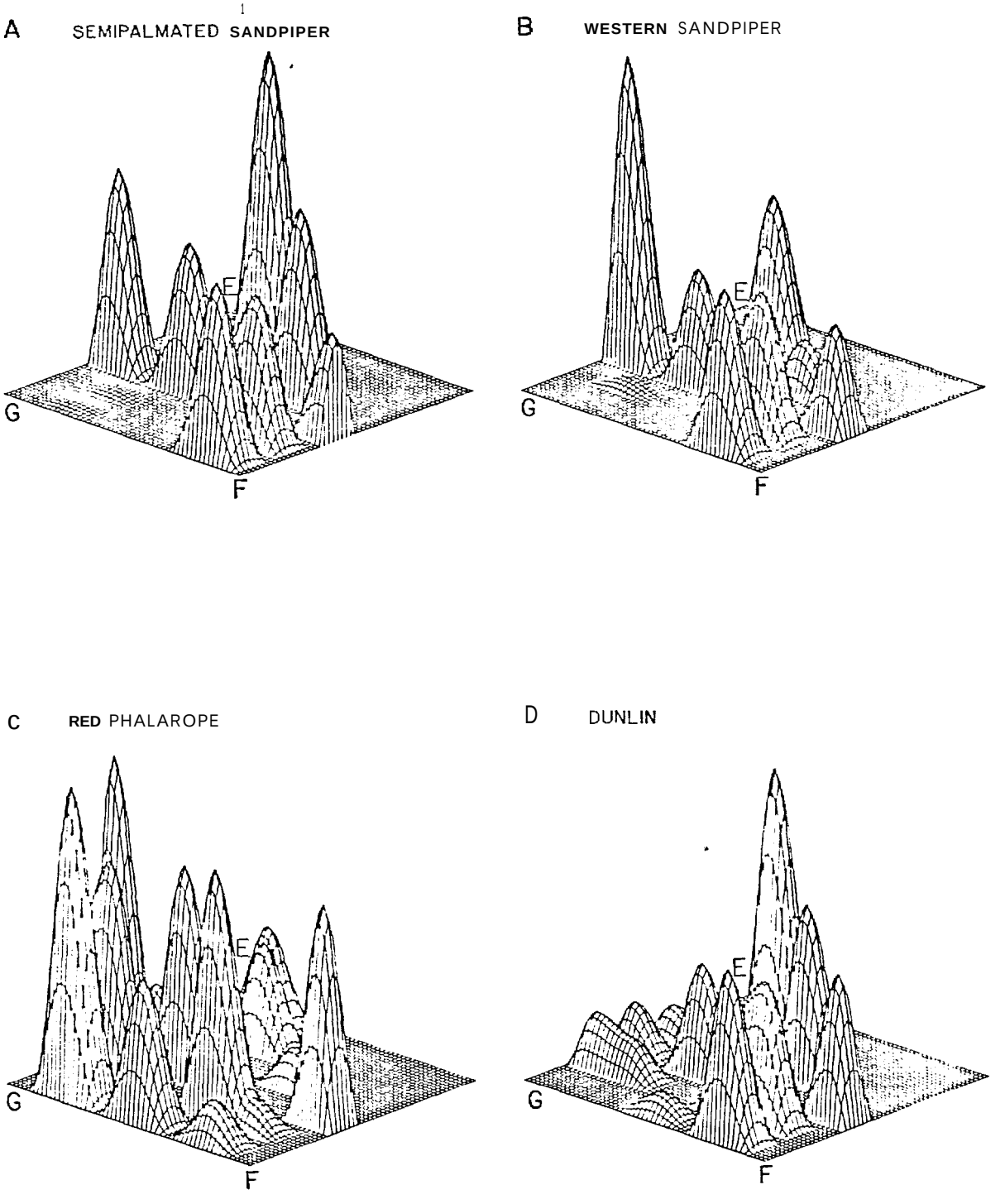


Figure 17. Littoral zone habitat use patterns of 4 species. Plane represents principal component habitat space of Figure 14. Gravel beach (G), littoral flat (F), slough edge (E).

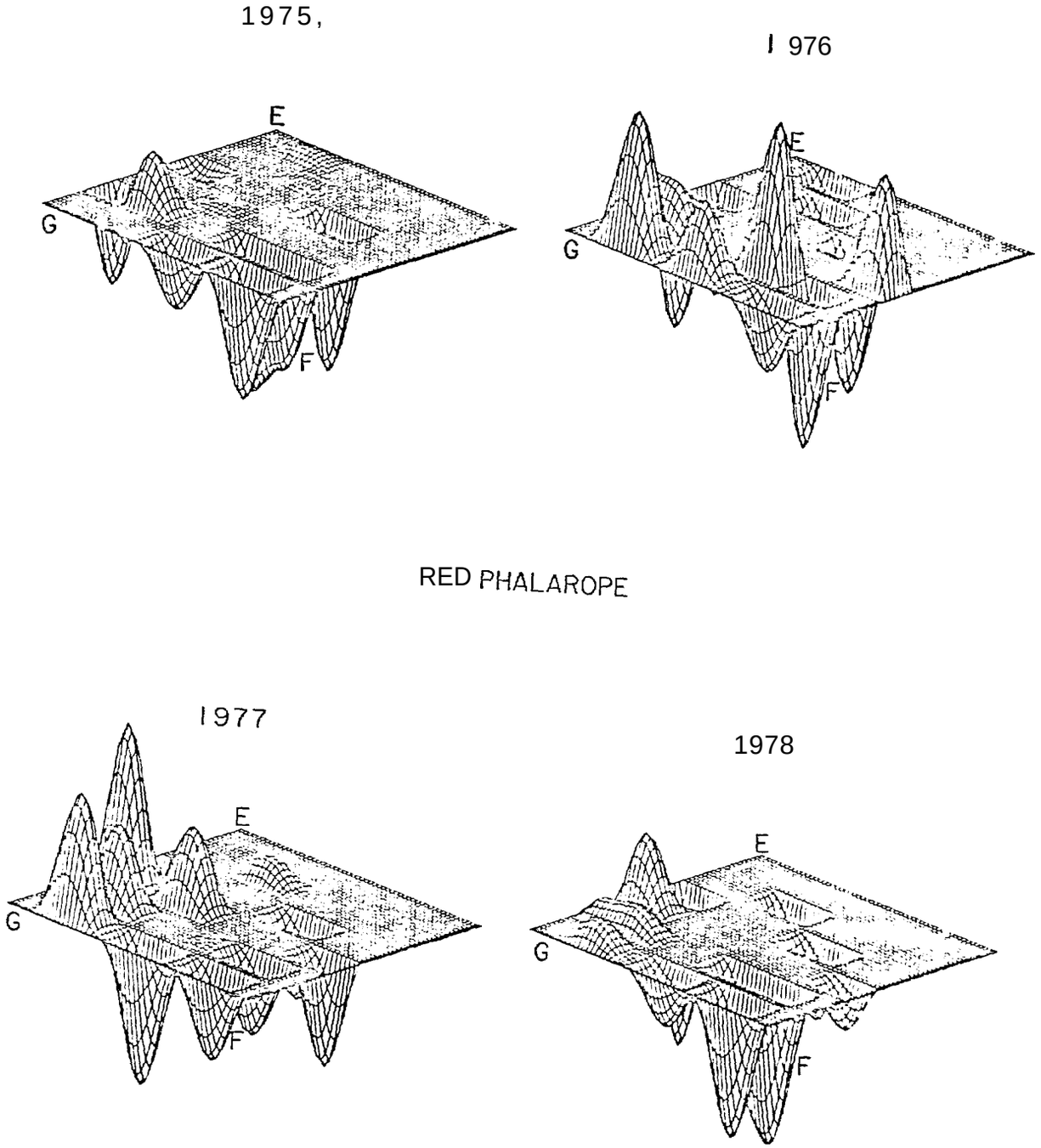


Figure 18. Annual *variation* in *littoral habitat use.* *principal component habitat space of Figure* 14. *Plane represents and below plane represent cumulative bird dinsities above and below mean densities over* all *habitat space.* *Peaks above*

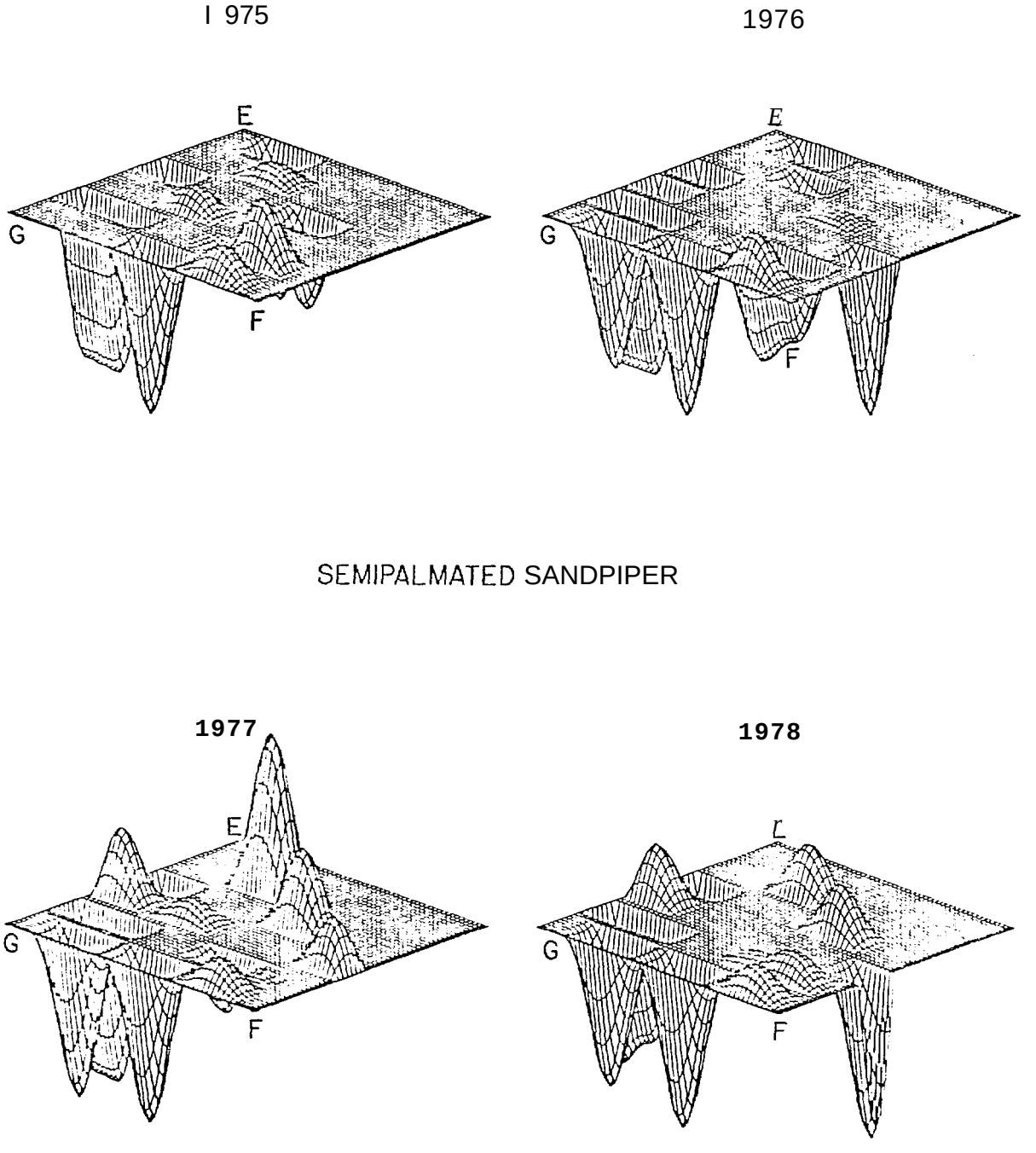


Figure 19. Annual variation in littoral habitat use. See Figure 18.

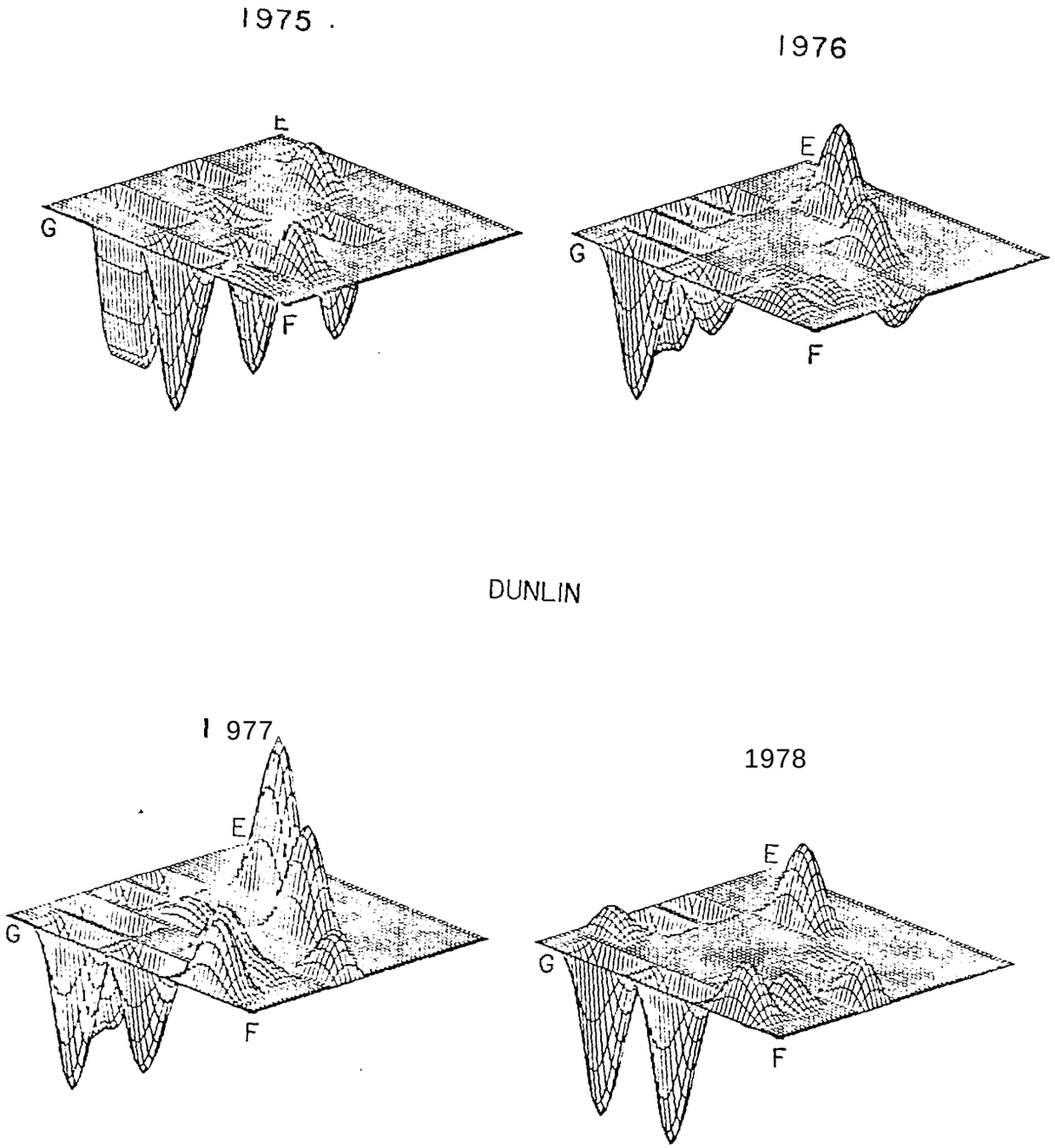


Figure 20. Annual variation in littoral habitat use.

See *Figure* 18.

that variability in species habitat use patterns from year to year occurs in response to environmental conditions, such as water levels or availability of prey species of different types. If both species have similar prey items (discussed below) and prey conditions vary drastically from year to year, both species can be expected to alter their habitat selectivity or foraging behavior. In the event of an oil spill greatly altering foraging conditions, several species might shift their habitat use patterns to take advantage of alternate food sources. This apparent flexibility of species with respect to habitat preferences may bode well in the event of environmental perturbations? but it may also indicate a sensitivity of species to changes in trophic conditions under the influence of natural fluctuations.

Foraging microhabitat preferences

The results of microhabitat foraging measurements on 1210 individuals of nine species of Barrow shorebirds were presented in Connors and Risebrough (1977). To briefly summarize these results, factor analysis of the six microhabitat variables (see Methods) separated species along microhabitat gradients. Table 12 presents ordered lists of species on each of the first two factors running from positive to negative scores. The lines to the left of each ranking show groups of species defined along each gradient using a Tukey B a posteriori multiple comparison test: each line brackets a set of species whose mean values are not significantly different at the .05 level. Factor 1 is correlated most closely with distance to water's edge and water depth. Long-billed Dowitcher and Red Phalarope forage in significantly deeper water than any of the other species. Factor 2 shows a positive correlation with grain size and a negative correlation with bill penetrability indicating that Sanderlings, Ruddy Turnstones and Red Phalaropes forage in habitats with large grain size and low bill penetrability, compared to the other groups of species shown. These species groupings! especially along Factor 2, agree with groupings of species by habitat preference on the broader scales discussed above. The significance of this microhabitat analysis for assessing species susceptibilities to oil-related damage lies in the probability that a species' preferred microhabitat will be affected by oil spillage, either directly through the presence of oil or indirectly through detrimental effects on the food chain. We assume that preferred microhabitats below the water line are more susceptible than those above, at least to damage from oil spills transported on the water. The oil's distribution will be controlled by water transport and thus will spread only as far as water carries it. Second, we assume that increasing grain size indicates increased exposure to wave action. This means that sites characterized by large grain size are more likely to be impacted because of the increased rate of water transport in these areas. However, the duration of impact may be less than in areas of smaller grain size once the latter are hit, for the same

Table 12. Shorebird rankings along microhabitat gradients. Lines bracket groups with similar factor scores.

Factor I	Factor II
Long-billed Dowitcher	Sanderling
Red Phalarope	Ruddy Turnstone
Pectoral Sandpiper	Red Phalarope
Dunlin	Dunlin
Western Sandpiper	Semipalmated Sandpiper
Baird's Sandpiper	Western Sandpiper
Sanderling	Baird's Sandpiper
Ruddy Turnstone	Pectoral Sandpiper
Semipalmated Sandpiper	Long-billed Dowitcher

reason; oil will be more likely to be carried away in large grain size, high energy environments. Given these qualitative assumptions, we argue that species using microhabitats falling high along Factor 1 and high along Factor 2 are those which will be most frequently exposed to oil damage. Red Phalaropes, Sanderlings and Ruddy Turnstones stand out in this respect. Their foraging style and habitat choice expose them to conditions where they are likely to be contaminated with oil.

However, the decreased rate of transport, which may be inversely correlated with Factor 2, must also be taken into account, particularly in light of our evidence on trophic dependencies. Birds foraging in protected areas (usually small grain size) tend to rely on benthic infauna, especially insect larvae which complete their life cycle in these habitats. Birds foraging in areas characterized by large grain size typically feed on wave washed zooplankton either in the water column or along the water line. Long-term effects of oil spills may therefore be more pronounced in protected areas since birds are using a resource originating *in situ*. Plankton feeders in contrast utilize a resource which may be replenished from outside the local area. Such questions of bird susceptibility through secondary trophic and habitat effects are complex and cannot be answered without knowledge of the effects of oil on different food sources and the recovery rates within different environments.

Relative habitat use within the littoral zone

On the basis of the habitat analyses discussed above we classified all Barrow transects into one of three groups representing gravel beaches, littoral flats, and lagoon edges (Table 2). We calculated densities within each habitat group of transects for each period of each year for each species. This permits us to assess relative density within the three

habitat types for different species averaged over four years of study (Figures 21 and 22). The results, expressed as a proportion of the total density summed over three habitats, show several distinct patterns of relative habitat use. Figure 21A shows the results for groups of species. Considering all shorebirds combined, all three habitats were heavily used but densities were lowest in gravel habitats. It is relevant however that in the Barrow area gravel beaches represent the largest component of littoral habitat available to birds. The solid line represents a four year average; the dotted line indicates an average for the years 1975, 1976, and 1978. In 1977, densities of Red Phalaropes, Northern Phalaropes and Arctic Terns were extremely high on one lagoon edge transect (MWE) for a brief period in August. Densities of a small calanoid copepod were also high at that time and probably attracted these plankton foragers from other habitats, more so than in the other three years. The habitat use pattern for these three species was therefore significantly different in 1977 than in the other 3 years. We are unable to say whether the 3 or the 4 year average is a better representation of a long term mean in relative habitat use and therefore report them both. Passerine, in this case only two common species, Lapland Longspur and Snow Bunting, show a significantly different pattern, with extremely low densities on gravel beaches and highest densities on littoral flats. The three common species of gulls plus arctic terns occurred in all three habitats but at highest densities along gravel beaches in all years except 1977.

Within the shorebirds, several distinct patterns of relative habitat use were evident. We have separated them into five groups, all significantly differently by a chi-square test. Group B includes the same three species, Sanderling, Ruddy Turnstone and Red Phalarope, which constitute a species group formed on the basis of tundra vs. littoral zone habitat use (see above discussion). These species occur almost entirely in the littoral zone in late summer where they forage principally along gravel beaches on marine zooplankton. Group C, Baird's Sandpiper and Dunlin, occur in all three habitats but densities in non-gravel habitats are considerably higher. The other seven shorebirds and two passerine occur in much lower densities along gravel shores and are grouped here somewhat arbitrarily according to their relative use of littoral flats and lagoon edges. A few of these species require further comment. In Group D, Semipalmated and Western Sandpipers display almost identical relative habitat use patterns. These two species have been discussed above as demonstrating remarkably similar annual fluctuations in numbers. This similarity of habitat pattern is another indication of how ecologically similar these two related species are and is consistent with our suggestion that annual variability in post-breeding numbers is determined in some way by conditions in post-breeding littoral habitats.

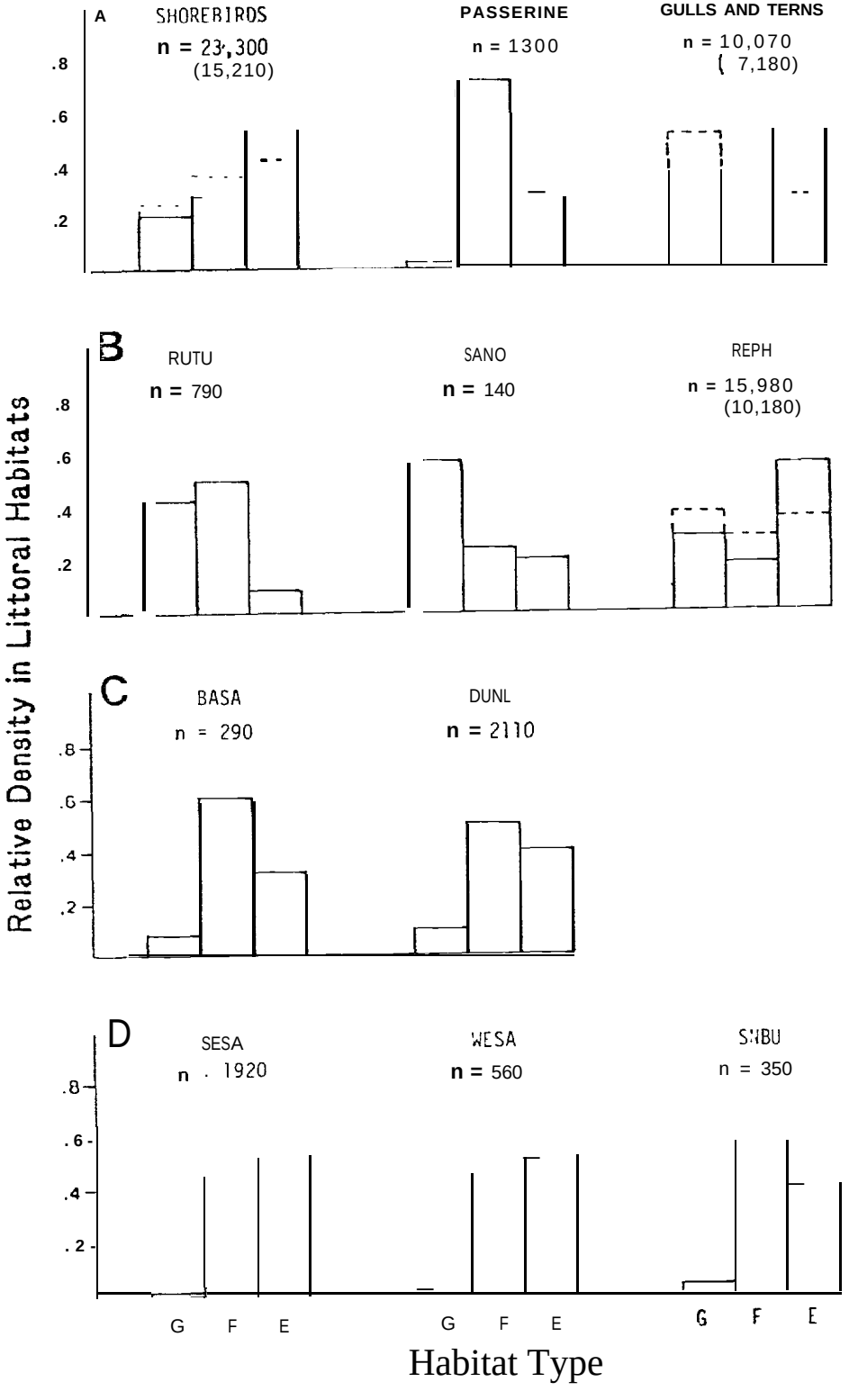


Figure 21. Relative use of littoral habitats: gravel beach (G), littoral flat (F), slough edge (E).

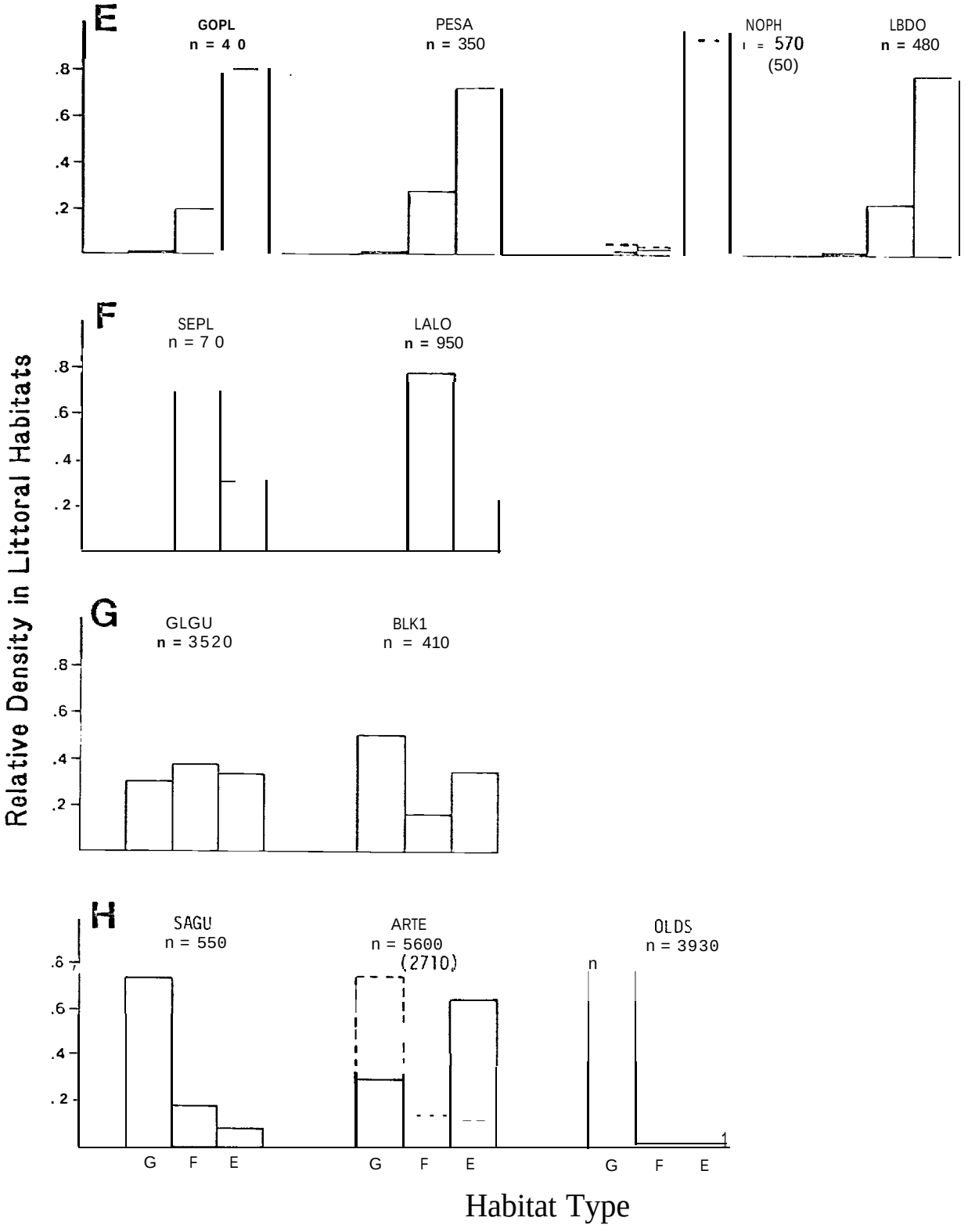


Figure 22. Relative use of littoral habitats: gravel beach (G), littoral flat (F), slough edge (E).

The apparent heavy association of Northern Phalaropes (Figure 22, Group E) with lagoon and slough edges may be somewhat misleading. Northern Phalarope densities are quite low at Barrow in most years but several flocks have been recorded while foraging on small calanoid copepods in Middle Salt Lagoon. In, fact, most of the Northern Phalaropes recorded in four years of censusing at Barrow consisted of a single flock during one census of transect MSE. At sites to the east such as Prudhoe Bay, where Northern Phalaropes are much more common, they forage also along gravel beaches in a manner similar to most Red Phalarope foraging at Barrow. The results shown here suggest however that given the same set of available habitats and food sources, the choices of Northern Phalaropes differ from those of Red Phalaropes.

Although we present the relative habitat use patterns in several groups, we caution that differences in these data sets may be significantly different statistically but not biologically. The large sample sizes for most species make the chi-square test quite sensitive to differences in relative use of different habitats. In view of shifts in the use levels of different transects from week to week or year to year, however, and keeping in mind the ordination analyses discussed above, we are not certain that the differences shown here in relative use of littoral flats and slough edges are as important as may appear. We therefore retain the possibility that Groups D, E and F might better be presented as one group characterized by high use of non-gravel habitats relative to gravel beaches. Finally, we note the close similarity in habitat use pattern between the passerine species and several shorebird species, indicating that some passerine and shorebirds might be affected in similar ways by changes in littoral habitats arising from oil development.

GEOGRAPHIC VARIATION IN SHOREBIRD LITTORAL ZONE USE

Results presented above reflect the local distribution of shorebirds and habitat near Barrow. In general the conclusions from these site-specific studies apply quite well to a large region of the northern Chukchi and Beaufort coasts of Alaska. However, two sets of factors affect the applicability of specific results to other sites. First, the habitat use information reflects to some extent the availability of habitats in the local Barrow area. From Icy Cape west of Barrow to Prudhoe Bay east of Barrow (Figure 1) there is no clear geographic cline in littoral zone habitat types, but local sites vary depending on such factors as presence or absence of spits and barrier islands, elevation of tundra adjacent to the shore, and extent of local river deltas. A second set of factors, the changing distribution of individual species, follows a primarily longitudinal gradient along the coast.

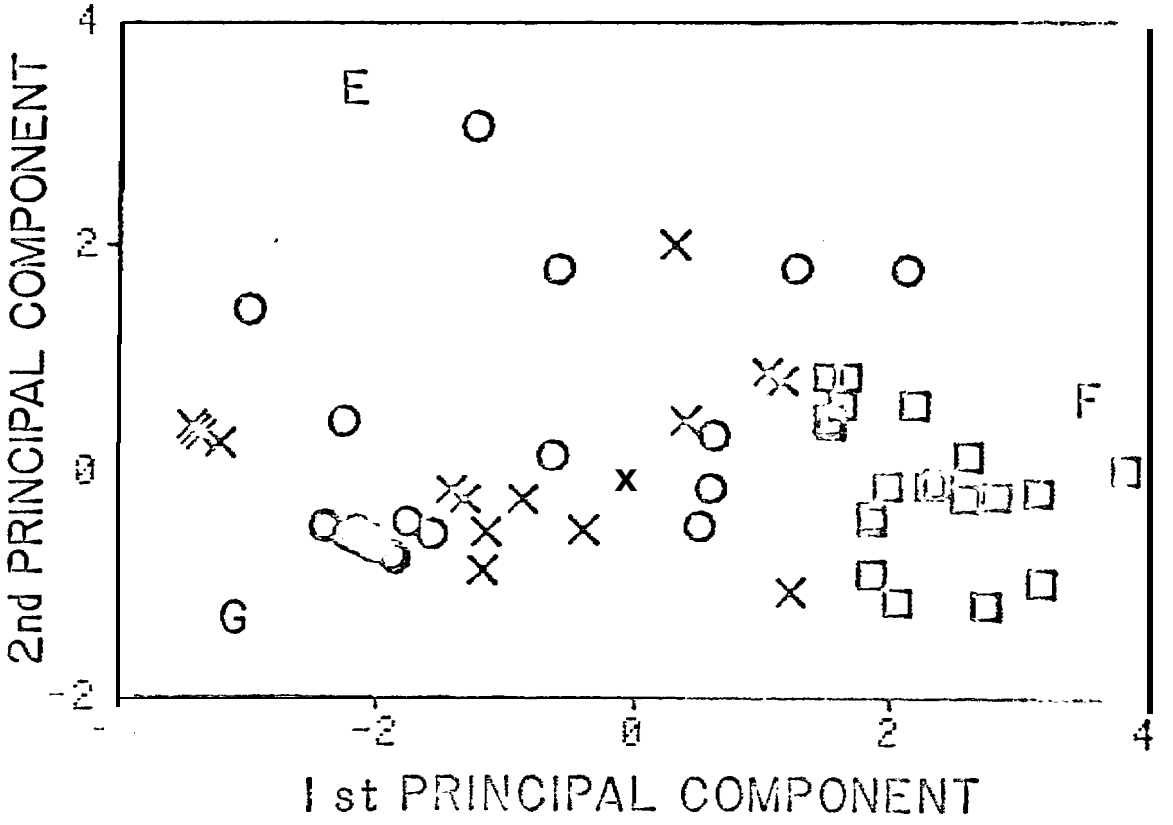


Figure 23. Locations of transects in principal component littoral habitat space. Barrow transects (circles), Prudhoe Bay (X's), Fish Creek Delta (squares). Letters indicate habitat types: gravel beach (G), littoral flat (F), slough edge (E).

Habitat availability

Figure 23 shows the placement of our littoral zone transects at Barrow, Prudhoe Bay and Harrison Bay (Fish Creek Delta) study sites in a habitat space defined by the first two principal components. This analysis is similar to that discussed for Barrow transects alone (Figure 14) but with measured distances replaced by their logarithms. This change was made because the pool of all transects from three sites has a much wider range of distance measurements. As in the Barrow analysis, gravel beach transects are represented by low values on both axes, while littoral flats score high on PC I and lagoon edges score high on PC II. Both Barrow and Prudhoe Bay transects represent a similar range of littoral zone habitat types with the principal difference being the much higher frequency of gravel beach transects at Barrow. At Fish Creek Delta, however, located between the other two sites (Figure 1), all transects are in one class of habitat space (saltmarsh and mudflat) with positions more extreme than any recorded from the other two sites. This difference relates primarily to the more extensive areas of littoral

flats at Fish Creek Delta compared to the other two sites. Saltmarsh occurs farther from the shoreline at Fsh Creek Delta. These transects are characterized by wider flood zones, lower slopes, more vegetation and muddier substrates than transects censused at Barrow and Prudhoe Bay. Shorebird use of mudflat and saltmarsh habitats was very similar at all three sites, but the overall pattern of shorebird use varied among the sites because of the different mix of habitats available.

Species distributions

The relative abundance of different shorebird species at the three principal study sites varied partly in response to the changes in local habitat mix. Thus, for example, Ruddy Turnstones, Sanderlings and Red Phalaropes were almost absent from Fish Creek Delta in 1980 but this arises primarily from the absence of gravel shorelines which these species preferentially frequent during migration. However, longitudinal gradients in species distribution also affected local densities. The major changes in species abundance in littoral habitats over the regions studied affect four species. Western Sandpipers at Barrow are near the eastern limit of their breeding range. Densities of Western Sandpipers at Harrison Bay were an order of magnitude less than densities of Semipalmated Sandpipers, and they did not occur at Prudhoe Bay. Stilt Sandpipers occur in very small numbers at Barrow as a late summer migrant but are common during this period at Prudhoe Bay where they forage on littoral flats and slough edges.

Finally, the two Phalarope species vary in relative abundance. At Barrow, the ratio of Red Phalaropes to Northern Phalaropes on our transects over four years was approximately 30:1. At Prudhoe Bay, the ratio is almost reversed, with nearly all phalaropes along shoreline transects being Northerns in 1978. At Herschal Island at the western edge of the western edge of the Canadian Beaufort coast, Vermeer and Anweiler (1975) reported a ratio of about 40:1 favoring Northerns. On the Jones Islands just west of Prudhoe Bay, Johnson (1978) recorded 4:1 Red:Northern Phalaropes. At Harrison Bay, Red Phalaropes were almost absent but Northern Phalaropes were common on the littoral flats. This last difference may arise primarily from a difference in habitat selection by the two species which may also account for some of the difference between densities at Jones Islands and Prudhoe Bay. Red Phalaropes are most common along beaches on spits and barrier islands while Northern Phalaropes occur more frequently in sloughs and lagoons. The differential distribution of these two species in our study is apparently a result of the two factors of geography and habitat selection. This difference in Phalarope occurrence during the post-breeding period at Harrison Bay and at Barrow is demonstrated by Figures 24A and 39 A, B.

Figures 24B and 25A, B show the density comparisons for three other common species: Dunlin, Semipalmated Sandpiper and Lapland Longspur. Harrison Bay densities were comparable to somewhat greater than the four year average of Barrow densities. These species are all common on littoral flats at both sites; however, at Harrison Bay the relative and absolute amount of this class of habitat is much greater than at Barrow, so our figures represent a much larger number of birds in the littoral zone at Harrison Bay. Timing of the post-breeding peak of these species varies also, but in an inconsistent pattern, with Lapland Longspurs peaking much earlier at Harrison Bay and Semipalmated Sandpipers peaking later. However, since these are based on only one year's data compared to four years at Barrow, they may represent a poor estimate of average timing of these movements.

Shorebird concentration areas

Areas considered sensitive because of high levels of use by birds of many species were identified in the Interim Synthesis Report: Beaufort/Chukchi (Weller et al., 1978). These include many of the areas where shorebird densities are high during late summer in the littoral zone. These regions correspond primarily to areas with gravel spits and barrier islands where densities of the gravel beach shorebirds are highest; and areas with extensive littoral mudflats, saltmarshes and slough edges, from Icy Cape in the Chukchi sea to Prudhoe Bay in the Beaufort sea. They include Icy Cape, Peard Bay, Point Barrow, the Plover Islands, Fish Creek Delta, Colville Delta and the Jones Islands (Figure 1). Smaller areas with heavily used shorebird littoral habitats occur at several other points along this coast and some rather extensive regions of coastline have not been adequately surveyed during the appropriate season.

SHOREBIRD DIETS AND FAT ACCUMULATION

Overlap in shorebird diets

Detailed lists of food items found in shorebird stomachs and of species composition and density of plankton samples have been reported in Connors and Risebrough (1976, 1977, 1978 and 1979). In this final report we summarize the major points arising from those collections but do not repeat the detailed data. Table 13 lists the numbers of each bird species collected at Barrow and a few nearby sites. These collections do not permit a definitive listing of average diets because of small sample sizes and because the diets of most species depend closely on the availability of prey species at the site sampled. The central conclusion of our shorebird diet studies is that the diets of most species correspond to the habitats in which they forage rather than to strong species differences in diet preference within habitats. The diets of many species overlap broadly while foraging in the same habitat type. In earlier reports, we cited numerous examples of shorebirds of two, three or four

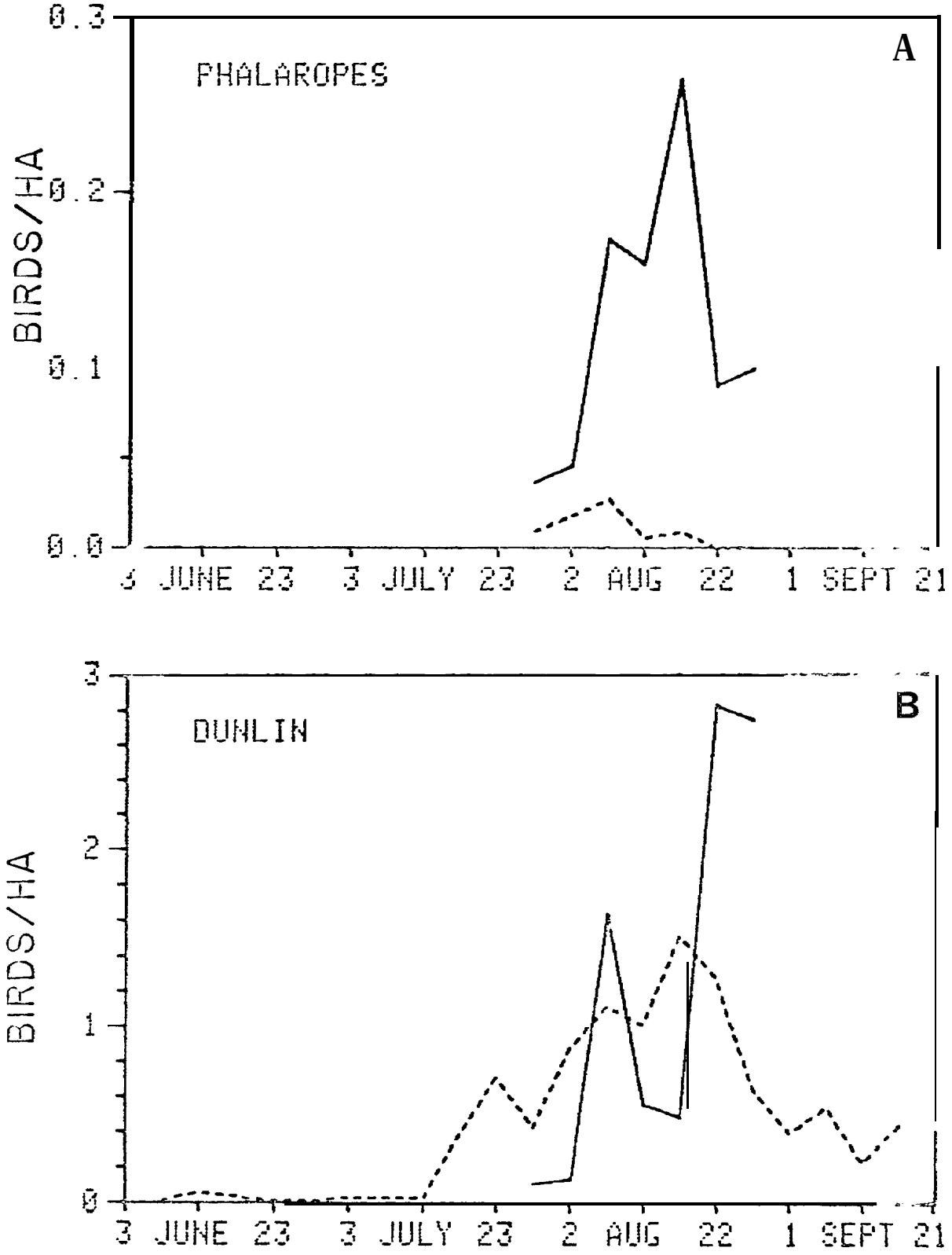


Figure 24. (A) Littoral zone densities of Red Phalarope (dashed line) and Northern Phalarope (solid line) at Fish Creek Delta.
(B) Comparison of littoral zone densities of Dunlin at Fish Creek Delta, 1980 (solid line) and Barrow 1975-1978 (dashed line).

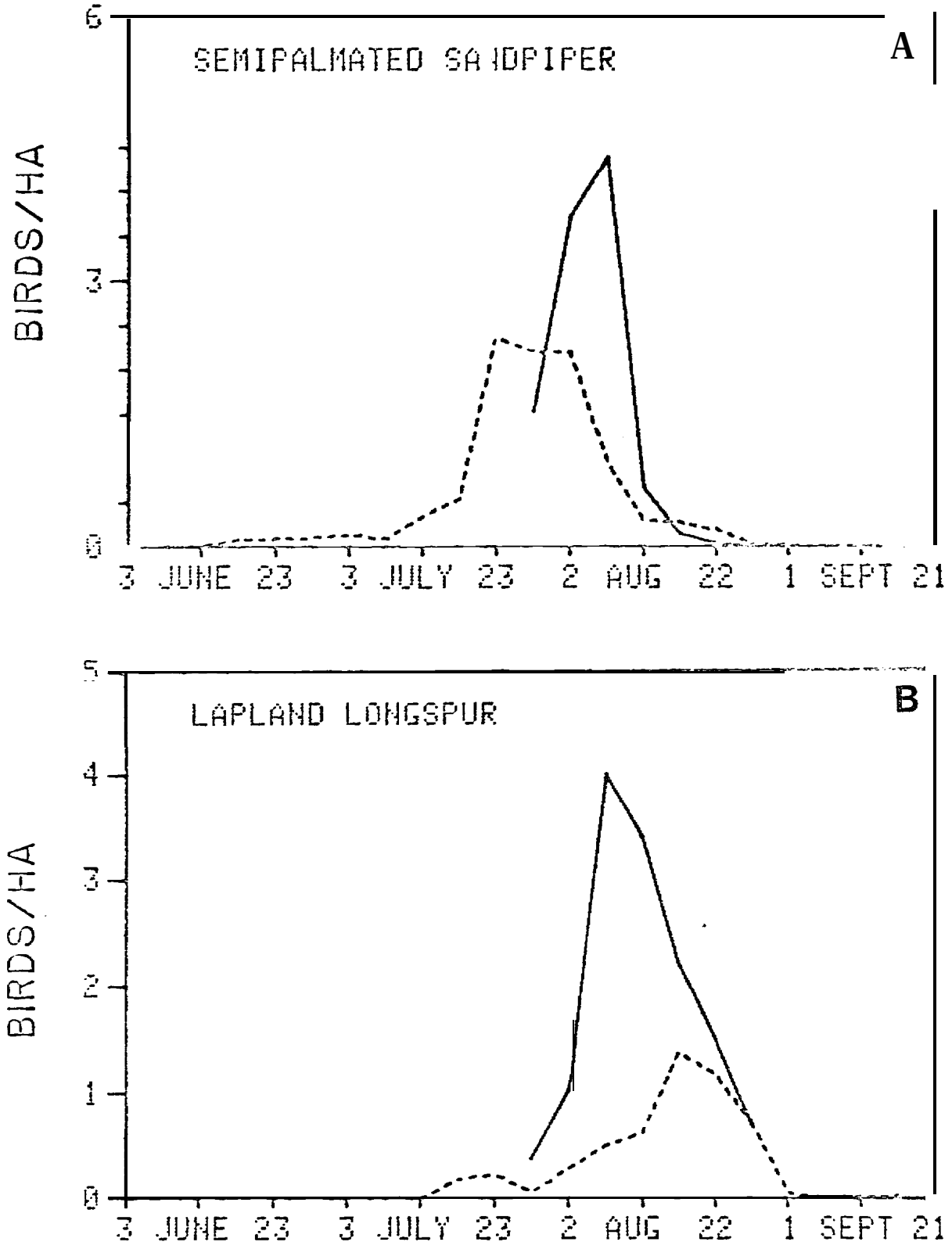


Figure 25. Comparison of littoral zone densities at Fish Creek Delta, 1980 (solid line) and Barrow, 1975-1978 (dashed line).

species foraging on very similar prey while together at one site. However, at other sites in different habitats or at different times within the same habitat the diets of all these species vary. There are of course exceptions; individual species do exhibit differences in foraging methods and some distinctions are imposed by species morphology. But in general the main differences in diet correspond to differences in habitat use. These can be summarized as follows: shorebirds foraging on littoral flats, in saltmarshes and along the shores of small lagoons and sloughs foraged principally on chironomid larvae in the substrate but in several areas small oligochaetes were also taken. Early in the post-breeding season (late July) adult chironomids are present and are taken by many species. Along gravel beaches on marine shores most species foraged on a wide variety of marine zooplankton and amphipods associated with the substrate or the under surface of ice. The actual species taken varied widely over time and place both within a season and between seasons, but the differences in prey between species at one time and place were relatively slight. This similarity of diet along arctic shores extends from Red Phalaropes who forage while swimming in shallow water along gravel beaches to Ruddy Turnstones, Sanderlings, Dunlin and occasionally a few other species which forage by walking at the water's edge. Phalaropes take zooplankton directly from the water column, while other shorebirds take the same prey species either washed up on the gravel or in the extremely shallow water right at the water's edge. All these species show a tendency to select larger sizes of zooplankton compared to sizes available in plankton tows (Connors and Risebrough, 1977), and the species favored included amphipods of the genera Apherusa and Onisimus, euphausiids (Thysanoessa), copepods (Calanus) and decapod zoea. We believe, however, that these apparent diet preferences vary widely depending on the availability of species within the zooplankton community.

Table 14 lists the groups of shorebird species which we believe have overlapping diets within habitat classes. This Table, when used in conjunction with Figures 21 and 22 summarizing relative littoral zone habitat use, will convey a good idea of the expected diet of each species in the Barrow area. The species listed as zooplankton predators may select some prey species preferentially; this distinction would require large sample sizes to identify; our samples only show considerable overlap. Among the group of species listed as foraging on chironomid larvae, species may differ in microhabitats or depths at which prey are taken, in prey size or prey species. Nevertheless, this is a very uniform prey base compared to tidal flat communities in temperate regions; the stomach samples indicated broad overlap.

Two other species which occur commonly on littoral flats and along lagoon and slough edges are passerine. Although they forage in the same habitat as many shorebird species our very limited collections suggest that they feed on the seeds

Table 13. Numbers of specimens from Barrow area examined for studies of diet and fat condition, 1975-1978.

Red Phalarope	2	Red Phalarope	76
Semipalmated Sandpiper	8	Northern Phalarope	3
Western Sandpiper	1	Sabine's Gull	2
Baird's Sandpiper	2	Arctic Tern	2
Dunlin	16	Lapland Longspur	2
Sanderling	12	Snow Bunting	2
Long-billed Dowitcher	2		

Table 14. Groups of species with overlapping diets in littoral habitats.

Habitat	Diet	Species
Marine shores, gravel beaches	Marine zooplankton, including copepods, euphasuiids, decapod zoea	Ruddy Turnstone, Dunlin, Sanderling, Red Phalarope, Northern Phalarope, Arctic Tern, Sabine's Gull
	Amphipods	Red Phalarope, Baird's Sandpiper
Small lagoons	Copepods	Red Phalarope, Northern Phalarope
Mudflats, saltmarsh, lagoon and slough edges	Adult chironomid flies	Ruddy Turnstone, Dunlin, Western Sandpiper, Red Phalarope
	Chironomid larvae	Ruddy Turnstone, Semipalmated Sandpiper, Western Sandpiper, Dunlin, Long-billed Dowitcher, Red Phalarope, Lapland Longspur
	Oligochaetes	Ruddy Turnstone, Dunlin
	Seeds	Lapland Longspur, Snow Bunting

of plants found in these areas but possibly also on chironomid larvae. At the other extreme of habitat and size the diets of Sabine's gulls and Arctic Terns overlap with gravel beach zooplankton foraging shorebirds, although these species also take fish.

There is a strong seasonal component to shorebird diets in the arctic. Many species take adult chironomid flies during July on the tundra, and birds of 4 species collected in late July in littoral habitats, including Red Phalaropes, contained adult flies. By mid-August these are no longer available, and these same bird species have shifted to other prey. Thus the diets of shorebirds change as species change foraging habitats and also as prey availability within habitats changes.

Red Phalarope diets and foraging behavior

The diets of shorebirds foraging on littoral flats are probably fairly consistent from year to year although little is known of the life cycles and ecology of the species of chironomid flies whose larvae develop in these littoral areas. In contrast, diets of birds foraging along the marine shorelines vary more widely from year to year because of annual variation and even within-season variation in relative abundance of different zooplankton species. Our Red Phalarope data provide the clearest example of this variation. In 1976, densities of marine zooplankton were strikingly lower than densities in 1975. Mean densities of the three prey species taken most commonly by shorebirds in 1975 were reduced by approximately 25 times. Diets of Red Phalaropes showed corresponding differences between the two summers, with copepods scarcer and amphipods more common in 1976 (Connors and Risebrough, 1977).

This change in diet reflected an observed difference in foraging behavior. In 1975, juvenile Red Phalaropes foraging along the shores of Barrow spit were most abundant in the shallow water zone 0 to 2 meters out from shore. Day to day distribution along the shores of Barrow spit and Plover spit varied considerably however. Using our census data of Red Phalarope distribution along shorelines which face in four different directions (Figure 2), we plotted the percent of birds present on each shore on seven days with wind speeds above 8 knots, against the deviation of wind direction from a full onshore wind (Figure 26A). The very restricted scatter of these data indicate that phalaropes rarely foraged on beaches with onshore winds (angles less than 90 degrees) if alternative shores were available. We repeated this analysis with strikingly different results for seven windy days in 1976 (Figure 26B). Clearly Red Phalaropes were responding differently in relation to wind direction in the two years. We suggest the following interpretation, related directly to the change in zooplankton conditions between the two seasons. In 1975 Phalaropes foraged on dense zooplankton in shallow water within 2 meters of shore almost exclusively. In this situation the protected shore probably provides increased

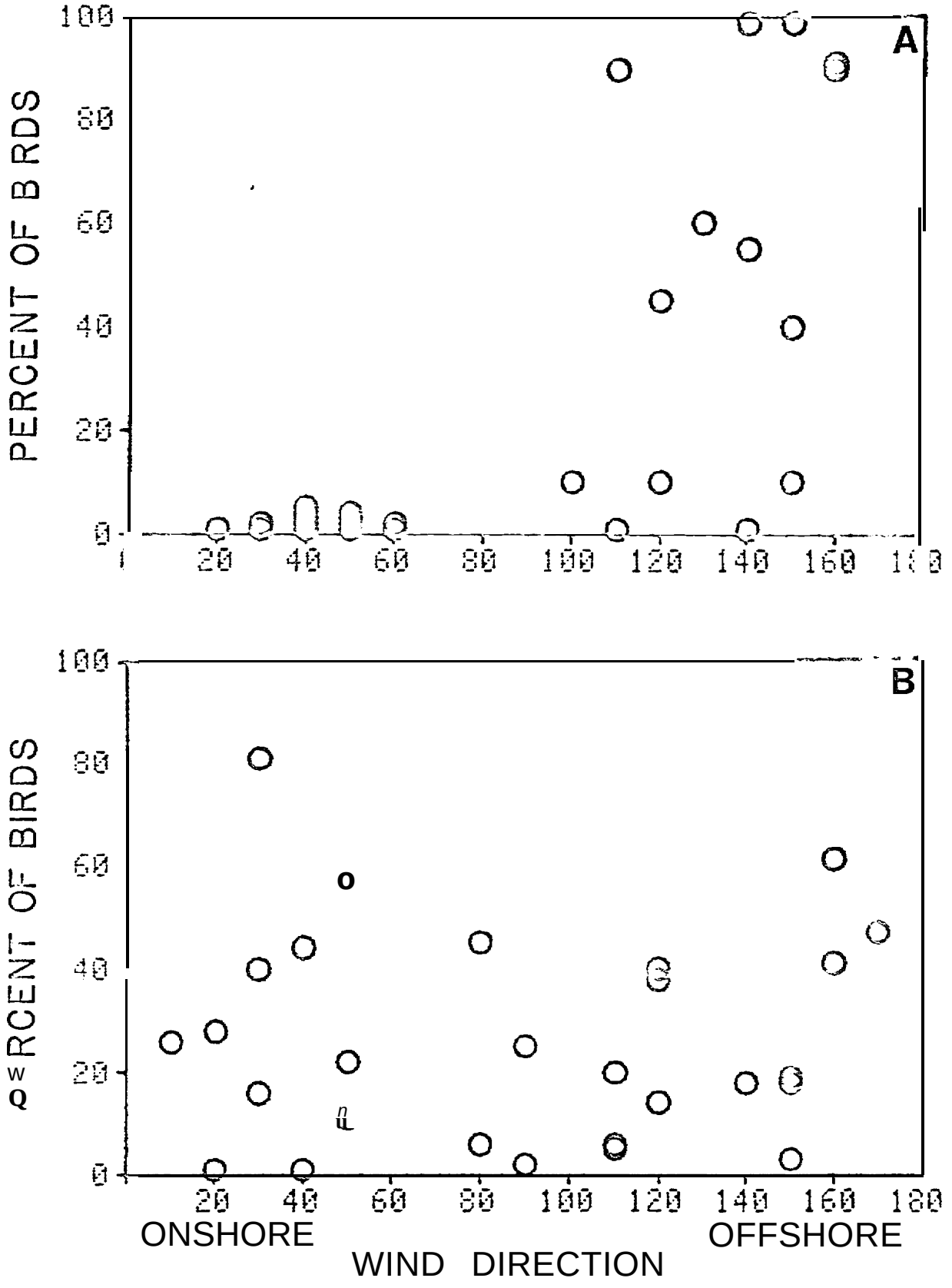


Figure 26. Distribution of foraging Red Phalaropes in relation to wind direction. (A) 1975. (B) 1976. See text.

foraging efficiency, possibly by improved surf and ice conditions and decreased turbidity and possibly through enhanced zooplankton density. In 1976, however, with drastically lower densities of the same zooplankton, Red Phalaropes also foraged on under-ice amphipods which became available on windy days when pieces of ice piled up on the windward shore. The absence of any wind related pattern in Figure 26B results from phalaropes utilizing multiple food sources with different responses to wind conditions.

Under conditions of either high or low zooplankton density our proposed explanation of Phalarope distribution in relation to wind direction suggests also an explanation of the large concentrations of phalaropes near spits and barrier islands. The complex shoreline topography of these sites provides a greater variety of foraging conditions with respect to wind direction than does a simple mainland shore. There is always a protected shore and a windward shore, permitting phalaropes to select the best foraging conditions, determined by the interacting factors of wind, water, ice conditions, and zooplankton densities.

Effect of oil spills on shorebird prey species

We discussed earlier the potential differences in oil spill effects on different microhabitats. These differences also apply to different prey communities. Spilled oil offshore might be expected to reach open water gravel shoreline areas first, where the possibility of toxicity to zooplankton communities or under-ice amphipods might reduce the densities of these food species. Littoral flats and slough edges might be affected by oil only if it occurs with storm flooding. However, oil spilled on beaches might be removed sooner, by subsequent wave action, than oil transported to protected littoral flats. In addition, zooplankton densities influenced strongly by water movements and phytoplankton activity might recover relatively soon after the initial phase of an oil spill. In contrast, oil spilled on muddy sediments within protected littoral areas might continue to affect chironomid life cycles and populations within the substrate. Assessing these differences will require studies of the sensitivity of various prey species to oil contamination and the recovery rates of prey populations in different habitats.

Premigratory fat deposition by shorebirds

We recorded fat conditions for all collected birds by assigning the OCS fat code to each specimen (Code 1 = no fat; Code 2 = little fat; Code 3 = moderate fat; Code 4 = very fat; Code 5 = excessive fat). Only two species showed any change in fat condition with date after August 1st. Both species showed an increase in fat levels during this period (Red Phalarope mean score $\bar{x}$ = 2.6, Spearman correlation coefficient r_s = .40, $p<.01$ and Dunlin $\bar{x}$ = 2.5, r_s = .41, $p<.05$). This suggests strongly that the long period in which these species forage in arctic habitats is important for the deposition of fat prior to southward migration. Arrival of these species at the latitude of California occurs in middle October or later in most years, considerably delayed compared to Sanderlings and Ruddy Turnstones. These latter species apparently accumulate higher fat reserves during August (Sanderling $\bar{x}$ = 3.8, Ruddy Turnstones $\bar{x}$ = 3.3) and migrate southward more rapidly. Juvenile Semipalmated Sandpipers leave the arctic much earlier, in late July and early August, but with lower fat levels than these two species ($\bar{x}$ = 2.6). Semipalmated Sandpipers may migrate more slowly, replenishing fat supplies more frequently during migration. Johnson (1978) also found an increase in fat level of Red Phalaropes during August at Simpson Lagoon. His data suggest a difference in the fat deposition schedule of the two phalarope species: Northern Phalaropes had consistently higher fat levels throughout this period. Three Northern Phalarope juveniles we collected at Barrow over two years on 8 and 9 August had significantly higher fat levels than 20 Red Phalarope juveniles taken over four years 8 - 12 August (Mann-Whitney test, $p<.01$). We do not know what differences in foraging ecology or metabolism account for this surprising ability of Northern Phalaropes to accumulate fat more quickly than Red Phalaropes.

Unlike juvenile phalaropes, adult females and adult males, freed from nesting duties in late June and late July respectively, begin their southward migrations without a long post-breeding foraging period in the arctic. If juveniles require the long foraging period to build up energy reserves necessary for migration, have adults already achieved similar fat levels when they leave the tundra and depart southward? We compared fat levels in 14 adult male Phalaropes collected along shorelines from 15 July - 3 August, 1975 - 1978 with 20 juveniles taken 8 - 12 August, 1975 - 1978. The adult fat levels were significantly higher ($p<.02$, Mann-Whitney test). We believe this also indicates that juveniles require the late summer shoreline foraging period to build fat reserves necessary for southward migration.

DEVELOPMENT EFFECTS ON SHOREBIRDS

Effects of habitat changes on bird densities

In Table 15 we list the kinds of habitat alterations potentially associated with OCS development which might

affect shorebirds. We addressed the first two listed factors, including several kinds of habitat changes as well as the effects of noise and activity disturbance, with sets of transects primarily at Prudhoe Bay and to a lesser extent at Barrow in 1978. We compared bird densities between transects of similar habitat differing in degree of habitat disturbance. The effects of a variety of habitat changes already accomplished at Prudhoe Bay were reported in Connors and Risebrough (1979). In this final report we present the comparisons indicating the greatest effects of habitat change on shorebird numbers.

Habitat removal. Habitat can be affected in varying degrees. At the crudest level, it is simply removed. Total loss due to gravel roads or construction pads for onshore facilities can be quantified in the Prudhoe Bay area. Our rough 1978 estimates of this tundra habitat loss within a 14 km x 26 km rectangle encompassing much of the oilfield amounted to about 10 sq km. This is only about 3% of the enclosed tundra, which sounds unimportant, but it implies a total loss of about 1000-2000 pairs of nesting shorebirds from this area, along with waterfowl and other species.

Road effects. Construction has other effects which also diminish usable habitat. A considerable dust shadow accompanies gravel construction, with vegetation coated to varying degrees with dust at distances measuring tens or hundreds of meters from all roads. This affects bird density.

A summertime prevailing wind direction from the northeast produces a more extensive dust shadow on the southwest side of roads at Prudhoe Bay. In Figure 27A we compare the seasonal changes in total shorebird density on the dust shadow transects, PG1 and PG2 (see Figure 28), with control transects, PG3 and PG4. Densities on the dusted tundra were significantly lower by a sign test ($p<.01$), especially during the breeding season. Comparing the inner and outer pairs of transects separately, densities are lower on PG1 than PG3 ($p<.01$) and lower on PG2 than PG4 ($p<.05$). The cross comparison of PG2 and PG3, transects with similar dust effects (Table 16) was not significant ($p>.05$). A similar effect is evident for passerine (Lapland Longspur and Snow Bunting; Figure 27B).

Before we interpret these differences in shorebird densities as the results of dust deposition on the tundra, we must establish that other habitat differences are unlikely to have produced the differences. The four transects were chosen in early June in a level area of superficially uniform tundra with respect to topography, vegetation, and surface water area and distribution. More detailed measurements of habitat parameters made during the summer indicate that this initial assessment was substantially accurate. Some distinguishable differences do exist, however (Table 16). Water cover decreased on all transects during June and between June and August, as expected. Average water cover in June on the four transects fell in a narrow range, with the

Table 15. Potential effects of oil development on arctic shorebirds.

1. Habitat changes
   a. Loss of habitat
   b. Change in quality of habitat
   c. Construction of new habitat
2. Activity disturbance
3. Changes in prey resource
4. Direct oil spill effects

Table 16. Characteristics of dust shadow and control transects.

	Dust		Control		
	PG 1	PG 2	PG 3	PG 4	n
June water cover[1]	18	25	25	21	6
August water cover[2]	4.4 ±11.4	13.0 ±12.0	7.0 ±7.1	5.9 +4.1	20
Plant cover[3]	74+11	77+4	82+6	86+4	20
Relative disturbance[4]	60±10	15±5	25±5	0±0	20

[1] means of 6 census period estimates

[2] per cent of surface area. Means of 20 plots ± standard deviation

[3] per cent of non-water area. Means of 20 plots ± standard deviation

[4] scale of 0 to 100, means of 20 plots + s.d.

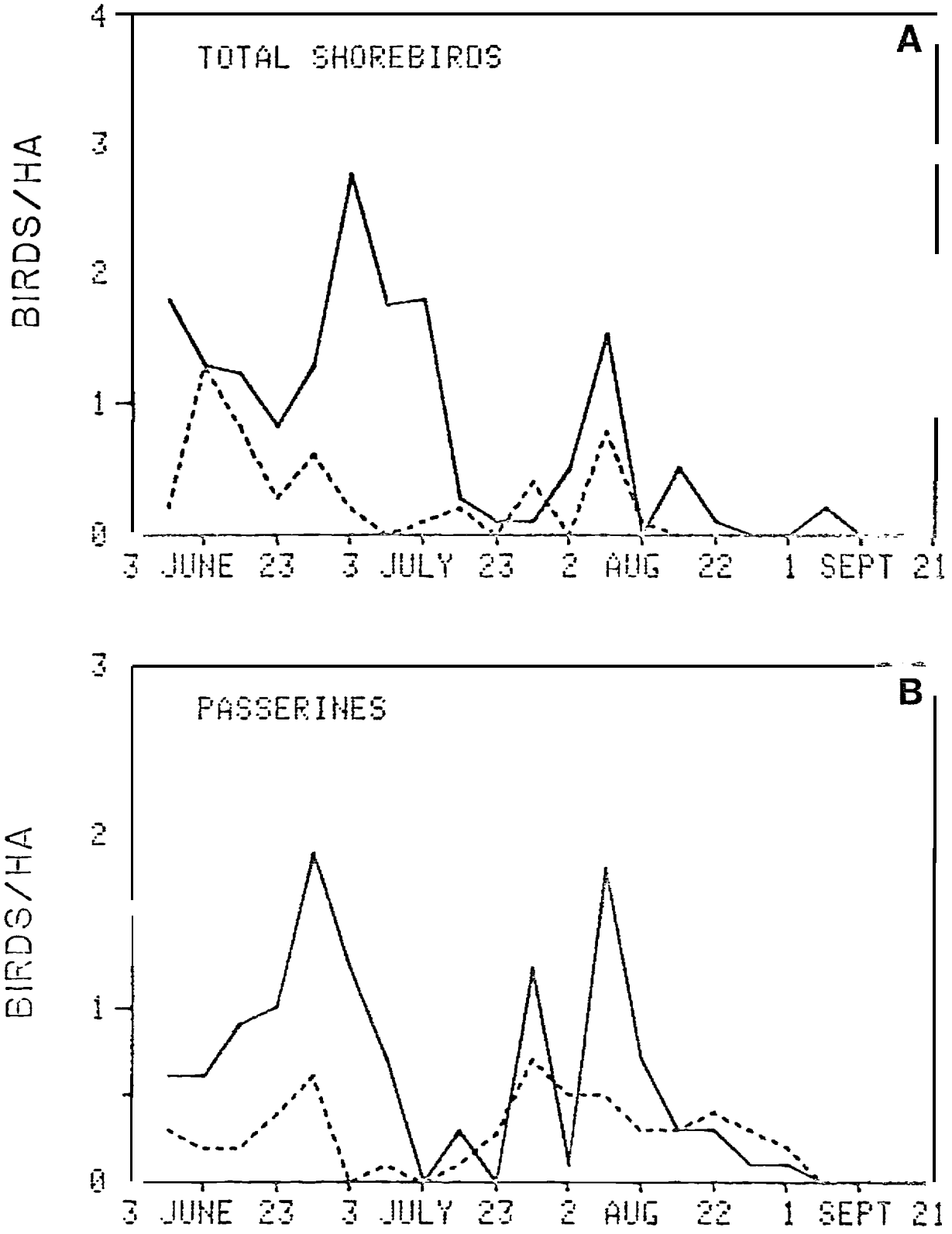


Figure 27. Comparison of bird densities on Prudhoe Bay dust shadow transects (dashed line) and on control transects (solid line).

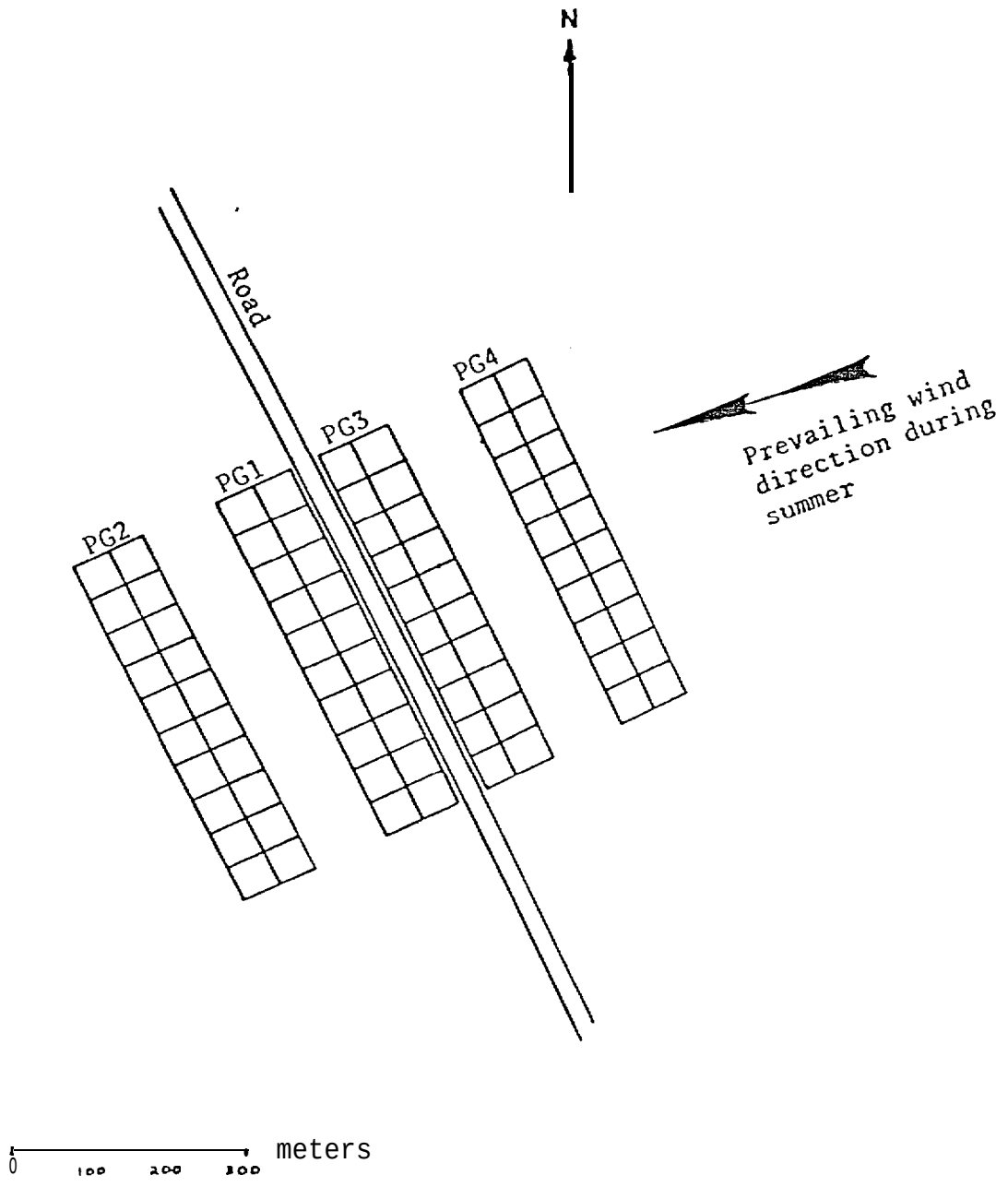


Figure 28. Diagram of Prudhoe Bay dust shadow transects (PG1 and PG2) and control transects (PG3 and PG4) .

disparity increasing toward the end of the month. By August several plots had become dry or nearly so, and the relative range of average transect values had increased further. A Mann–Whitney test comparing the disturbed transects (PG1 and PG2) with undisturbed transects (PG3 and PG4) distinguishes between August water conditions on PG1 vs PG3 ($p<.002$) but not between PG2 and PG4 or between the combined PG1 and PG2 compared to PG3 and PG4. Thus, some differences do exist in August, but these differences are smaller in June. Furthermore, elimination of the driest 120 plots from transect PG1, which leaves a half transect indistinguishable in water content from PG3, still provides a comparison of bird densities which is significantly lower on the disturbed transect. Finally some of the habitat difference may, in fact, derive from the disturbance: the heavier deposition of dust on PG1 compared to PG3 may have reduced the surface water content of that transect, and may be responsible for the slightly lower per cent plant cover on the dust shadow transects (Table 16).

The upwind transects are, of course, not completely dust free. The full effect of dust on bird densities may therefore be greater than that shown in Figure 27. A possible additional effect, that of noise and activity disturbance associated with the road, is difficult to measure in the presence of the dust effect. We think there is such an effect, but that it is smaller than the dust effect.

The net result of these road effects is to increase the effective disturbance zone associated with the road. Instead of losing only the 30 m wide strip which is covered by gravel, the total loss of nesting habitat may be equivalent to a 60 m to 200 m wide strip. This change will multiply our total habitat loss by a factor of several times. In other words, the estimate of 1000-2000 pairs of shorebirds lost in the Prudhoe Bay oilfield increases to 3000 to 6000 pairs.

Drainage changes. Tundra construction frequently affects drainage patterns, either by increasing or diminishing local drainage, and these changes, by altering water levels and areas, can greatly influence habitat use by shorebirds and waterfowl. We show one example of an altered drainage effect in Figure 29A, comparing densities on pairs of transects differing principally in the effect of a road with an inadequate culvert system on drainage. The dotted line traces density of shorebirds on transects which remain flooded during early summer, but which drain considerably by late August. The area has been essentially eliminated as nesting habitat for shorebirds, but is very attractive to late summer migrants.

Human activity. We've also looked for effects of activity disturbance by people and machines along shorelines in late summer at Barrow, comparing densities on 7 shoreline transects, 3 with high disturbance (BBV, BBD, BDC) and four with low disturbance (BCS, BCN, BAP, BBS), scattered along 19 km of Chukchi coast. In general, most bird species occurred in higher densities along undisturbed shorelines, but the

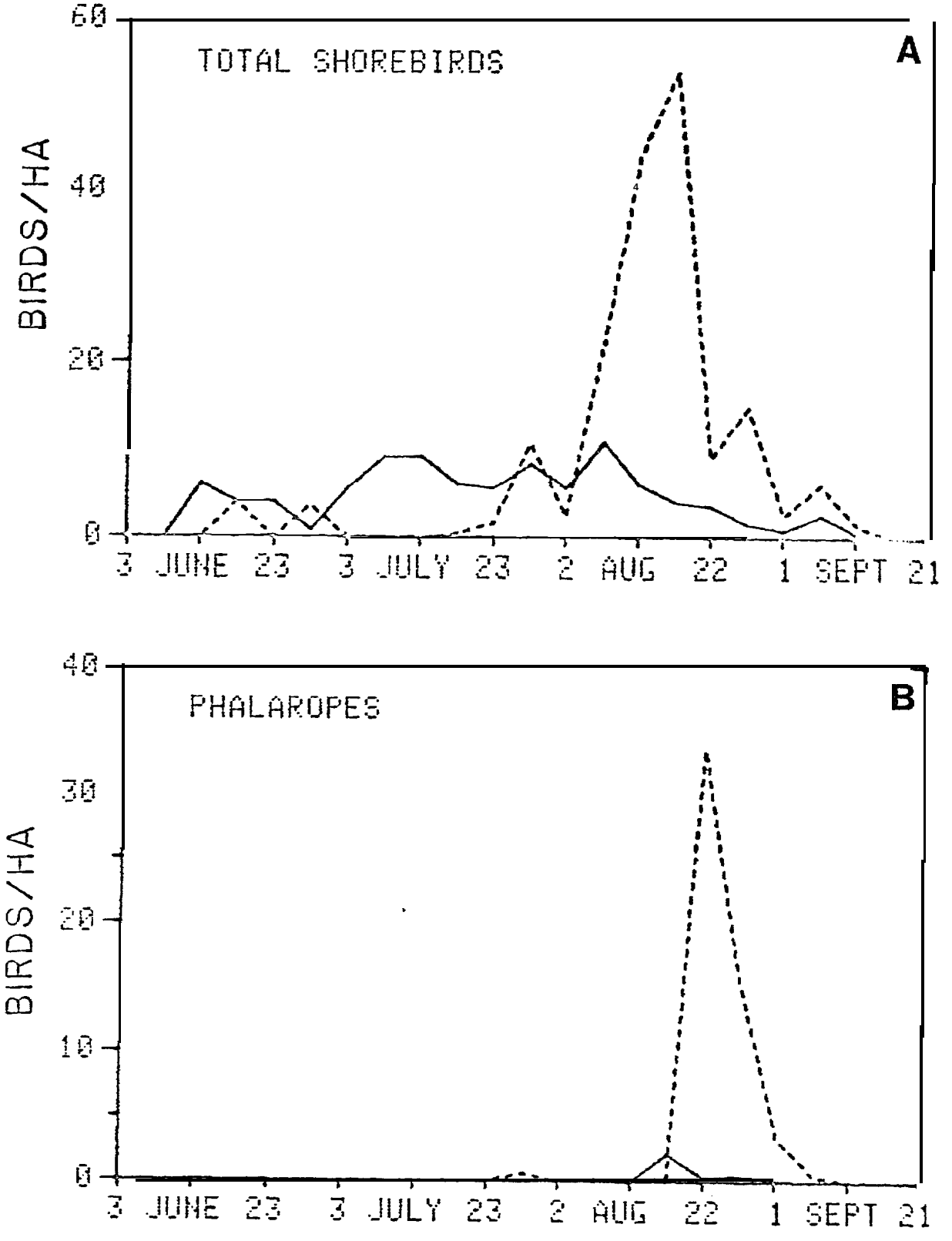


Figure 29. Prudhoe Bay bird densities on (A) altered drainage transects (dashed line) and control transects (solid line), and (B) artificial pier shorelines (dashed line) and mainland shores (solid line).

differences were not significant for any species. Two species were more common on the disturbed transects, however. Ruddy Turnstones and Glaucous Gulls are both preferential garbage foragers, occurring in higher densities on the transects where garbage was more frequent.

The extent of any deleterious effects of noise and activity disturbance will vary with the species involved and with their activities in the disturbed area. Colonies of nesting waterfowl will be very sensitive to disturbance during the breeding season. Our gravel shoreline transect comparisons indicate that the sensitivity of late summer migrant shorebirds and gulls is rather low, but that turnstone and gull populations might be locally enhanced if shoreline garbage becomes widespread.

Artificial causeways. Prudhoe Bay also offers a preview of what we might expect from the construction of artificial gravel shorelines -- drilling islands and causeways in shallow water -- in the form of the ARCO west dock, a gravel pier over 2 km long extending into the bay and used for unloading barges, and the shorter east dock. Our transects along these artificial spits indicate that zooplankton foraging birds -- phalaropes, gulls, terns and some other shorebirds -- will use these shorelines in preference to the adjacent natural mainland shores. In fact, densities of phalaropes (mainly Northern) were an order of magnitude higher along the artificial spits in August (Figure 29B). Shorebirds which are less dependent upon zooplankton during this period (especially Dunlins) were more common on the muddier mainland shores (Figure 30A). Lapland Longspurs and Snow Buntings, foraging on seeds and insects, were almost confined to the mainland shores (Figure 30B).

This result for zooplankton-foraging birds is just what we predicted based on the high density use of natural spits and barrier islands in 1975-1977 along the Beaufort-Chukchi coasts (Connors and Risebrough, 1978). Since the prey base is mainly marine zooplankton and under-ice amphipods, species more strongly associated with the water than with the particular shoreline substrate, the artificial spit apparently functions similarly to its natural counterpart. We don't know why spits and islands were more attractive than mainland shores during these 3 years, and a different result in 1978 calls this conclusion into question (Connors and Risebrough, 1979). We suspect that local current effects may be involved in producing occasional blooms of zooplankton along these shorelines. Extremely high densities of euphausiids, copepods, and chaetognaths occurred along Barrow Spit during the 4 years of this study, and a short but intense bloom of copepods along the ARCO dock in August 1978 attracted large numbers of phalaropes, gulls, and fish.

We have suggested above an additional hypothesis to explain apparently heavier use of spits and islands by phalaropes. The flexible foraging behavior of phalaropes in relation to wind direction and zooplankton densities indicates that spits and islands, with exposed and protected

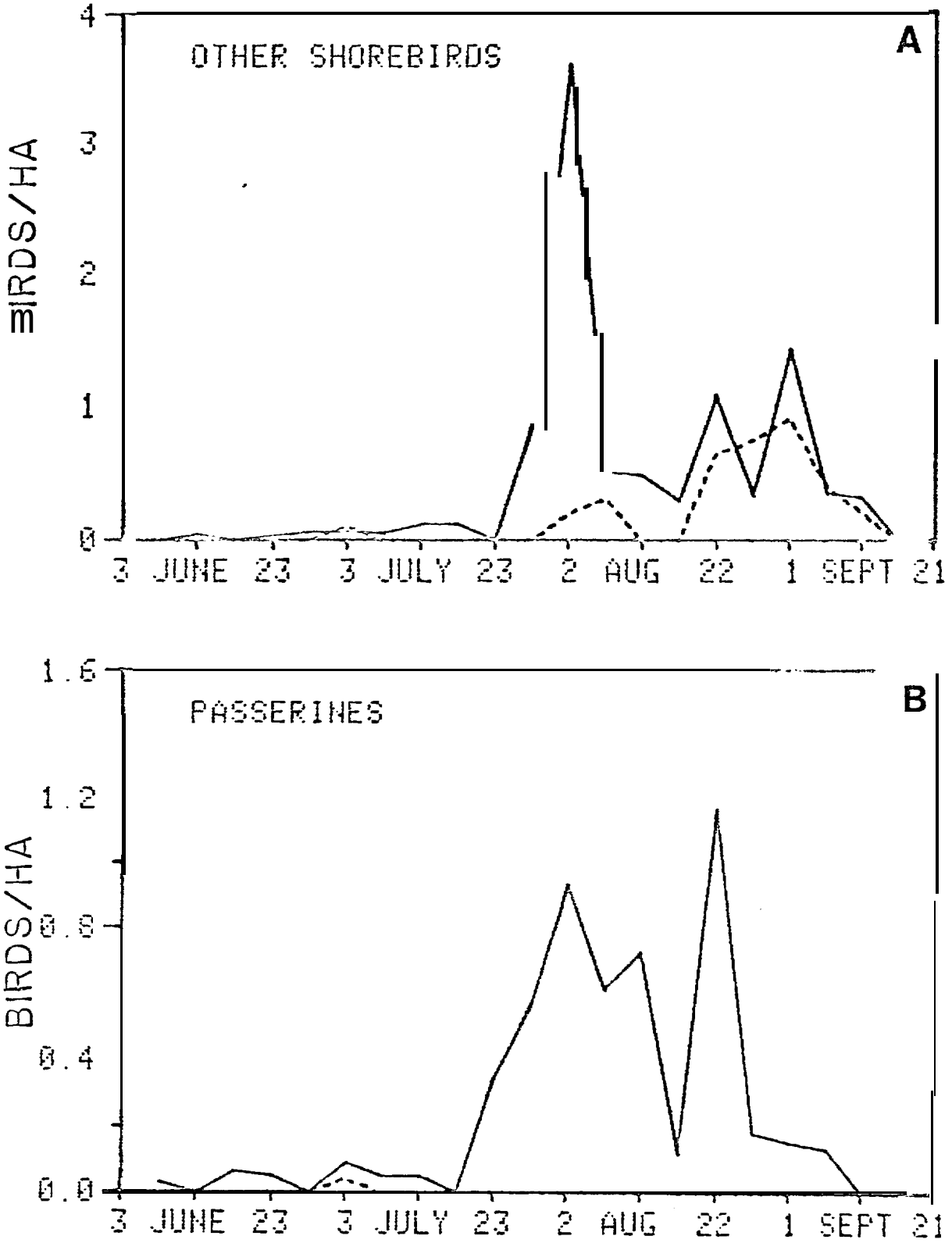


Figure 30. Comparison of bird densities on Prudhoe Bay artificial pier shorelines (dashed line) and on mainland shores (solid line).

shores in all wind conditions, offer more foraging options than do mainland shores.

Our Prudhoe Bay results suggest that artificial gravel piers and drilling platforms will be more heavily used than natural mainland shores by several species of shorebirds, gulls and terns, which on the surface sounds like an argument in their favor. However, the net effect will be one of attracting birds to precisely those habitats where oil spills will be most likely to occur, that is, where construction, barge traffic, and drilling activities will be most intense.

Responses of juvenile Red Phalaropes to thin oil films

The results of our foraging experiments and choice experiments to determine the effects of thin oil films on phalarope behavior were presented in full in Connors and Risebrough (1980). The results are of sufficient importance that we will repeat the main points in this report.

The initial results of the choice experiment are presented in Figure 31, comparing the number of choices made for clean pans and for oiled pans as a function of the sequence number of the choice. Of 12 birds making choices, all 12 made a first choice, 6 of them for oiled pans and 6 of them for clear pans. Only 10 of them made a second choice, 8 made third choices, and so forth, with only one bird making a twelfth choice. There is no suggestion of any discrimination in that first choice; birds were as likely to choose oiled as clear pans. But on subsequent choices, behavior changed. After the second round of choices, birds were able to make a distinction and were opting for clear pans rather than oiled. Of the last 33 choices, only 2 were for oiled pans. The birds seem to have learned something of the effects of the oil very quickly. They apparently can make the distinction and do learn to avoid the oil.

Figure 32A addresses a possible alternative explanation for these results: that any birds entering the oil on the first or second choice might be so damaged by the oil that they failed to make any subsequent choices, and that all later choices were made by birds who chose clear pans consistently. This explanation does not apply. Figure 32A is a comparison of the total number of choices made by all 12 individuals split up into two groups depending on whether they chose oil or clear on the first choice. It demonstrates that birds choosing oil initially did continue to make subsequent choices; most of these choices were for clear pans.

The duration of foraging periods also differed between oiled and clear pans, as indicated in Figure 32B. The frequency histograms contrast markedly. A Mann-Whitney comparison of the duration of foraging periods on oiled vs. clear was significant ($p<.01$). The median duration on clear pans was 33 seconds, compared with a median time of only 5 seconds on oiled pans, an indication that once the birds get on the oil, they quickly respond to something and on average get out early.

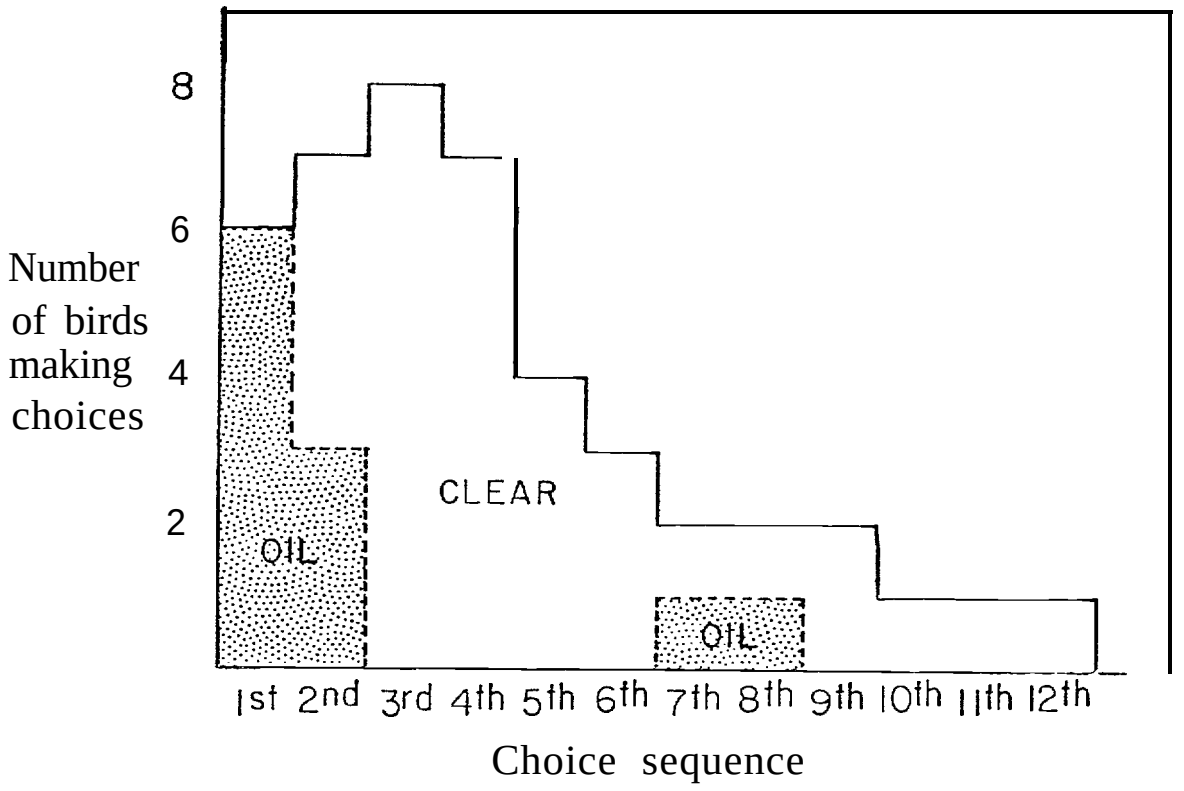


Figure 31. Comparison of phalarope choices for oiled versus clear surfaces.

The aquarium experiments support this conclusion. Phalarope behavior was recorded as foraging, resting, and escape behavior. This latter category includes swimming hard against the side of the aquarium, swimming rapidly from one side of the aquarium to the other, and occasionally attempting to fly. The percent of time spent by phalaropes in these escape behaviors varied widely, but increased strongly with increasing oil film thickness (Figure 33). In the presence of even these extremely thin oil films, the birds quickly sensed the difference and responded by trying to avoid the oil.

What is the relevance of these results to OCSEAP? Admittedly these experiments present artificial situations and small sample sizes. Nevertheless, the statistical tests take into account the samll sample sizes and judge the results significant. Naive juvenile Red Phalaropes apparently do not distinguish between oiled and clear surfaces for foraging before they have any experience with the oil. However, upon contact they have a fairly consistent and very quick response to try to get away from the oil, and subsequently they can and do distinguish between clear and oiled surfaces, and they avoid the oiled surfaces. This suggests that phalaropes may reduce the impact of an oil spill by behavioral adjustments after a brief learning period, but some questions remain.

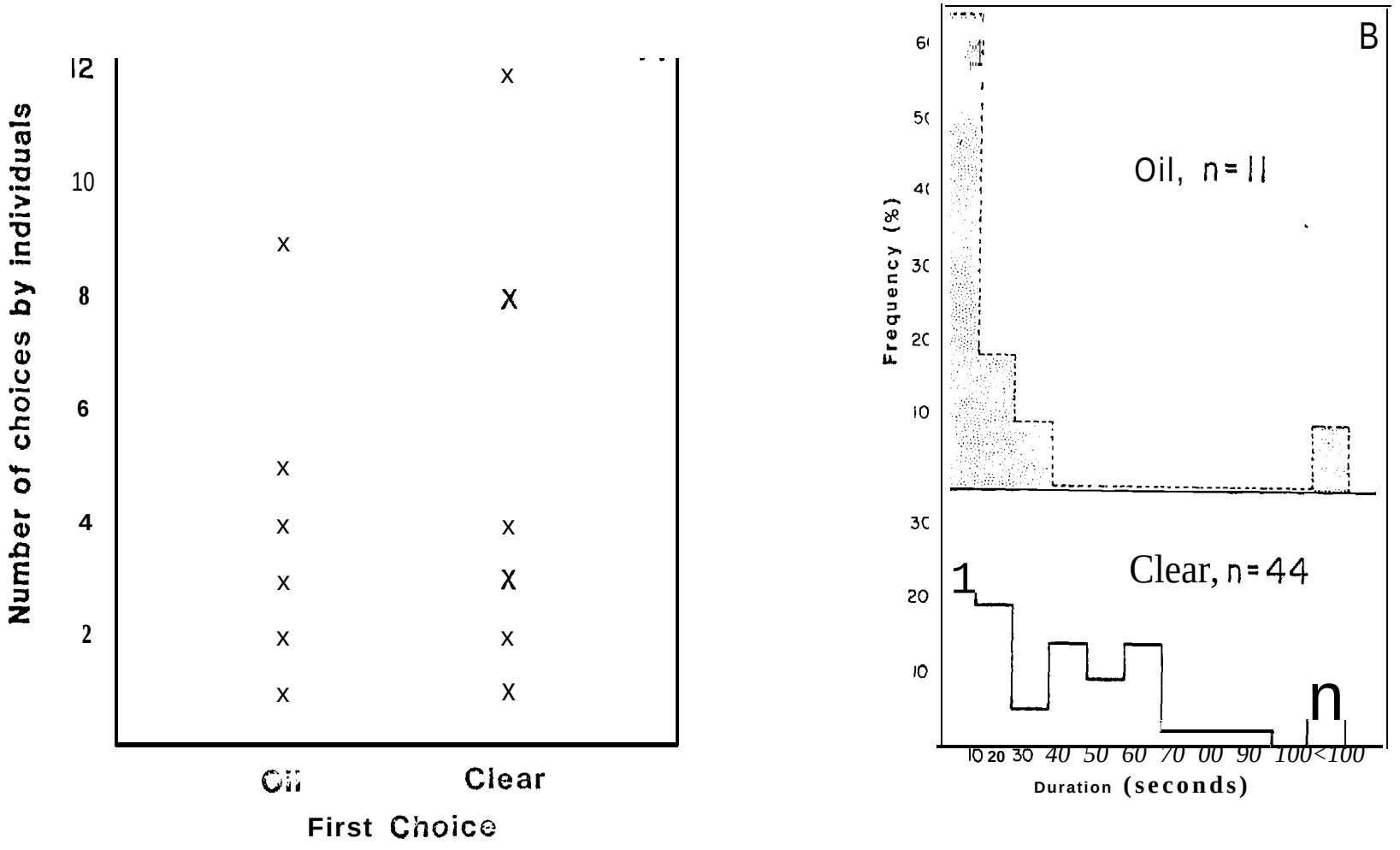


Figure 32. (A) Numbers of total choices by phalaropes after initial choice for oiled or clear pans. (B) Frequency of swimming periods of different durations on oiled or clear surfaces.

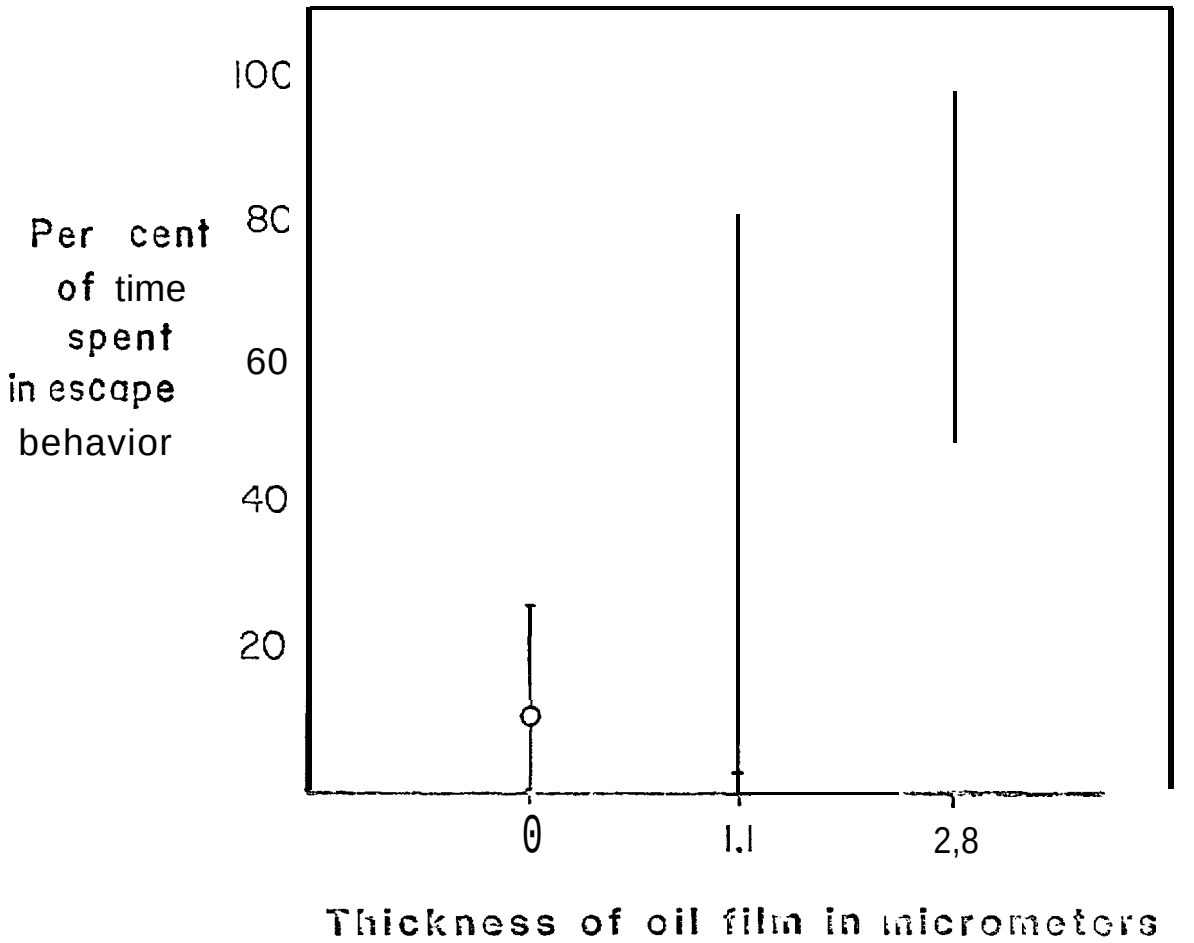


Figure 33. Escape response of Red Phalaropes in the presence of thin oil films.

For one thing, the bird can only avoid the oil if it has some alternative. In a very large, widespread, thick spill, the birds may not "have nearby alternate choices of clean water. We have not tested whether they will fly long distances along the coast to avoid an extensive continuous spill. 'We suspect, however, that they will try to avoid small slicks if they have a clean nearby alternative, as might be the case in a small or patchy, broken-up oil slick.

The other critical question which remains is whether a bird after contact with oil for 5 seconds can be saved by subsequent behavior. Is that already too late? Within our experiment, we cleaned most of the birds after oil contact. Five seconds on one of the small pans was enough time to pick up a considerable amount of oil. On three of the individuals who had been in very briefly we did not do any cleaning. We merely returned them to their wire holding cage, outside at Barrow. They had plenty of food but may well have been under other stresses due to captivity. In each case these birds had, within a matter of a few hours, reworked all their plumage and had changed wet, sticky smears on their underparts to a dry and very uniform huffy color on all the

plumage. The feathers were in good fluffy condition so the birds were probably able to control their temperature while out of the water. In experiments within the next few days these birds appeared able to swim reasonably well, so they had their plumage back in apparently functional shape, although the huffy color betrayed the lingering presence of oil residue on the feathers.

Whether a bird in the wild after this kind of brief exposure to a thin film could regain a healthy condition will depend on a wide variety of factors. Survival will depend on the type and thickness of the oil film, degree of contact, stress due to environmental factors - weather and foraging conditions - and the physiological state of the bird. We are presently unable to assess this. However, our guess now is that in many circumstances, phalaropes with this brief exposure (5 seconds or less to a thin film) would have a good chance of recovery and survival.

V. CONCLUSIONS

Many of the detailed conclusions of our studies have been presented in the preceding section. We summarize here our rankings of relative sensitivity to oil development for species, habitats, areas, and seasons.

Relative sensitivity of shorebird species

We have classified the common Beaufort coast shorebirds with respect to each species' relative sensitivity to littoral zone disturbances associated with oil development (Table 17). The principal disturbance being considered in this assessment is of course the threat of oil spills along the coast. The factors employed in making the assessment included primarily habitat use patterns of the various species. We gave primary weight to the relative use of tundra vs. littoral habitats, determined for each species by our transect work, but modified this with information on the choice of littoral habitat (gravel beaches, littoral flats or lagoon edges), the choice of foraging microhabitat within littoral habitats, and individual species foraging methods and behavior, to arrive at the final categorization. This assessment does not take into account, however, the possible duration of effects of an oil spill in different kinds of habitats as discussed above. The species with high sensitivity, Red and Northern Phalaropes, Sanderlings and Ruddy Turnstones, spend almost all of their time in late summer foraging in littoral habitats and usually in relatively exposed areas which would be the first hit by an oil spill. If however, oil is deposited on littoral flats and within lagoons and sloughs where it might affect prey densities and habitat conditions for several seasons, other species classed as moderately sensitive would also be strongly affected.

Relative sensitivity of habitats

Since the most effective method of managing bird populations is frequently a habitat management approach, we will summarize our results in terms of the littoral habitats we have studied. Table 18 summarizes this sensitivity ranking for six general descriptions of Beaufort coast littoral habitats. These categories emphasize the habitat features which correspond to major differences in bird use in terms of species composition and densities of shorebirds. The ranking also takes into account relative amounts of each habitat along the Beaufort coast.

Sensitive coastal areas

Results of mapping the Beaufort coast regions of highest bird use have been published in the Interim Synthesis Report: Beaufort/Chukchi (Weller *et al.*, 1978) with information added for the Harrison Bay area in the Synthesis Report for Lease Sale #71. For shorebirds, the sensitive areas correspond to the main concentration areas at spits and barrier islands - Peard Bay, Pt. Barrow, Plover Islands, Jones Islands, and

Table 17: Relative sensitivity of common shorebirds to littoral zone disturbances.

HIGH	MODERATE	LOW
Red Phalarope	Semipalmated Sandpiper	American Golden Plover
Northern Phalarope	Western Sandpiper	Pectoral Sandpiper
Sanderling	Baird's Sandpiper	
Ruddy Turnstone .	Dunlin	
	Long-billed Dowitcher	

Table 18: Relative sensitivity of Beaufort littoral habitats. (Listed in order of decreasing sensitivity)

1. Littoral flats and saltmarsh
2. Sloughs and small lagoons (water surface and shorelines)
    1. with broad muddy margins
    2. with narrow margins
3. Spits and barrier islands
4. Mainland shorelines with broad beaches
5. Mainland shorelines with narrow beaches

perhaps other less studied barrier islands - and regions of extensive littoral flats or sloughs and lagoons - Fish Creek Delta, Colville Delta, and other sites less extensive or less studied (perhaps Pitt Point and Cape Halkett areas; see Figure 1). These are the main areas where highest total numbers of shorebirds are likely, but heavily used habitat areas are present along many other regions of the Beaufort coast. In these cases habitat protection will be most profitable.

Sensitive seasons

Shorebirds are present along the Beaufort coast from the end of May to late September. During June most birds are confined to tundra habitats, but densities in littoral areas are high from mid-July through early September. This is the period during which habitat disturbances will have the greatest impact on shorebird numbers. Most habitat disturbances will last through many seasons regardless of the time of initiation. Nevertheless, the winter period, when shorebirds are absent, corresponds to the frozen period, when habitats are less sensitive to alteration: we recommend that development take place during winter months whenever possible.

VI. APPENDIX

SEASONALITY OF LITTORAL ZONE USE - COMMON SPECIES

1. Semipalmated Plover (*Charadrius semipalmatus*). Figure 34A. Densities of this species are probably very low throughout the Alaskan arctic. They nest in sparsely vegetated gravel areas, conditions which occur frequently near gravel beaches. Most of the individuals recorded on our transects had nests nearby. An oil spill along the Beaufort coast washing into gravel areas along the edge of lagoons and sloughs or behind beaches might affect a large percentage, but few individuals, of the small population of this species.

2. American Golden Plover (*Pluvialis dominica*). Figure 12A. Of all common Barrow shorebirds, this species is the most nearly restricted to tundra habitats. Figure 12A shows the four-year mean density in littoral zone transects compared to densities on tundra transects over five years (Myers and Pitelka, 1980). Littoral zone use is almost insignificant even after all littoral habitats are ice-free. This pattern in Golden Plovers suggests they would not be readily affected by developments along the shoreline or by accidents involving spilled oil. Our observations at other sites along the Beaufort coast corroborate this habitat use pattern. However, along the southern Chukchi coast near Kotzebue, Golden Plovers show a very different habitat distribution. In August the extensive salt marsh and flooded tundra areas of this region support large numbers of juvenile Golden Plovers. This may be a response to differences in the availability of habitats in the Beaufort compared to the southern Chukchi or to differences in the availability of prey within these habitats in the two areas; or it may relate to differences in the behavior of the two subspecies, *P. d. dominica*, the Barrow breeding race and *P. d. fulva*, the race which becomes more common in the southern Chukchi (Connors, in prep). At any rate our Barrow data suggest that along the Alaskan Beaufort coast the Golden Plover is relatively insensitive to disturbance by offshore oil development.

3. Black-bellied Plover (*Pluvialis squatarola*). A regular breeder inland and east of Barrow, this plover shifts to littoral habitats during migration more than does its congener, but numbers seen on our transects have been low at all Beaufort sites.

4. Ruddy Turnstone (*Arenaria interpret*). Figure 34B. Common breeder and migrant. Adult Turnstones breed on the tundra at Barrow in low densities (approximately .024 pairs per hectare; Myers and Pitelka, 1980) but shift to littoral habitats as nesting duties are finished. Adults depart Barrow in early August but juveniles remain in the littoral zone throughout August; densities here are much higher than on the tundra. This shift in late summer habitat agrees with

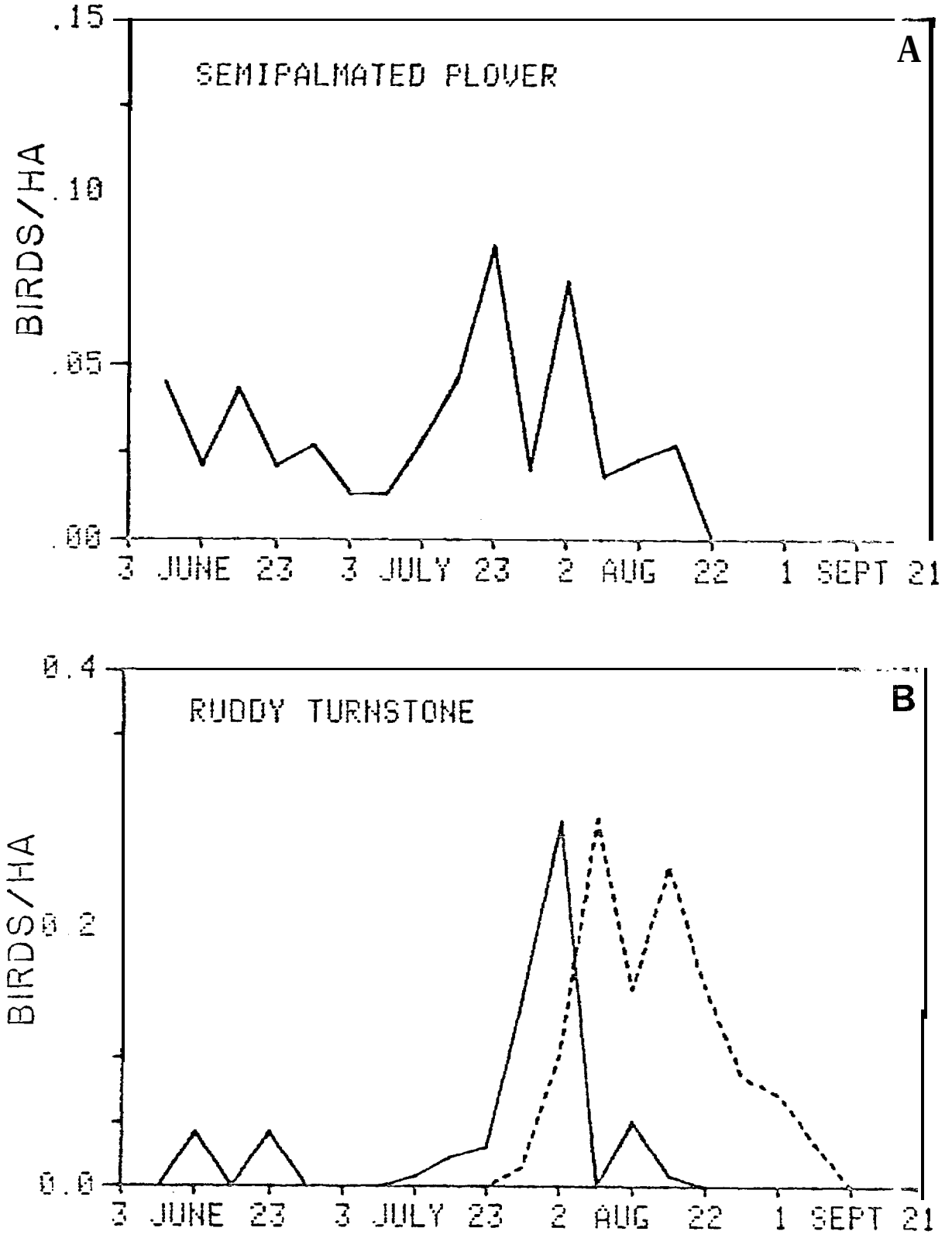


Figure 34. Mean shorebird densities at Barrow 1975-1978. (A) Semipalmated Plover. (B) Ruddy Turnstone. Adults (solid line) and juveniles (dashed line).

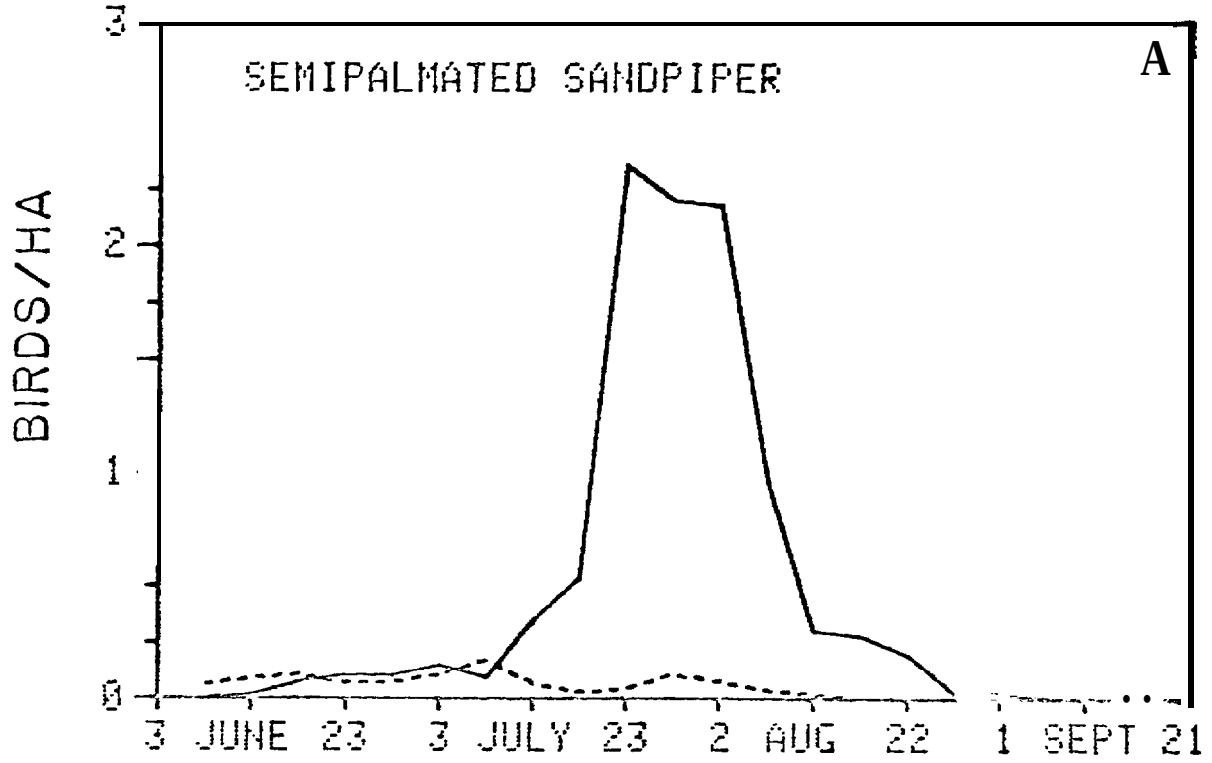
a report by Nettleship (1973) for an area in the Canadian arctic where fledged juveniles began foraging on the shores of a large cold lake.

5. Semipalmated Sandpiper (Calidrus pusilla). Figures 7, 8A, 25A, 35A, 35B. This species is a common breeder along the Beaufort coast. Adults nest on tundra but often forage on stream margins or mudflats adjacent to the nesting areas. Adults are therefore fairly common in littoral habitats throughout the early part of the season, in contrast to most of the Barrow sandpipers. As juveniles fledge in late July however, we observe a sudden and striking movement of this species into littoral areas (Figure 35B). This juvenile peak occurred at Barrow in all four years (Figure 8A) as well as at Fish Creek Delta (Figure 25A), Prudhoe Bay, Icy Cape and Wainwright. It is very short lived but may be important to juveniles for accumulation of fat reserves prior to southward migration.

6. Western Sandpiper (Calidrus mauri). Figure 8B, 36A. This species is an uncommon breeder at Barrow and becomes more rare eastward along the Beaufort coast. It is a fairly common migrant at Barrow however, with a seasonal habitat use pattern quite similar to that of Semipalmated Sandpiper. Adults occur on tundra and in littoral areas in early summer with a peak in late June or early July of most years followed by a juvenile littoral zone movement slightly later than, and of less magnitude than, Semipalmated Sandpiper.

7. Baird's Sandpiper (Calidris bairdii). Figure 36B. Seasonal habitat use by this species contrasts with most of the other Calidris sandpipers. Baird's Sandpipers nest frequently near lagoon edges, in tundra near brackish pools and on or near gravel beaches. One nest on Barrow spit was located in drift material 5 meters from the edge of Elson Lagoon on the gravel beach. The young hatched out several hundred meters from the nearest small patch of tundra vegetation. We located another brood near Nuwuk Lake on Point Barrow. These downy young, approximately one week old, were foraging directly on live zooplankton in the shallow water of a brackish flood pool. This species also nests commonly on coastal tundra in non-littoral areas. Departure of Baird's Sandpipers occurs earlier in August than that of most other Sandpipers, and densities of juveniles prior to departure remain low, indicating no movement of birds from distant areas through the Barrow area. The densities of individuals on littoral transects compare to a mean breeding density of .06 pairs per hectare at Barrow (Myers and Pitelka, 1980).

8. Sanderling (Calidris alba). Figure 37A. This species occurs in small numbers as adults at Barrow in early June, primarily in littoral areas near lagoons. In August and early September it is fairly common on gravel shores of Barrow Spit but much less common along mainland shores and



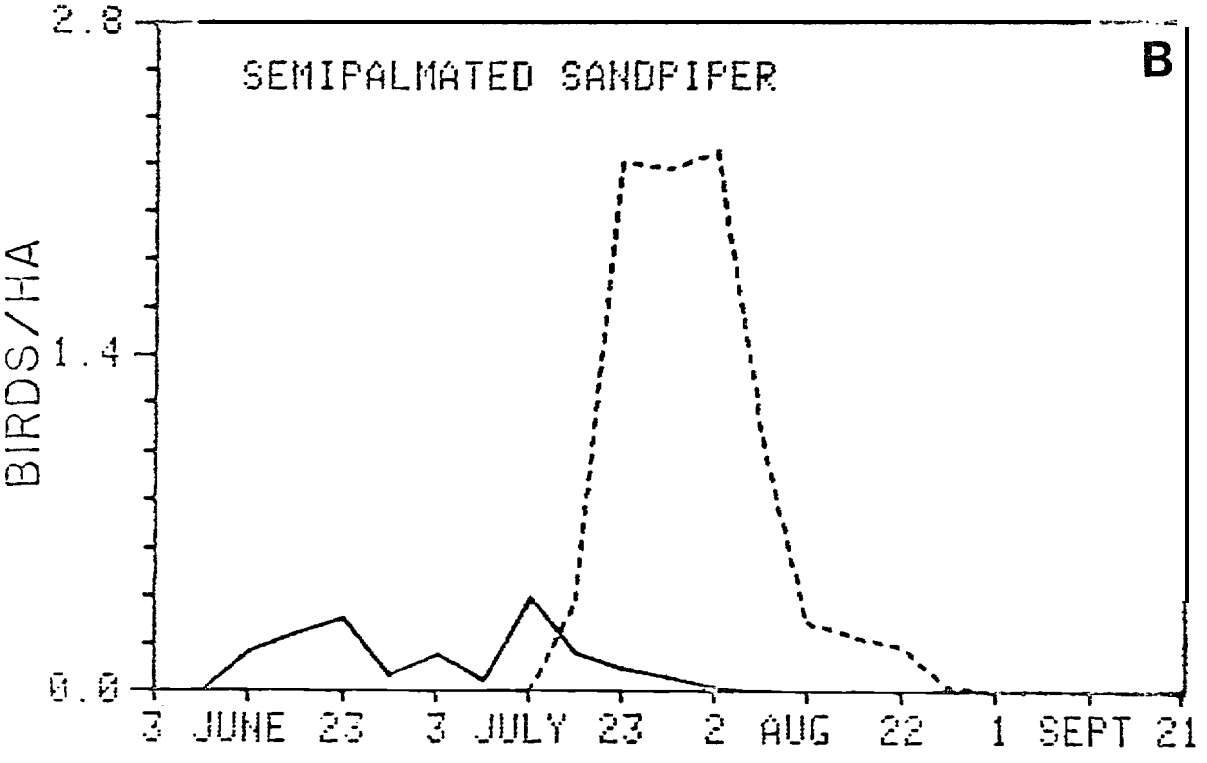


Figure 35. Mean Semipalmated Sandpiper densities at Barrow, 1975-1978. (A) Tundra (dashed line) vs. littoral (solid line). (B) Littoral transects: adults (solid line) vs. juveniles (dashed line).

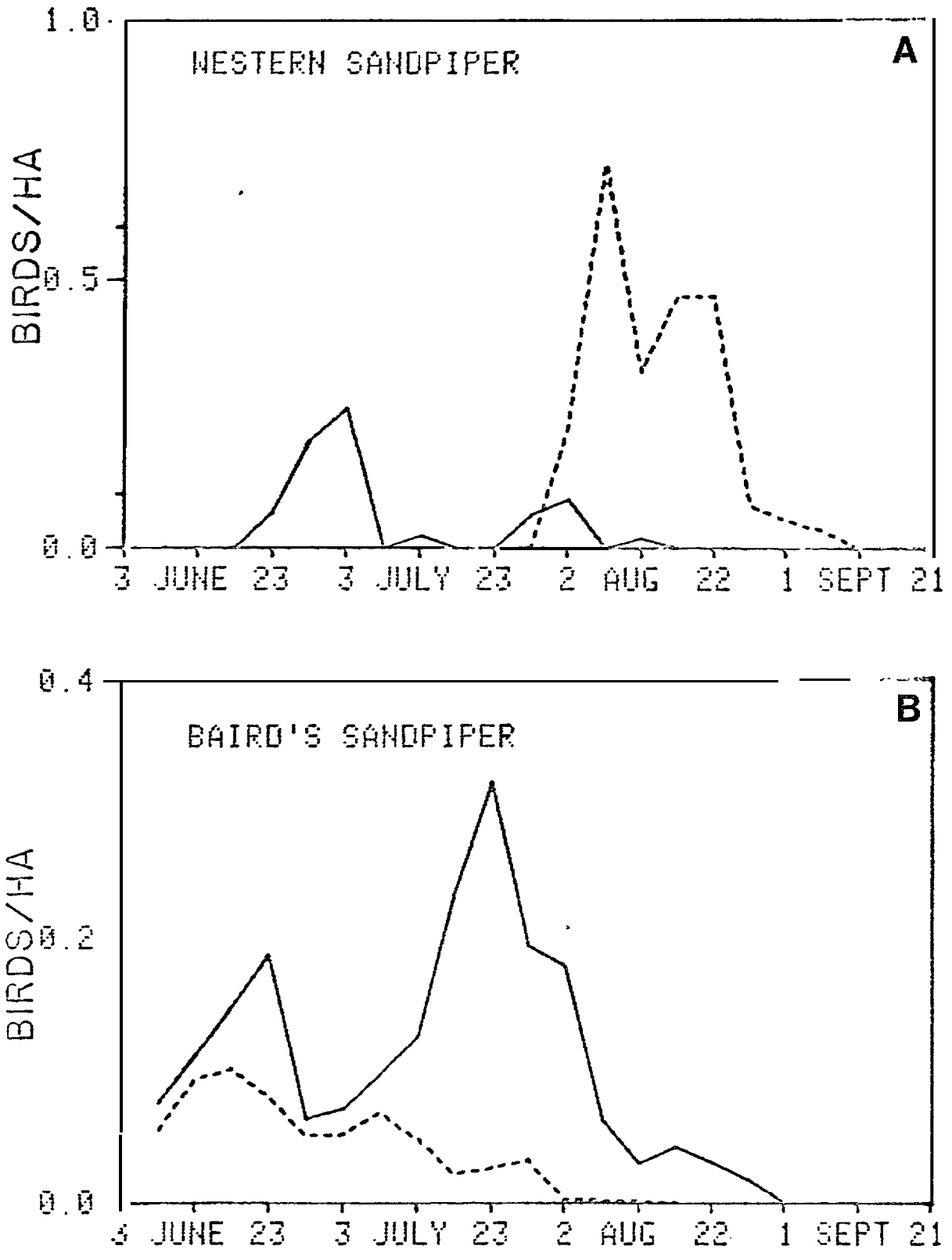


Figure 36. Mean shorebird densities at Barrow, 1975-1978. (A) Western Sandpiper, littoral habitats. Adults (solid line) vs. juveniles (dashed line). (B) Baird's Sandpiper, tundra (dashed line) vs. littoral (solid line).

almost absent from other littoral habitats. Essentially all late summer Sanderlings at Barrow are juveniles, foraging on marine zooplankton along the water's edge and accumulating heavy fat reserves prior to migration.

9. Pectoral Sandpiper (Calidris melanotos). Figure 37B. This species remains common on tundra in late summer, with limited-movement to the littoral zone, primarily in muddy habitats near wet tundra or in salt marshes. Flocks occur irregularly in these areas as first post-breeding males and later females and juveniles begin southward migration.

10. White-rumped Sandpiper (Calidris fuscicollis). This species nests uncommonly at Barrow and probably at other sites along the Beaufort coast. We encountered only a few individuals on littoral zone transects.

11. Dunlin (Calidris alpina). Figures 12B, 24B, 38A. This common and widespread arctic sandpiper occurs in moderate to high densities on tundra throughout the summer but forages commonly in littoral habitats in late summer. At this time both adults and juveniles occur in tundra and littoral habitats. Juveniles appear to be somewhat more common in littoral areas, especially during late August, but this distinction is not as clear as earlier observations had indicated (Holmes, 1966a, b). We also suspect a distinction between the types of habitat used by adult and juvenile Dunlin within the littoral zone. Adults appear more likely to forage in mudflat and brackish pool margin habitats, whereas juveniles are more likely on gravel shores where they forage on plankton.

12. Stilt Sandpiper (Micropalama himantopos). A rare migrant at Barrow, nesting near Prudhoe Bay and farther east, where it is fairly common in littoral areas with shallow brackish pools.

13. Buff-breasted Sandpiper (Tryngites subruficollis). An irregular breeder at Barrow, more common eastward toward Prudhoe Bay. Restricted to tundra during the breeding season and occurring in migration on tundra near shorelines.

14. Long-billed Dowitcher (Limnodromus scolopaceus). Figure 38B. Juveniles of this species occur in high densities on tundra and in littoral areas (mudflats, saltmarsh, slough edges) at Barrow in mid to late August every year. This is a sudden, heavy migrational movement of juveniles beginning southward migration, probably from nesting areas inland on the north slope.

15. Red Phalarope (Phalaropus fulicarius). Figures 11A, 11B, 24A, 39A. This common nesting species at Barrow and along the Beaufort coast becomes abundant in littoral areas during late summer migration. Several aspects of Red

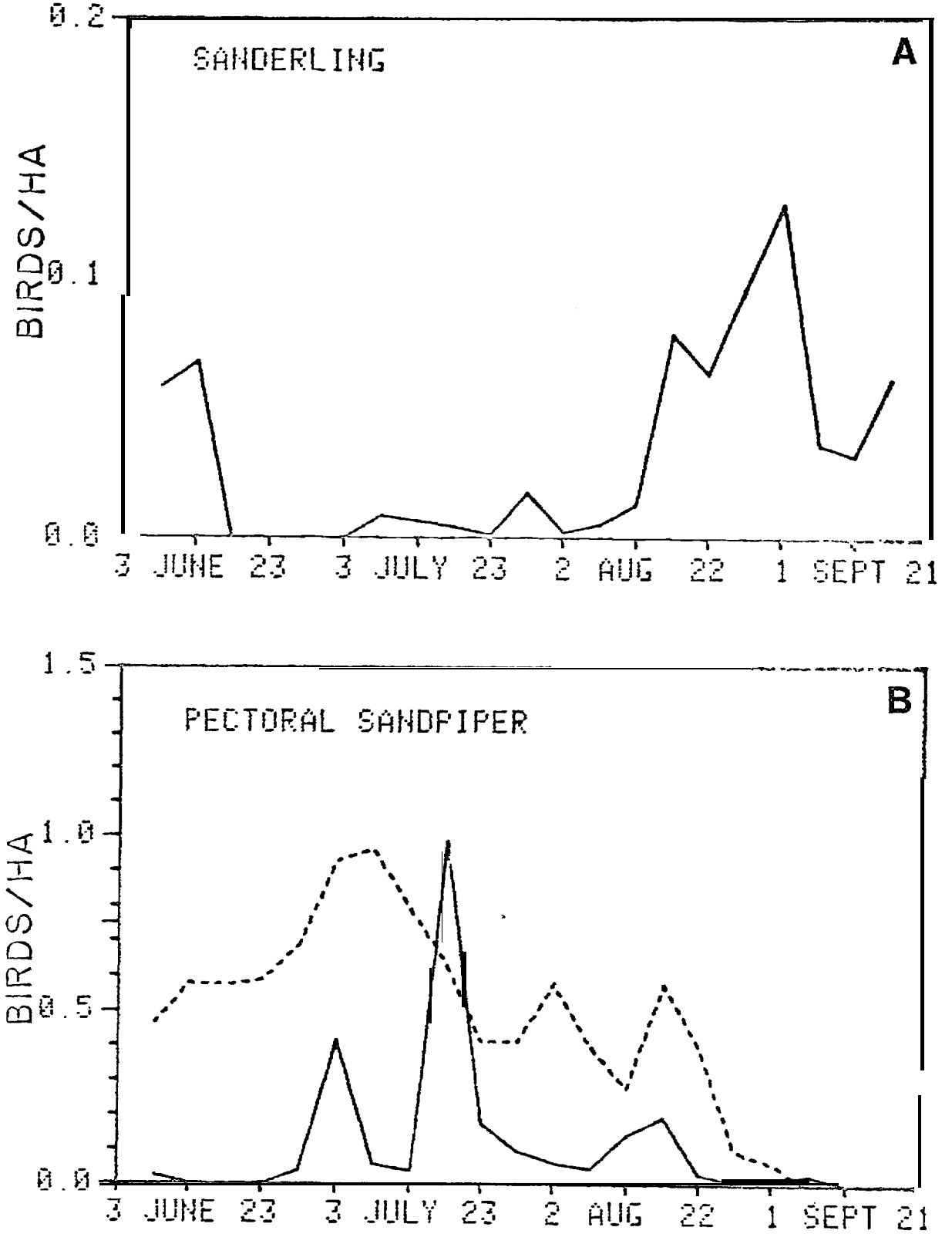
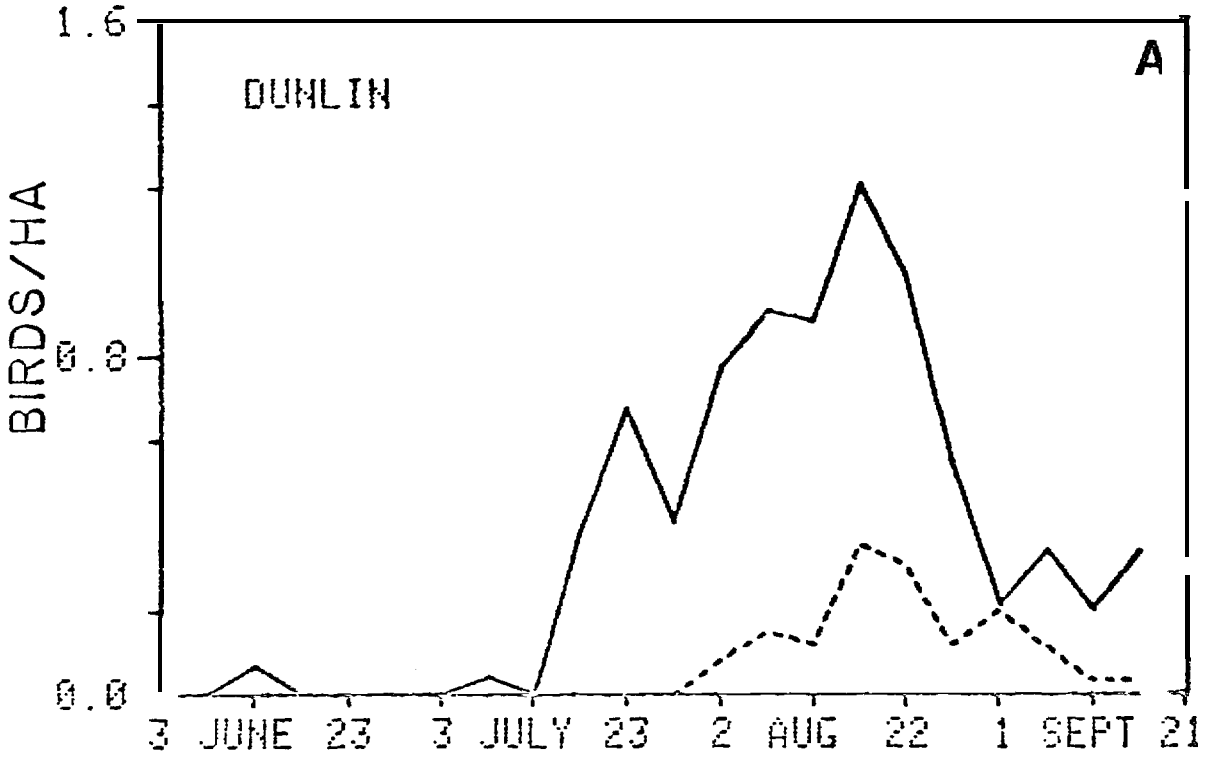


Figure 37. Mean shorebird densities at Barrow, 1975-1978. (A) Sanderling, littoral habitats. (B) Pectoral Sandpiper, tundra (dashed line) vs. littoral (solid line).



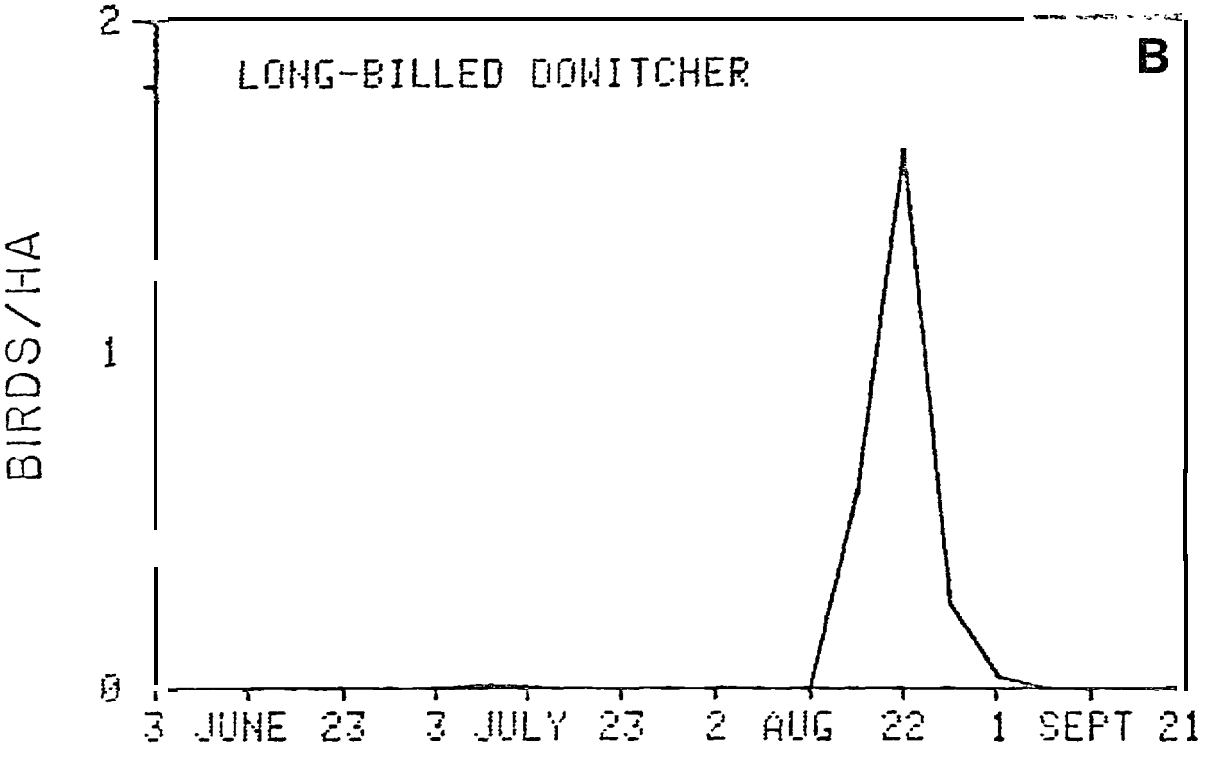
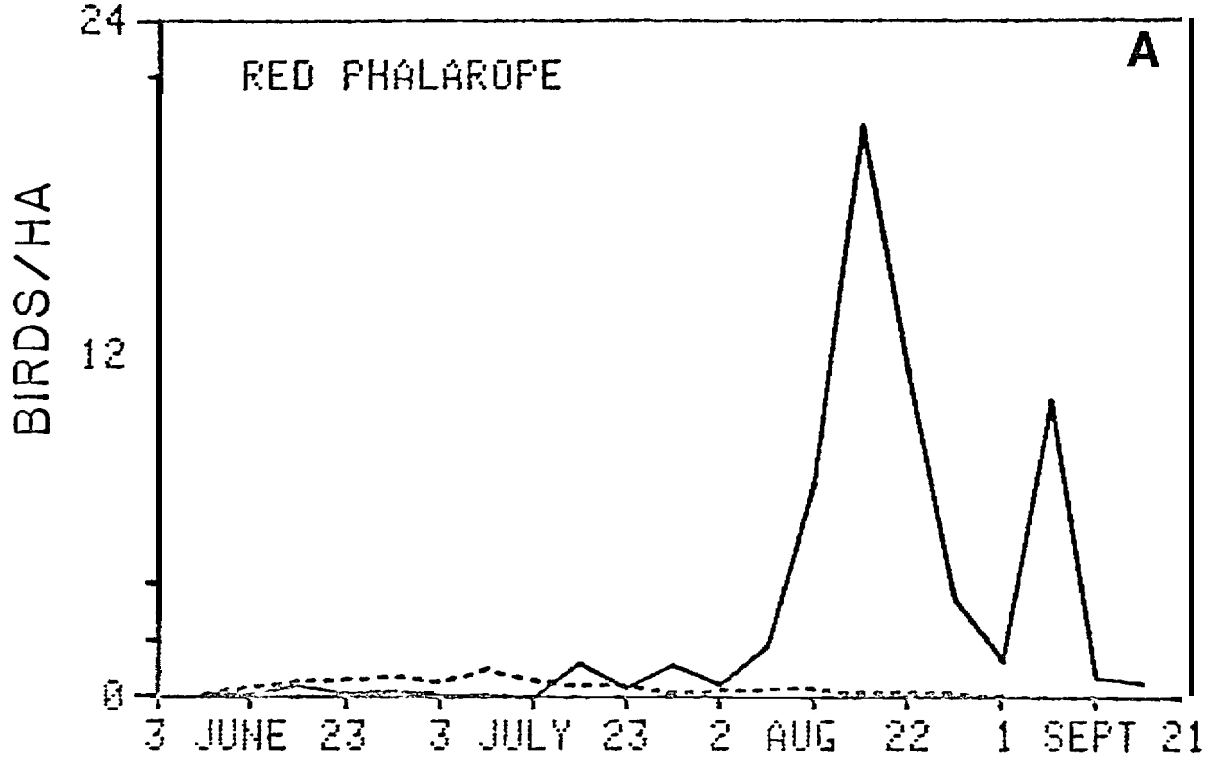


Figure 38. Mean densities at Barrow 1975-1978. (A) Dunlin, littoral transects. Adults (solid line) vs. juveniles (dashed line). (B) Long-billed Dowitcher, littoral transects.



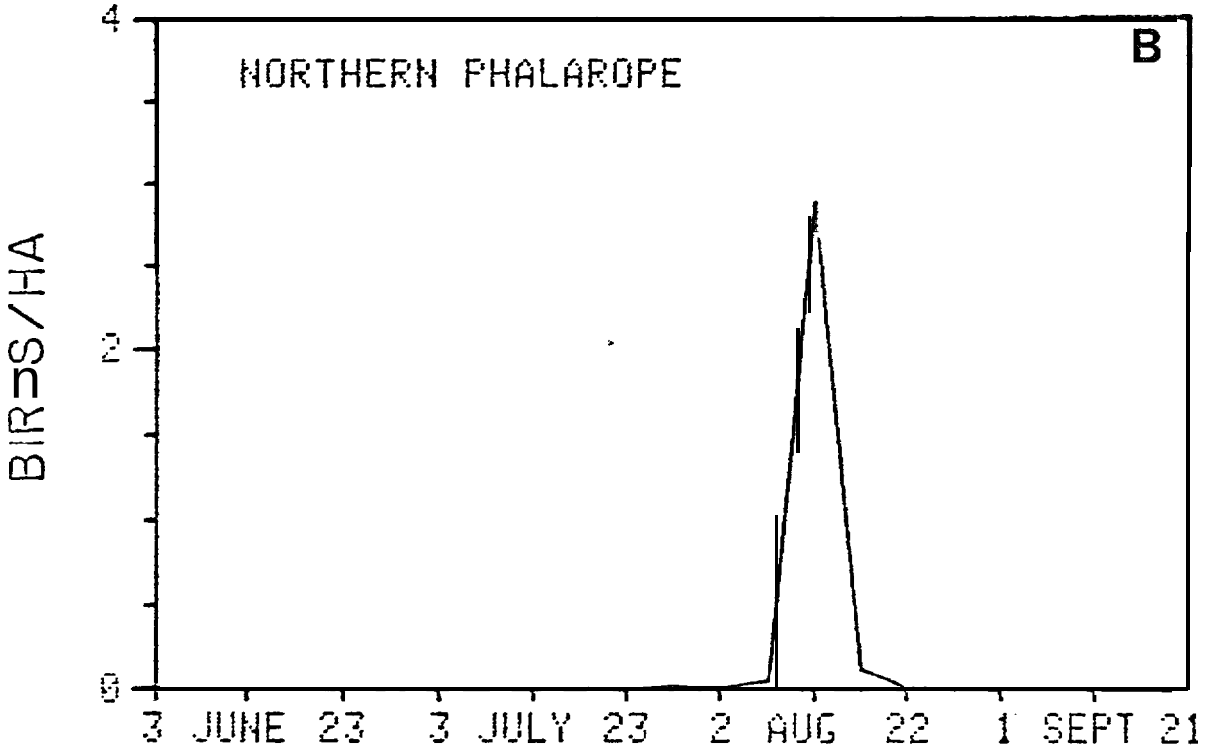


Figure 39. Mean shorebird densities at Barrow, 1975-1978. (A) Red Phalarope, tundra (dashed line) vs. littoral (solid line). (B) Northern Phalarope, littoral transects.

Phalarope movements and foraging ecology have been discussed within Results. Briefly, males and females nest on tundra in June. After clutch completion, females flock and begin migration, spending some time in ice-free littoral areas in late June or early July. Adult males tend the young, moving to some extent into littoral habitats in late July before they migrate southward. In early and middle August a flood of juveniles reaches the littoral zone, mainly along gravel shorelines where they forage on marine zooplankton. Densities in areas of gravel spits and barrier islands become extremely high, where phalaropes will be highly susceptible to damage from oil spills.

16. Northern Phalarope (Lobipes lobatus). Figure 24A, 39B. Uncommon but erratic at Barrow and increasingly common eastward along the Beaufort coast. Ratios of Red to Northern Phalaropes vary at different sites along the Beaufort, as discussed in Results. Northerns were much more common than Reds along the coast at Prudhoe Bay in 1978.

17. Glaucous Gull (Larus hyperboreus). Figure 40A. This largest and most common gull at Barrow occurred in highest densities along two of our transects because of proximity to the Barrow dump; nevertheless this species appears to be widespread along shorelines at all arctic sites.

18. Sabine's Gull (Xema sabini). Figure 40B. Fairly common along the shores of Barrow Spit during August, usually foraging on marine zooplankton with Arctic Terns and phalaropes.

19. Black-legged Kittiwake (Rissa tridactyla). Figure 41A. This species occurs commonly along Barrow spit shorelines in August but is also present as a non-breeder along shorelines beginning early June.

20. Arctic Tern (Sterna paradisaea). Figure 41B. Sporadically present in very high numbers in the Barrow spit area throughout August and early September. Large numbers of terns forage and roost on several areas of gravel spits and barrier islands in the Beaufort. They forage on small fish and marine zooplankton and therefore occur at Barrow on the same transects as phalaropes, Sabine's Gulls and Sanderlings.

21. Lapland Longspur (Calcarius lapponicus). Figures 25A, 42. The most common tundra nesting Passerine along the Beaufort coast. During the breeding season it is essentially confined to tundra habitats but in August flocks of migrating birds, predominately juveniles, occur in areas of saline pools, lagoon edges, and saltmarsh flats. Their diet probably overlaps somewhat with that of shorebirds in these habitats but two juveniles collected at Barrow had been feeding principally on seeds.

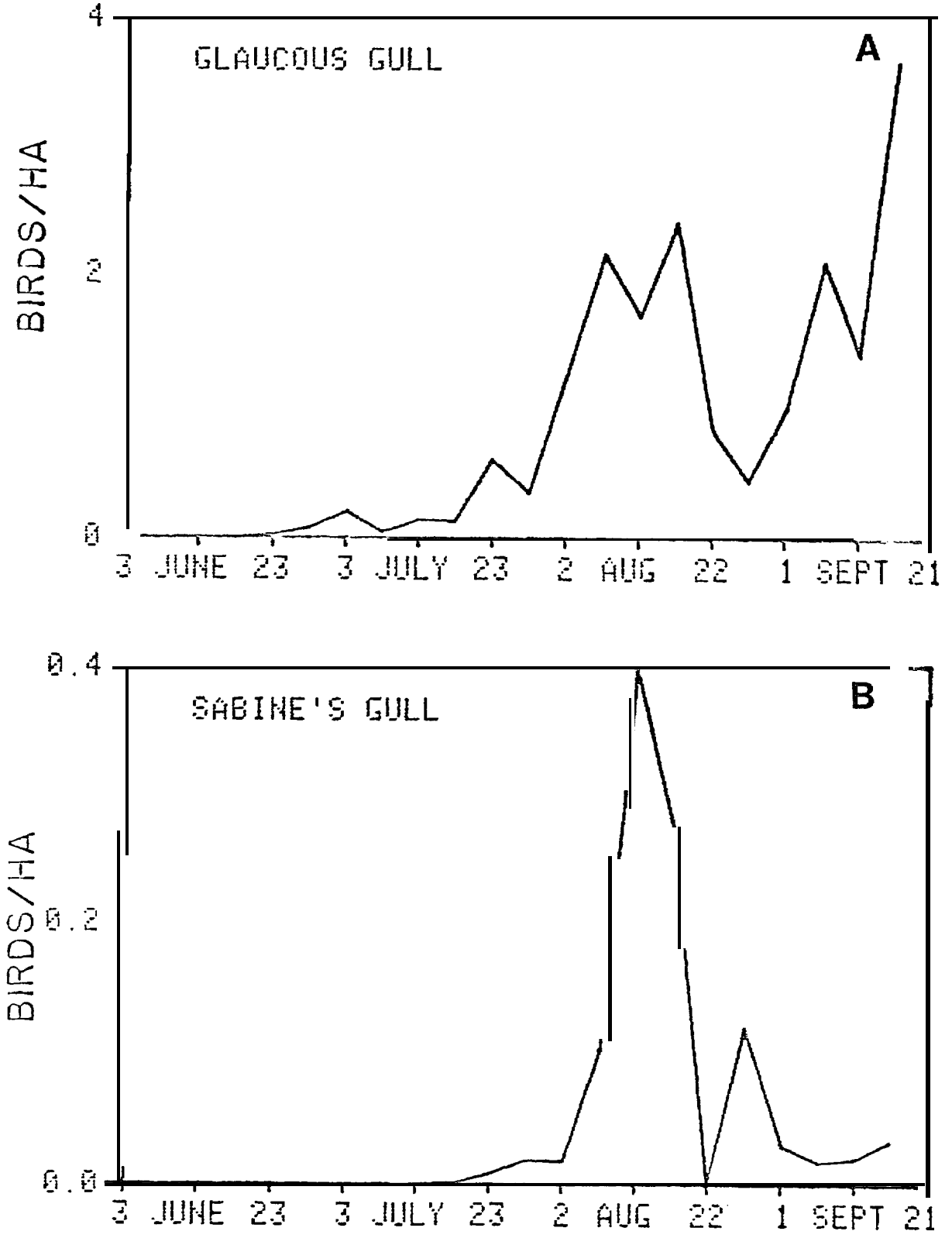
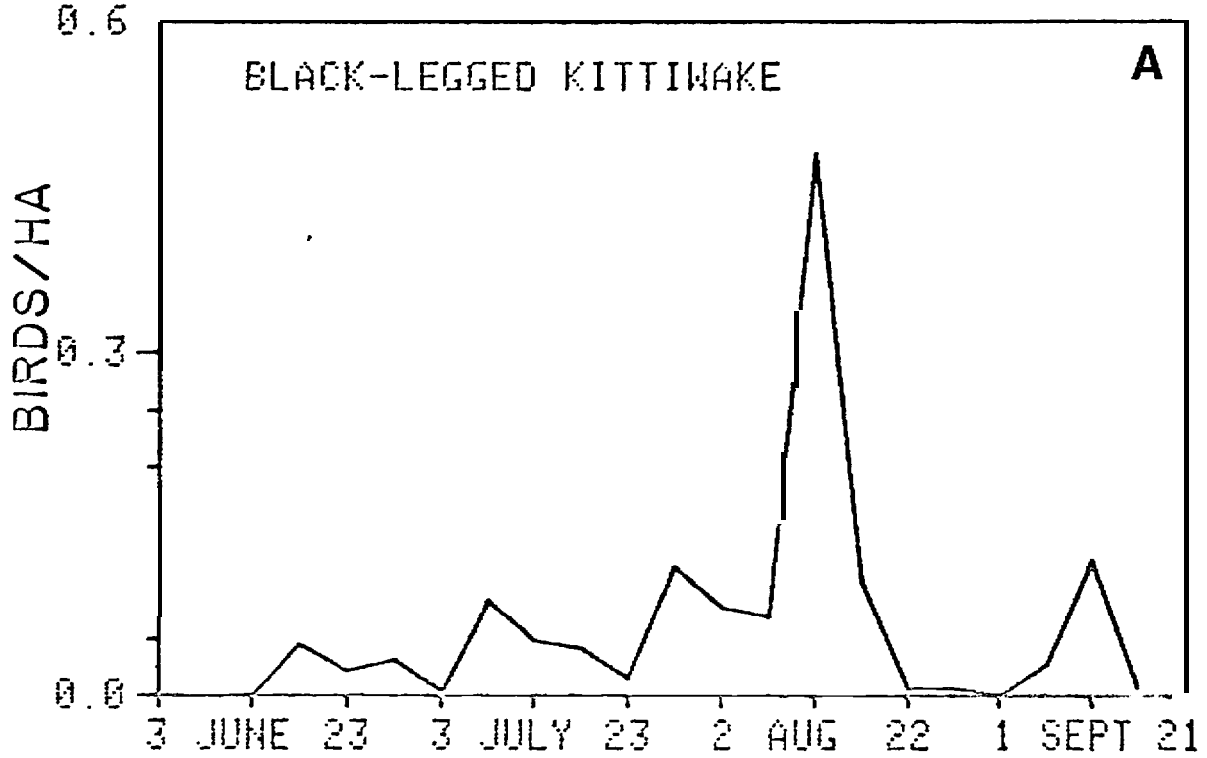


Figure 40. Mean densities on littoral transects, Barrow, 1975–1978.



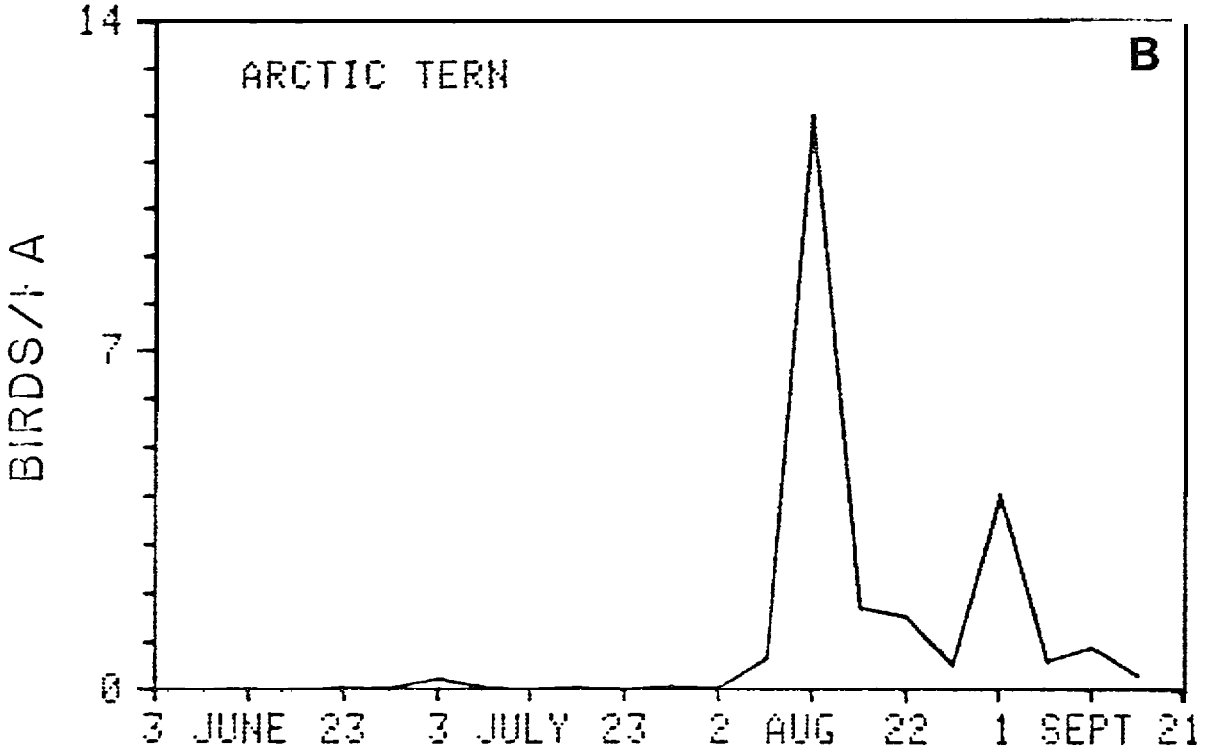


Figure 41. Mean densities on littoral transects, Barrow, 1975-1978.

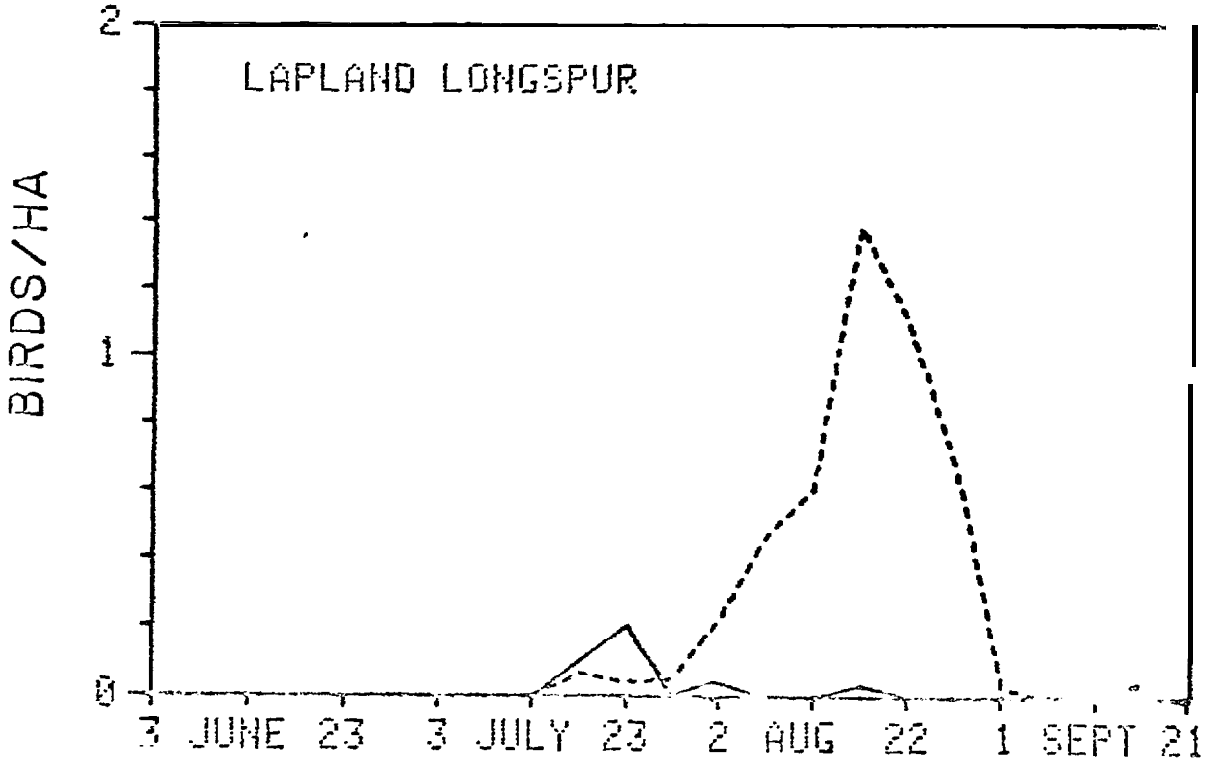


Figure 42. Mean densities on littoral transects at Barrow, 1976-1978. Adults (solid line) vs. juveniles (dashed line).

22. Snow Bunting (Plectrophenax nivalis). Snow Buntings are less widespread than Longspurs and individuals nesting near the littoral zone frequently forage in these habitats during the breeding season. In August there is a similar movement of juveniles and some adults into saltmarsh areas.

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