Littoral Zone Use by Post-breeding Shorebirds on the Colville River Delta, Alaska

A Thesis

Presented in Partial Fulfillment of the Requirements for the degree Master of Science in the Graduate School of the Ohio State University

by

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To Vernon Ora Dennis (1895-1972) and

Edward Abbey (1927-1989)

Eastward dark Falcon

On strong, enduring wing flies.

Knows not its fate.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE		PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

INTRODUCTION

Justification

The U.S. Fish and Wildlife Service, through the North Slope Bird-Habitat Study, charged the Ohio Cooperative Fish and Wildlife Research Unit with the task of assessing post-breeding shorebird occurrence in the littoral areas of the Colville River delta in 1986. This assignment complemented the Study's larger survey of bird-habitat relationships on the central Alaskan coastal plain (see Field et al. 1988). Through a Research Work Order between the Service and the Unit, a study was initiated, in 1986, to survey littoral habitats for the presence of post-breeding shorebirds.

Background

Shorebirds (Charadrii) are generally long distance migrants traveling from boreal or arctic breeding grounds to tropical or southern hemisphere wintering grounds. Recent studies have documented the abundance of, and habitat use by, staging and migrating shorebirds in temperate regions (e.g. Pitelka 1979). These investigations identified areas where shorebirds were particularly abundant during staging and migration (Myers et al. 1988). Although shorebirds are dispersed during the breeding season, many species concentrate in small, usually estuarine, areas when migrating (Myers 1983). Areas that host over a million shorebirds during this period have been found throughout the world (United Kingdom: Prater 1981; North Atlantic coast: Morrison and Harrington 1979, Hicklin 1987; Pacific coast: Senner and Howe 1984).

Within arctic Alaska, Connors et al. (1979) demonstrated a transition of shorebird use from upland tundra breeding areas to coastal habitats by mid-summer. The move to littoral habitats is thought to be related to changes in prey availability (Connors et al. 1979). Coastal zone use is characterized by an increase in shorebird density and diversity compared to inland tundra sites. Use of the littoral zone by shorebirds in arctic Alaska has been documented from the Chukchi Sea and Beaufort Sea coasts in a series of surveys from 1975-1981 sponsored by the Outer Continental Shelf Environmental Assessment Program (Connors and Risebrough 1976, 1977, 1978, 1979, 1980; Connors and Connors 1985; Connors et al. 1984). Surveys of shoreline habitats on the eastern North Slope were conducted during the baseline study of the Arctic National Wildlife Refuge (Garner and Reynolds 1986, Moitoret 1983).

The Colville River delta provides the most extensive saltmarshes and coastal silt barrens along the central Beaufort coast. These areas are suspected of supporting a large population of staging shorebirds (Connors et al.

1981). Surveys conducted on the nearby Fish Creek area have demonstrated substantial use by post-breeding shorebirds (Connors et al. 1984). Although bird surveys have been conducted in the past on the Colville River delta, no information has been gathered on littoral habitat use by post-breeding shorebirds. Also, "little quantitative work has been done to isolate those features within mudflats or saltmarsh, for example that correlate with bird density distributions within the habitat" (Connors 1986:360). During a pilot study in the summer of 1986, it was determined that substantial numbers of shorebirds were occurring in the littoral zone of the delta (Andres et al. 1987).

Specifically, the objectives of the study were:

1. To estimate the abundance and density of post-breeding shorebird species using the littoral areas of the Colville River delta and to determine if differential use of habitat types existed;
2. To characterize the behavior of post-breeding shorebirds while present in the delta;
3. To determine if prey abundance contributed to habitat selection in shorebird species.

CHAPTER 1

THE COLVILLE RIVER DELTA AND ITS LITTORAL ZONE

Study Area

The Colville River delta lies about 75 km west of Prudhoe Bay. The river, draining 29% of the North Slope, forms a 600 km^2 delta where it empties into Harrison Bay (Walker 1983). The littoral zone includes a 6 km swath at the northern edge of the delta (Figure 1). This area is composed of well-vegetated and partially-vegetated saltmarshes, brackish ponds, and barren silt flats. Although permafrost is the underlying force in shaping the surface of the delta, the character of the coastal fringe is largely influenced by flooding of the river during spring break-up and by inundation of the ocean during fall storms. The river's influence is also evident in the large silt deposits in the central delta. For the ensuing discussion, Connors et al's (1979) definition of littoral as the region from the interface of land and bay to the inland extent of terrestrial saltwater intrusion will be followed. Inundated areas can be readily identified by floristic composition.

The proximity of the ocean affects the summer microclimate of the coast by increasing humidity and decreasing temperature. Coastal fog is common throughout the summer and often extends only a few kilometers inland. Mean cloud cover for July and August in 1988 was 80.4%. Temperatures at the coastal camp in 1988 would often be 5-6^{o}C lower than those reported 12 km inland at Deadhorse. Mean morning temperature (taken at 0800) at the coastal camp in 1988 was 4.1^{o}C. Wind speed at this time averaged 12.8 km/hr. Although winds on the coastal plain are predominantly from the northeast (50% of the days in 1987 and 1988), strong northwest systems in 1988 caused high water levels on coastal silt barrens. The Colville River break-up dates were June 6, 1987 and June 12, 1988.

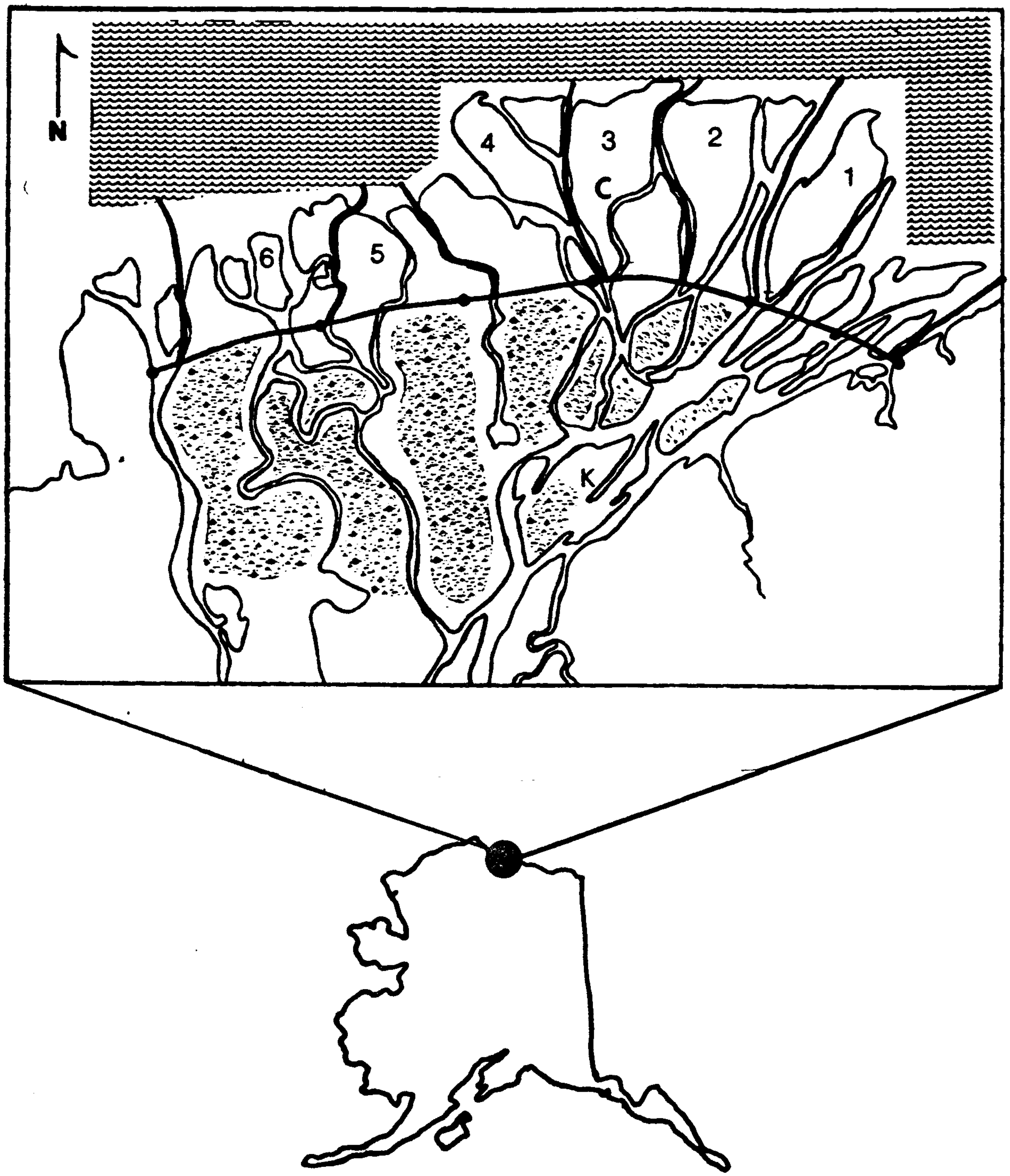

Figure 1. Inland extent of the littoral zone of the Colville River delta and six delineated sections (see text for section explanation, K = Kupigruak Camp location (1987), C = Coastal Camp (1988).

Habitat Delineation and Definition

Vegetation studies by Markon (Rothe et al. 1982), Walker (1985), and North Slope Study personnel were used as a basis for distinguishing five littoral covertype habitats in 1987: terminal shoreline silt barrens, subterminal shoreline silt barrens, interior silt barrens, sparse forb-graminoid tundra, and saline wet sedge/grass-sedge tundra. These types can be consolidated into two broad classes of silt barren and saltmarsh. In 1988, types were further refined to include components of polygonization and moisture. Definitions of covertypes and comparisons with Markon and Walker types are given in Table 1. Nomenclature of habitat covertypes was constructed to complement Walker's (1985) system. Saltmarsh types were defined as coastal wetlands (VIII) by Bergman et al. (1977). An example of the dispersion of littoral habitat types (1987 system) in the delta is shown in Figure 2.

The study area was divided into habitat strata using Markon's (Rothe et al. 1982) vegetation covermap. Each stratum consisted of a single habitat type and represented the primary sampling unit. Ground-truthing of the covermap occurred during the first two weeks of surveys. In 1987, 65 strata of five habitat types were delineated. In 1988, the number of habitat designations was increased to 12 and the number of strata to 79. Strata were grouped into 6 east-west sections (Figure 1) to reduce travel costs associated with surveying the plots. Delineated strata comprised 97% of the total littoral zone of the delta. Individual stratum size was constrained by topographic features, access, and time costs of sampling (Appendix A). Sizes reflected only the terrestrial portions of covertypes and excluded water bodies evident at 1:30,000. The width of each shoreline stratum was determined by estimating the average maximum distance (5-30 m) from the water's edge that birds occurred along its length. Areas and lengths of strata were determined using the digitizing software package SigmaScan at The Ohio State University.

Table 1. Hierarchical description of vegetation covertypes defined as habitats in the littoral zone of the Colville River delta. Covertype, Markon and Walker types, and a description are given.

Covertype	Markon	Walker	Description
A. Shoreline Silt Barren	16	Barren (VII)	Unvegetated silt deposits lying at the terminus of the delta.
1. Regular Terminal	16		Silt flats within 10 meters of the ocean edge. Linear, abrupt shorelines with a clear strand line.
2. Irregular Terminal	16		Silt flats within 30 meters of the ocean edge. Meandering shorelines with a gradual slope. Small patches of _Puccinellia_ and algae may be present.
3. Subterminal	16		Silt flats lying within 5 meters of channels emptying into the bay within 3 km of the ocean.
B. Interior Silt Barren	16	Barren (VII)	Unvegetated silt deposits completing the remainder of the terminal flats not represented by the three preceding types. Only inundated during break-up and strong fall storms, this type is unaffected by daily flooding rhythms and dries out during the summer.

Table 1 (cont.).

Covertype	Markon	Walker	Description
C. Sparse Forb-graminoid Tundra	08	Sparse (VI) saline?	Sparsely vegetated (15-60%) areas underlain with clumps of dead plants killed by saltwater intrusion.
1. Sparse Forb Tundra	08		Dominated by Cochelaria officinalis and Bryophytes. Minor amounts of Stellaria humifusa, Puccinellia, and Carex are present. This association appears to be mix of a pioneer floodplain and the following type.
2. Sparse Forb-graminoid Tundra			
a. Moist	08		Moist areas dominated by Stellaria humifusa. Secondary species include Cochelaria and Bryophytes. Small amounts of Puccinellia, Carex rariflora, C. ramenskii, Dupontia fischerii, and Salix ovalifolia are occasionally present.
b. Wet	08		Areas with saturated soils or standing water. Codominant plants include all those listed above except Salix ovalifolia and Cochelaria.
c. Polygonal	08P		Low-centered polygons where the rims are vegetated with Carex, Dupontia, and occasionally Eriophorum. Basins are saturated soils with dead plant material and Stellaria.

Table 1 (cont.).

Covertype	Markon	Walker	Description
D. Saline Sedge Tundra	06	Wet Sedge (saline II-d)	Carex-Puccinellia community dominated by Carex subspathacea and Puccinellia phyrganodes. Vertical height of this community resembles "astroturf" due to the grazing by geese. Other plants include Carex ursina, C. ramenskii, Dupontia, and Eriophorum.
1. Wet	06		Plants as above with soils that are saturated or flooded.
2. Polygonal	06P		Low-centered polygons where the rims are dominated by a sedge community (either D or E) and the basins consist of wet sedge vegetation types. Basins may be partially composed of open water or barren soil.
E. Saline Grass-sedge Tundra	07	Wet Sedge (saline-IId)	Primarily composed of Dupontia, Carex and Eriophorum. Alopeccurus alpinus, Salix ovalifolia, Rumex arcticus and Saxifraga are usually conspicuous components of this type. The latter four species are indicative of saline grass-sedge tundra.
1. Moist	07		Moist, well vegetated meadows.
2. Polygonal	07P		Low-centered polygons where the rims are composed of type E. Flooded basins have either open water or emergent communities containing combinations of Ranunculus, Caltha palustris, Arctophila fulva, Hippuris vulgaris and green algae.

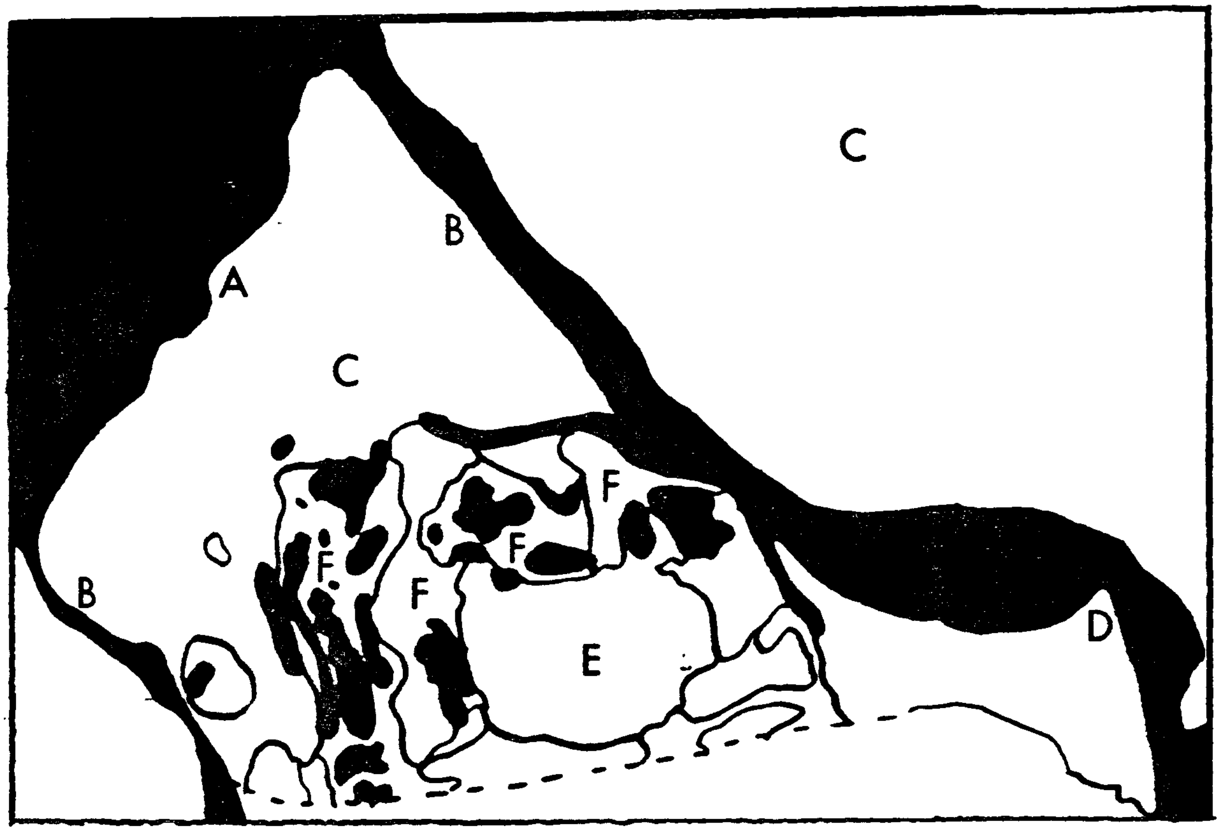

Figure 2. Location of littoral habitat types on the Colville River delta (A = Terminal shoreline, B = Subterminal shoreline, C = Interior silt barren, D = Channel barren, E = Sparse forb-graminoid, F = Saline sedge/grass-sedge tundra, shaded = water).

CHAPTER 2

ABUNDANCE, DENSITY AND HABITAT USE BY POST-BREEDING SHOREBIRDS

Sampling Procedures

The visitation schedule for each stratum was planned at the start of the season and changed only as a result of severe weather or logistic problems. On each day that a stratum was sampled, observers covered the entire stratum. Since variability in bird use was found to be higher on shorelines (Andres et al. 1987), sampling intensity was increased on shoreline strata (Appendix A). This study design follows Cochran's (1977:96-99) "optimal allocation with stratified random sampling". Strata were surveyed by a two-person crew who recorded the number of individuals of each species present in the stratum. Detection rates of the all the observers was felt to be reasonably similar. Behavioral and microsite information was also collected on individuals (Chapter 3).

Two to four stationary point counts lasting 30 minutes each were conducted in 1987 at locations along channels on each survey-day in an effort to determine turnover rate of shorebirds using the delta. During a point count, species, number, direction, and whether or not the bird landed were recorded.

Thirty-seven semipalmated sandpipers were mist netted and color-marked during early August of 1988 in an attempt to obtain information on the length of stay of shorebird migrants in the delta. Three subsequent surveys (2 hours each on 3 days) were made in the saltmarsh banding area to locate marked birds. A mist-net was also operated at camp (Figure 1) during non-survey times. A list of species and numbers banded is given in Appendix D, Table 29.

Statistical analyses of stratum surveys were carried out using standard formulae for stratified random sampling (Cochran 1977, formulae in Appendix B). Average density, total number, proportion of the total and their associated variances were calculated within strata and then appropriately combined to obtain estimates for all or part of the delta. Analyses were directed at species that provided $\geq$ 1% of the observations (Appendix B). Point estimates should be interpreted as a density or abundance of shorebirds present in the delta in an instant in time. Because selection of habitat strata was not independent (strata chosen to be surveyed on a given day were restricted to one section), covariance estimates between strata surveyed on the same day were calculated for both years of data and were included in estimates of variance.

Differential habitat use by shorebirds was determined in two ways: first, by comparing the estimated proportion of the total number present between habitat types for each species (Appendix B) and then combining groups that did not differ and testing for differences in densities and abundances between habitat types, and second, by comparing the proportional use of a habitat to the proportional representation of the habitat in the littoral zone. (Significance levels for detecting statistical differences between groups was determined by the number of tests involved.) Both approaches merit attention. If a management decision would affect the entirety of a particular covertype, then the total number present (and hence the proportion of the total number) of shorebirds occurring in that type would be a valid measure of the importance of the type to a species or group of species. Alternatively, if a management decision would affect only small patches of a given covertype, an area-sensitive measure (either density or use-availability) would be instructive in determining the value of the covertype. Density estimates are provided in both linear and two dimensional aspects for shoreline habitats. Linear calculations have been used by past workers (particularly when a transect survey was used) and may accurately reflect the nature of bird use of these areas. However, for comparing between two-dimensional saltmarsh habitats and shorelines, it seems desirable to use area measure determined by the shorebirds.

In the analysis of temporal trends, average numbers per stratum for a short period were needed. However, since individual strata were only sampled once during a period, variances could not be calculated for individual strata. Therefore, strata within the same habitat type were combined to create super-strata, each of which had more than one survey in the period of interest (see Cochran 1977:136-138 for additional explanation). Due to unequal strata sizes, ratio estimation was used to calculate means for the super-strata (Cochran 1977). The usual formulae for stratified random sampling were then applied to the results for these super-strata (Appendix B).

Abundance, Density and General Habitat Use

During the period from July 11 to September 2, 1987 and July 2 to September 1, 1988, 86 survey-days resulted in over 1100 observer-hours. Eighteen species of shorebirds were recorded during surveys of which five species comprised 90% of the sightings (Table 2). An additional twelve species, four that were recorded during non-survey times in this study, have been recorded as rare visitants to the littoral areas of the delta (Table 3). The number of shorebird species recorded in the littoral zone of the Colville River delta represents 71% of the total species found on the North

Slope (Troy 1985). Only the Barrow region rivals the delta in hosting more shorebird species (Pitelka 1974).

The dunlin was the most common species found in the littoral zone of the delta in both years (Table 4) averaging 48% of estimated total. Semipalmated sandpipers (averaging 22% of the total) were also common in the delta. Despite apparent disparity in yearly estimates for several species (semipalmated sandpiper, western sandpiper, red-necked phalarope), no species exhibited significant differences (two sample t-test, $p>0.05$) in absolute abundance between the years.

In examining habitat use patterns of species (of areas defined in 1987), two dichotomous groups emerged. Dunlins and sanderlings occurred at a significantly ($p\leq0.05$, two sample t-test) higher abundance and density on shorelines than in saltmarshes (Table 5; $p\leq0.05$ for all two sample t-tests). Although positive covariance existed between the two groups, tests involving a difference or ratio were conservative because inclusion of the covariance would reduce the variance of the difference or ratio. Excluding dunlins and sanderlings, all other species occurred at significantly higher abundances in saltmarshes but did not differ in shoreline or saltmarsh density (Table 5). Dunlins and sanderlings differed significantly from other species in both density and abundance within each habitat.

Table 2. Composition of shorebird species observed (numbers and percentages of sightings) in littoral areas of the Colville River delta 1987,1988. Also given are four-letter species codes.

Species Scientific name	Code	Number	Percent
Dunlin *Calidris alpina*	DUNL	19376	59.36
Semipalmated Sandpiper *Calidris pusilla*	SESA	5836	17.88
Red-necked Phalarope *Phalaropus lobatus*	RNPH	2633	8.07
Western Sandpiper *Calidris mauri*	WESA	1439	4.41
Pectoral Sandpiper *Calidris melanotos*	PESA	950	2.91
Stilt Sandpiper *Calidris himantopus*	STSA	588	1.80
Red Phalarope *Phalaropus fulicaria*	REPH	366	1.12
Black-bellied Plover *Pluvialis squatarola*	BBPL	308	0.94
Ruddy Turnstone *Arenaria interpres*	RUTU	296	0.91
Lesser Golden Plover *Pluvialis dominica*	LGPL	259	0.79
Long-billed Dowitcher *Limnodromus scolopaceus*	LBDO	187	0.57
Sanderling *Calidris alba*	SAND	146	0.45
Baird's Sandpiper *Calidris bairdii*	BASA	81	0.25
Buff-breasted Sandpiper *Tryngites subruficollis*	BBSA	24	0.07
Bar-tailed Godwit *Limosa lapponica*	BTGO	11	0.03
White-rumped Sandpiper *Calidris fuscicollis*	WRSA	7	0.02
Whimbrel *Numenius phaeopus*	WHIM	6	0.02
Rock Sandpiper *Calidris ptilocnemis*	ROSA	1	0.00
Unidentified Sandpiper *Calidris* spp.		125	0.38
Totals		32639	100

Table 3. List of shorebird vagrants known to occur in the Colville River delta but not recorded during prescribed surveys. Common name, scientific name, and a reference is given for each species.

Species (Scientific Name)	Reference
Semipalmated Plover (*Charadrius semipalmatus*)	J.W. Helmericks (pers. comm.)
Killdeer (*Charadrius vociferus*)	Kessel & Gibson (1978)
Lesser Yellowlegs (*Tringa flavipes*)	Rothe et al. (1982)
Wandering Tattler (*Heteroscelus incanus*)	Kessel & Gibson (1978)
Black Turnstone (*Arenaria melanocephala*)	Gibson (1979)
Red Knot (*Calidris canutus*)	This Study (1988)
Rufous-necked Stint (*Calidris ruficollis*)	Kessel & Gibson (1978)
Least Sandpiper (*Calidris minutilla*)	Gerhardt et al. (1988)
Sharp-tailed Sandpiper (*Calidris acuminata*)	This Study (1987)
Ruff (*Philomachus pugnax*)	Kessel & Gibson (1978)
Hudsonian Godwit (*Limosa haemastica*)	Gerhardt et al. (1988)
Common Snipe (*Gallinago gallinago*)	This Study (1988)
Wilson's Phalarope (*Phalaropus tricolor*)	This Study (1987)

Table 4. Estimated abundance and density of shorebirds in littoral habitats of the Colville River delta. Entries are the average number of birds present on the delta during the 1987 and 1988 study period.

	Average Number Present During Study Period						Proportion Of Total	
	shoreline (km)		study area (km^2)		Total Number			
Species	1987	1988	1987	1988	1987	1988	1987	1988
All Species	16.0	17.6	135.5	164.3	4140	5031	1.00	1.00
DUNL	13.7	14.0	70.9	73.0	2167	2237	0.52	0.44
SESA	1.1	2.9	22.1	45.8	676	1404	0.16	0.28
RNPH	0.1	0.1	11.0	20.4	336	625	0.08	0.12
WESA	0.5	0.3	12.5	4.6	383	141	0.09	0.03
PESA	0.0	0.0	4.6	7.5	141	230	0.03	0.05
STSA	0.0	-	2.8	4.5	86	137	0.02	0.03
REPH	0.1	0.1	2.4	1.7	73	53	0.02	0.01
BBPL	0.2	0.1	2.4	1.5	72	46	0.02	0.01
LGPL	0.0	0.0	1.8	1.4	55	41	0.01	0.01
RUTU	0.1	0.0	1.7	1.6	52	50	0.01	0.01
LBDO	0.0	0.0	1.4	0.8	43	24	0.01	0.00
SAND	0.0	0.2	0.2	0.9	5	25	0.00	0.01
Other Species	0.2	0.1	1.7	0.6	51	18	0.01	0.00

With dunlins and sanderlings excluded, no other species differed from this pattern of high saltmarsh abundance (estimates for all species are in Appendix B; multiple, two sample t-tests, $p>0.025$, on the proportions of the total for each species).

The only significant difference between average density or abundance of shorebirds on terminal or subterminal shorelines was found when all species were considered together (Table 6). However, significantly higher numbers of dunlins and sanderlings did occur on terminal shorelines in 1987. Similarly, no significant differences between average density or abundance of shorebirds in saline sedge/grass-sedge or sparse forb-graminoid habitats were detected for any species group (Table 6).

Table 5. Average density (birds/km^2) and total number of post-breeding shorebirds occurring in shoreline and saltmarsh habitats of the Colville River delta - 1987, 1988.

Habitat Type	Area (km^2)	All Species Total SE	All Species Density SE	DUNL and SAND Total SE	DUNL and SAND Density SE	Other Species Total SE	Other Species Density SE
Shorelines	2.42	2135	882	1776	733	360	149
		547	226	549	227	168	69
Saltmarsh	28.16	2453	87	443	16	2011	72
		397	14	88	3	342	12

Table 6. Average density (birds/km^2) and total number of post-breeding shorebirds occurring in littoral habitats of the Colville River delta - 1987, 1988.

Habitat Type	Area (km^2)	All Species Total SE	All Species Density SE	DUNL and SAND Total SE	DUNL and SAND Density SE	Other Species Total SE	Other Species Density SE
A. Shorelines							
Terminal Shoreline	1.92	1665 429	867 223	1386 440	722 229	279 136	145 70
Subterminal Shoreline	0.49	469 123	954 251	390 124	793 252	80 33	163 67
B. Saltmarsh							
Sparse Forb-graminoid	11.23	1309 258	117 23	218 56	19 5	1091 244	97 22
Saline Sedge/ Grass-sedge	16.84	1144 164	68 10	225 54	13 3	919 151	55 9

Table 7. Estimated proportions and standard errors of shorebirds occurring in shoreline and saltmarsh habitats (defined in 1987) of the Colville River delta - 1987, 1988.

Habitat	All Species		DUNL & SAND		Other Species	
	87	88	87	88	87	88
Terminal	0.41	0.33	0.67	0.58	0.11	0.12
Shoreline	0.10	0.09	0.20	0.21	0.02	0.07
Subterminal	0.09	0.12	0.13	0.22	0.03	0.03
Shoreline	0.02	0.03	0.04	0.07	0.01	0.01
Sparse	0.27	0.30	0.08	0.12	0.49	0.44
Forb-grass	0.04	0.07	0.02	0.03	0.07	0.11
Saline Sedge/	0.24	0.26	0.12	0.09	0.37	0.40
Grass-sedge	0.03	0.04	0.03	0.02	0.05	0.07
Total Number in Delta	4140	5031	2172	2262	1968	2769

Comparing the proportion of the total in each habitat, both groups showed consistent relative habitat use between years (Table 7; two-sample t-tests, $p>0.025$ for each test). The tendency for the dunlin and sanderling to be found in higher proportions on subterminal shorelines in 1988 can be attributed to high water levels on the terminal shorelines in mid-August. This apparently forced the birds to seek the more inland shorelines and also resulted in a higher variance estimate for terminal shorelines.

Of the finer shoreline habitats distinguished in 1988, significantly lower abundances ($p\leq0.025$) of all species of shorebirds and of dunlins and sanderlings considered separately occurred on regular terminal shorelines than on irregular terminal or subterminal shorelines (Table 8). Although abundances on irregular shorelines were 3 times the abundances on subterminal shorelines, high variability in the former precluded statistical detection of differences. The number of birds per kilometer (all species) on irregular shorelines (36.9 ± 10.6) was significantly higher than that recorded on subterminal shorelines (7.5 ± 1.9). Densities between shoreline habitats for all groups showed no differences (Table 8).

Each species conformed to the overall pattern of shoreline and saltmarsh use exhibited by all species excluding the dunlin and sanderling, although the lesser golden plover tended (but did not statistically differ) to be present in drier habitats. (Estimates for all species are in Appendix B; multiple, two sample t-tests, p>0.01, on the proportions of the total for each species.)

Abundances of dunlins and sanderlings did not differ significantly (p>0.025) between wet and moist sparse forb-graminoid tundra; however, both of these types had significantly higher abundances of these shorebirds than did sparse forb or polygonal covertypes (Table 9). Excluding dunlins and sanderlings, other species occurred in a significantly higher abundance in wet forb-graminoid than in all other types. Overlaps in abundance ocurred between sparse forb and polygonal forb-graminoid and between moist and polygonal habitats. Density of dunlins and sanderlings was significantly higher in wet forb-graminoid than any other types. This was also true for all species considered together. Density of species when dunlins and sanderlings were excluded in wet sites was not different from density in polygonal sites (Table 9).

All species groups were found in significantly higher (p>0.025) abundances in wet saline sedge than all other types (Table 10). Since this covertype composed a major portion of the area covered by littoral sedges, densities were not significantly higher. For all species groups, densities were quite equitable with the exception of significantly lower densities of shorebirds occurring in moist grass-sedge tundra (Table 10).

Table 8. Density (birds/km^2) and total number of post-breeding shorebirds occurring in shoreline habitats of the Colville River delta - 1988.

Habitat Type	Area (km^2)	All Species Total SE	All Species Density SE	DUNL and SAND Total SE	DUNL and SAND Density SE	Other Species Total SE	Other Species Density SE
Irregular Terminal Shoreline	1.87	1585	849	1252	671	333	178
		456	244	450	240	186	100
Regular Terminal Shoreline	0.06	70	1111	61	963	9	148
		34	539	34	537	7	105
Subterminal Shoreline	0.49	584	1188	489	994	95	194
		152	309	150	304	43	87

Table 9. Density (birds/km^2) and total number of post-breeding shorebirds occurring in sparse forb-graminoid habitats of the Colville River delta - 1988.

Habitat Type	Area (km^2)	All Species Total SE	All Species Density SE	DUNL and SAND Total SE	DUNL and SAND Density SE	Other Species Total SE	Other Species Density SE
Sparse Forb	1.86	52	28	2	1	50	27
		41	22	1	0	41	22
Moist Sparse Forb-graminoid	6.62	497	75	52	8	445	67
		175	26	25	4	133	20
Wet Sparse Forb-graminoid	1.75	788	451	203	116	585	335
		191	109	51	29	156	89
Polygonal Sparse Forb-graminoid	1.10	147	133	10	9	137	124
		32	29	4	4	30	27

Table 10. Density (birds/km^2) and total number of post-breeding shorebirds occurring in sparse forb-graminoid habitats of the Colville River delta - 1988.

Habitat Type	Area (km^2)	All Species Total SE	All Species Density SE	DUNL and SAND Total SE	DUNL and SAND Density SE	Other Species Total SE	Other Species Density SE
Wet Saline Sedge	9.12	820	90	156	17	663	72
		180	20	47	5	150	16
Polygonal Saline Sedge	1.86	227	122	7	4	220	118
		42	23	3	2	40	22
Moist Saline Grass-sedge	3.77	92	25	10	3	82	22
		23	6	4	1	21	6
Polygonal Saline Grass-sedge	2.09	170	81	20	9	150	72
		29	14	7	3	29	14

Density and abundance considerations of shorebird habitat use can be integrated by examining the proportion of the total of birds occurring in a habitat in relation to the proportion of that habitat occurring in the littoral zone of the delta. Because parametric procedures were used to estimate sample values of density and total number, the same parametric approach was employed in use-availability analyses. The advantage of this type of analysis was to easily compare the entire littoral zone of the delta and provide managers with an index of the value, as dictated by density, of littoral habitats to post-breeding shorebirds. Results from these analyses need to be interpreted carefully. Although high, positive disproportionate use of a habitat type probably indicates a preference for this covertype (as additionally illustrated by behavioral and prey information presented in Chapters 3 and 4), neutral and negative results should not be viewed as habitat avoidance. True avoided habitats by post-breeding shorebirds were those where no birds occurred in late summer. Thus, all positive and negative habitat use patterns should be compared hierarchically.

When carrying out use-availability analyses, the number of habitat classes included in the analysis can greatly affect the results (Johnson 1980, Porter and Church 1987). Following the recommendation of Porter and Church (1987), only covertypes where birds were found were included in the analysis. Covering over 60% of the littoral area of the Colville River delta, the interior of terminal silt barrens were unused by post-breeding shorebirds. The lack of substrate moisture, and hence of benthic invertebrate prey, deters foraging shorebirds. Because of this lack of use, the interior silt barrens were eliminated from further analytical considerations. If this covertype were included in the analysis of use-availability, almost all other covertypes would display positive disproportional shorebird use. This occurs because of the dependence of a single covertype test on the distribution of other types to be included in testing procedures. Thus, nothing would be gained by the analysis because it is already known that all covertypes receive more use than the interior silt barrens.

Of the used littoral habitats, shorelines comprised only 8% of the delta yet on average received 47% of all shorebird use. Both terminal shorelines and subterminal shorelines incurred significantly higher disproportionate use by dunlins and sanderlings but not by other species (Table 11). Although irregular shorelines (6% of the littoral area) alone received 32% of the dunlin and sanderling use in 1988, a high variance estimate, largely influenced by a sudden pulse of birds moving onto the shorelines after high water receded in mid-August, precluded the detection of significant use-availability differences.

Only subterminal shorelines were used disproportionately by dunlins and sanderlings in 1988 (Table 12).

Saline sedge and grass-sedge types contributed 55% of the littoral area coverage but were under-used by all species (Table 11). Sparse forb and forb-graminoid habitats (37% of the delta) were under-used by dunlins and sanderlings but were proportionately used by other species (Table 11). On a finer scale, only wet, sparse forb-graminoid tundra received significantly higher use by species other than the dunlin and sanderling (21%) than expected by its proportional coverage (6%). All other saltmarsh types were either under-used (sparse forb, grass-sedge) or proportionately used by all species (Table 12).

Table 11. Comparisons of average shorebird use with the availability of the littoral habitats of the Colville River delta defined in 1987.

Habitat	Prop.of Area	DUNL,SAND (n=2217)			Other Spp. (n=2369)		
		P(T)	P(A)-P(T)	P	P(T)	P(A)-P(T)	P
Terminal Shoreline Silt Barren	0.063	0.626	0.563	0.009	0.115	0.052	0.204
Subterminal Shoreline Silt Barren	0.016	0.175	0.159	0.009	0.033	0.017	0.126
Sparse Forb/ Forb-graminoid	0.370	0.098	-0.272	≤0.001	0.465	0.095	0.227
Saline Sedge/ Grass-sedge	0.551	0.102	-0.449	≤0.001	0.385	-0.166	0.009

Z-values computed by LSA of binomial test (Hollander and Wolfe 1973) and were deemed significant if P≤ 0.025.

Table 12. Comparisons of shorebird use with the availability of the littoral habitats of the Colville River delta surveyed in 1988.

Habitat	Prop.of Area	DUNL,SAND (n=2262) P(T)	P(A)-P(T)	P	Other Species (n=2769) P(T)	P(A)-P(T)	P
Irregular Terminal Shoreline	0.061	0.554	0.493	0.019	0.120	0.059	0.271
Regular Terminal Shoreline	0.002	0.027	0.025	0.099	0.003	0.001	0.352
Subterminal Shoreline	0.016	0.217	0.201	0.004	0.034	0.018	0.194
Sparse Forb	0.061	0.001	-0.060	≤0.001	0.018	-0.043	0.007
Moist Sparse Forb-graminoid	0.216	0.023	-0.193	≤0.001	0.160	-0.056	0.201
Wet Sparse Forb-graminoid	0.057	0.090	0.033	0.144	0.211	0.154	0.010
Polygonal Sparse Forb-graminoid	0.036	0.005	-0.031	≤0.001	0.049	0.013	0.199
Wet Saline Sedge	0.298	0.069	-0.229	≤0.001	0.240	-0.058	0.225
Polygonal Saline Sedge	0.061	0.003	-0.058	≤0.001	0.079	0.018	0.174
Moist Saline Grass-sedge	0.123	0.005	-0.118	≤0.001	0.030	-0.093	≤0.001
Polygonal Saline Grass-sedge	0.068	0.009	-0.059	≤0.001	0.054	-0.014	0.178

Z-values computed by LSA of binomial test (Hollander and Wolfe 1973) and were deemed significant if $P \leq 0.01$.

Although great care was taken to ensure that a particular parcel of ground was assigned to the correct habitat type, some other non-vegetative component of the habitat may influence a shorebird's use. High variance estimates associated with terminal shorelines were a result of this spatial heterogeneity. Indeed, distribution of shoreline dunlins and sanderlings was far from uniform across an east-west gradient of the delta. Dunlins and sanderlings were more evenly dispersed between irregular terminal shorelines (19% of the total) and subterminal shorelines (14%) in the eastern delta (section 1 of Figure 1) than they were in the central delta (sections 2,4 of Figure 1, 38% and 3%, respectively). They were also more dense on irregular shorelines of the central delta. Similarly, sparse forb-graminoid types in the east-central delta (sections 2,3 of Figure 1) received higher use by all species than did more western sites (sections 4,5,6 of Figure 1, 29% and 10%, respectively). Since spatial differences would be important in site-specific management decisions within the littoral zone of the delta, proportion of the total for dunlins and sanderlings and for all other species in each section of the delta are provided in Appendix B. To ease implementation, saltmarsh habitat designations in this appendix were combined to exactly follow Markon's (Rothe et al. 1982) mapped types.

Comparisons of Abundance and Composition with Other Studies

Comparison of this study with those done in the past on the North Slope is somewhat tenuous. This is largely due to the following non-statistical approaches in design and analysis: 1) selective (non-random) placement of transects within littoral habitats resulting in a biased estimate and questionable inferential population, 2) combination of equal weighted means when unequal sample sizes were used, and 3) no estimates of variance. Nevertheless, these studies were important in identifying concentration areas of migrating shorebirds on the North Slope and in demonstrating the late-summer shift of use from upland to coastal sites. Qualitative comparisons of species abundance and composition between the Colville and other sites can still be made.

On the Colville delta, in relation to Barrow, the dunlin replaced the red phalarope as the most common species (Table 13). Farther east on the Canning River delta, red-necked phalaropes and semipalmated sandpipers were most common. The large proportion of red phalaropes observed at Barrow was attributed to the presence of gravel spits (Connors et al. 1984). Conversely, Barrow lacks the silt barrens that attract Colville dunlins. Red-necked phalarope occurrence on the Colville fit the pattern of being more prominent at eastern sites (Connors 1984). A similar pattern of increasing eastern frequency was found in the semipalmated sandpiper (Table 13). Western sandpipers, primarily a western Alaska species, were more common on the Colville than either at Barrow or the Canning (Table 13).

Average shorebird abundance along shorelines (only) on the Colville delta ranked it as one of the more productive sites on the North Slope (Table 14). Only Icy Cape (in northwestern Alaska) and Barrow had higher use by post-breeding shorebirds. Average density for this study was determined for periods in August that temporally complemented data from other sites and included only shoreline estimates (with area based on a width of 50 m) These comparisons seemed appropriate since all other studies used small width transects (50 or 100 m) that were usually located along land-water interfaces.

Temporal Trends in Abundance

The estimated total of individuals occurring in the study area during each weekly (1987) or ten-day (1988) period was calculated for each species comprising $\geq$1% of the observations (Appendix B). Inferential periods differed between the years due to differences in stratum visitation schedules. Heaviest use of littoral habitats occurred during August with maximum abundances for all species recorded between the second and third week of August in both years (Figure 3). Although use on shorelines remained relatively high into September, saltmarsh use waned by the end of August (Figure 4, Appendix B). Temporal shoreline

Table 13. Species composition (percentage of observations) of post-breeding shorebirds at North Slope sites.

Species	Barrow[a]	Colville[b]	Canning[c]
Black-bellied Plover	<1	<1	2
Lesser Golden Plover	<1	<1	4
Semipalmated Plover	<1	-	-
Ruddy Turnstone	3	<1	6
Sanderling	1	<1	8
Semipalmated Sandpiper	8	18	25
Western Sandpiper	2	4	<1
White-rumped Sandpiper	-	<1	2
Baird's Sandpiper	1	<1	8
Pectoral Sandpiper	2	3	4
Dunlin	9	60	6
Stilt Sandpiper	-	2	<1
Buff-breasted Sandpiper	-	<1	2
Long-billed Dowitcher	2	<1	<1
Red-necked Phalarope	2	8	21
Red Phalarope	69	1	10

[a] Connors et al. 1984
[b] This Study
[c] Moitoret 1983

Table 14. Average density (birds/km_2) of post-breeding shorebirds at North Slope sites (from Connors and Connors 1985, Connors 1984).

Location	Density
Barrow	950
Canning River Delta	163
Cape Krusentern	227
Colville River Delta	740
Icy Cape	1033
Oliktok	630
Peard Bay	337
Wales	377

patterns were driven by dunlins while semipalmated sandpipers largely dictated saltmarsh patterns. Temporal patterns of abundance are shown for each species in Appendix C.

High use of saltmarshes early in the season by pectoral sandpipers and lesser golden plovers reflected a staging adult component; in the case of pectoral sandpipers, males. Male pectoral sandpipers leaving by the end of July were not replaced by a movement of immatures or females into littoral sites. Species that reached maximum abundance in August (western, semipalmated, stilt sandpipers and phalaropes) were mainly immatures. One-hundred percent of 73 semipalmated sandpipers banded during August of 1988 were immatures. An exception to the late summer domination by immature shorebirds was the occurrence of adult dunlins. Connors et al. (1984) observed dunlins at Barrow into late September and they have been present during September on the Colville River delta (J.W. Helmericks pers. comm.).

Generally, maximum numbers in each habitat parallelled the overall peak use period for individual species. Several exceptions to this pattern follow. The proportion of dunlins using saltmarshes greatly decreased during later weeks. Initially high proportions of dunlins observed in saltmarshes (but small numbers) were due to forays by local breeders. Ruddy turnstones also nested in or near saltmarshes and were most common early in the season.

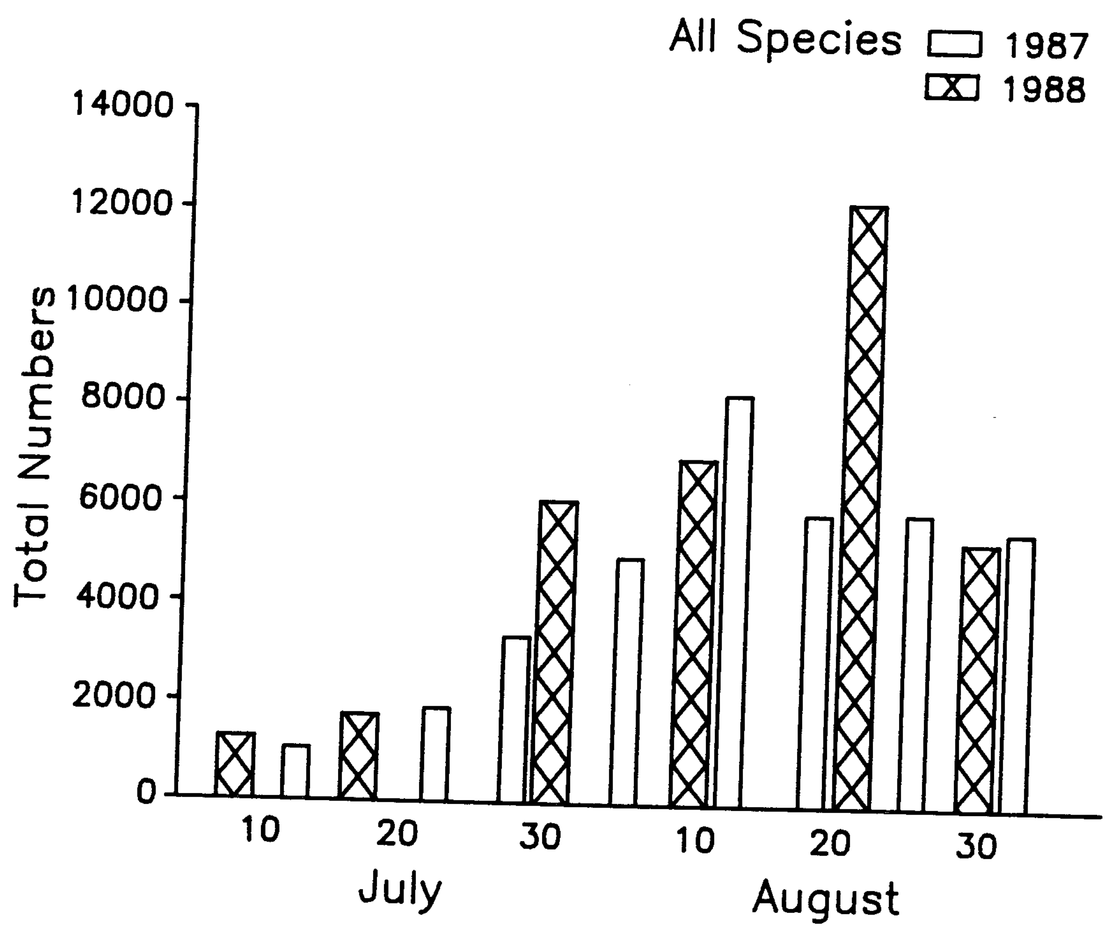

Figure 3. Temporal changes in abundance (total numbers) of shorebirds in littoral habitats of the Colville River delta - 1987,1988.

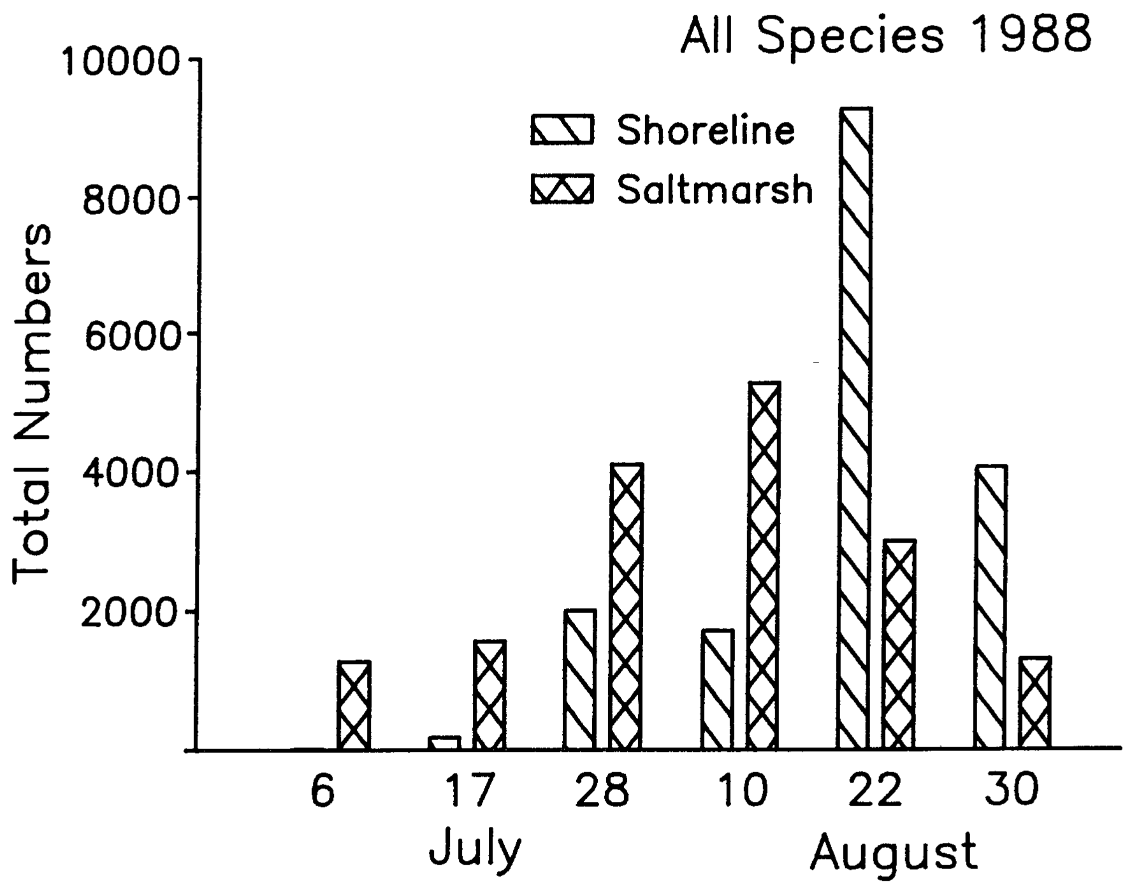

Figure 4. Comparison of temporal changes in abundance (average number) of shorebirds in shoreline and saltmarsh habitats of the Colville River delta - 1988.

Sampling Efficiencies

To determine the effect that covariance had on reducing the precision of estimates produced under the prescribed sampling plan, variances were calculated from the data both with and without the covariance component. For the delta-wide estimate of all species, covariance contributed an additional 33% to the overall variance estimate for 1987 and 50% for 1988. The effect of covariance was much less severe at finer habitat distinctions. In all species-habitat combinations positive covariance existed. Because of substantial covariance in spatial sampling units, a sampling plan based on temporal sampling units might be considered. This was examined by comparing the coefficient of variation (standard error of the total/total number = cv) of the spatial and temporal estimators. Despite the high covariance in spatial estimates, their cv's were substantially smaller than single-period temporal estimates (where no covariance exists). In only 1 of 14 periods for all species, was a temporal cv (0.15) less than the spatial cv (0.17). The optimal plan for sampling post-breeding shorebirds might be to create spatial habitat strata (as described here) and then to temporally define (and hence infer about) a mid-summer period (July 1 - July 31) and a late summer period (August 1 - August 31). A minimum of four visits to each spatial unit, two in each period, would be needed to gain the greatest advantage from stratification. If entire coverage of the delta was desired, a field crew of more than two people would be required. If there was interest in a specific area or habitat of the delta, this sampling plan could be functional with reduced personnel. The effect of a secondary temporal strata on changing the magnitude of point estimates and reducing variances is illustrated by shoreline dunlins (Table 15).

Table 15. Distribution of dunlin among irregular terminal and subterminal silt barren locations during the entire study period and during August of 1988. Proportions of total numbers refer to distribution of dunlin between habitat types during the same period and section.

Period	Habitat Type	Birds /km	SE	Total No.	Proportion of Total	SE
Entire	Terminal	28.7	10.4	1232	0.72	0.26
Entire	Subterminal	6.2	1.9	484	0.28	0.09
August	Terminal	47.8	16.1	2058	0.73	0.25
August	Subterminal	9.8	2.1	763	0.27	0.06

Population Turnover

In order to accurately assess the importance of the Colville River delta to post-breeding shorebirds, it is important to know how many different birds utilize the littoral zone during migration. One approach is to estimate the average number of birds present and the average length of stay of a bird. Since the notion of the importance of turnover rate in migratory shorebird research surfaced, estimation of an average length of stay has remained problematic (Recher 1966). In an attempt to provide this estimate, Connors and Risebrough (1977) marked 47 red phalaropes and released groups weekly at Barrow throughout August. During early August, eight were resighted within four days. As the season progressed and phalarope numbers swelled, no birds were located after release. In a similar experiment, none of 37 semipalmated sandpipers color-marked in saltmarshes of the Colville delta in 1988 were resighted after three 2-hour searches. The lack of resighting indicated that individuals were passing rapidly through these coastal staging areas, perhaps residing for less than 24 hours. Butler et al. (1987) found the average length of stay of western sandpipers (using maximum likelihood techniques) on the south coast of British Columbia to be three days. It therefore seems reasonable that a conservative estimate of the size of the shorebird population passing through the Colville River delta could be obtained by multiplying the seasonal average number by the number of 7-day periods that occurred during the study period. This would assume complete population replacement every 7 days. This estimate would also be conservative in its assumption of equal turnover rates among time periods. Certainly, slower rates that occurred at lower abundances early in the season were balanced by a faster rate at maximum abundance. Thus, at least 37,260±1542 (SE) shorebirds passed through littoral zone of the delta in 1987 and 45,279±2638 (SE) in 1988. Further techniques need to be developed to provide a more accurate assessment of the magnitude of the population passing through staging and migratory stop-over areas.

Data from point counts were explored comparing the number of birds that passed to the number that landed in the delta but were found to be insufficient to test this technique.

CHAPTER 3

ACTIVITY AND FORAGING BEHAVIOR OF POST-BREEDING SHOREBIRDS

Sampling Procedures

Data on the behavior of shorebirds encountered during stratum surveys was collected. The behavior of each bird when first observed was recorded as: feed, sleep (bill tucked under wing or along mantle), preen, walk, swim, breed (courtship or nest defense calls), stand, or flush. Microsite information collected on individuals consisted of location and moisture measures. Location measures included: pond basin, pond/lake edge, or land. Moisture measures were recorded as: moist, film, water level between the digits and the distal end of the tibiotarsus, water level above the distal end of the tibiotarsus, bird afloat. Also during stratum surveys, directions of birds flying over the plot during a survey were recorded in degrees when possible.

Focal animal and scan samples (Martin and Bateson 1986) were conducted opportunely throughout the two summers to help elucidate the foraging patterns of birds occurring in the littoral zone. Finer divisions of foraging style (land peck - no substrate penetration of the bill, water jab -

penetration of the water surface but not substrate, jab - penetration of half of the bill into the substrate, probe - penetration of more than half of the bill into the substrate) were recorded.

During early July of 1987, scan samples of shorebird behavior were conducted in sparse forb-graminoid habitats throughout the 24-hour clock. Samples were collected at six hour intervals over a 3-day period. Behaviors were recorded as above.

Foraging and Other Activity

Feeding was the dominant activity of shorebirds observed in the delta (Figure 5). This was true for all species comprising ≥1% of the observations although, the prevalence of foraging behavior of an individual species varied from 57% to 89% of the observations (Appendix D). Not all individuals could be behaviorally classified. For individual species, unclassified individuals ranged from 2% to 55% of the observations (Appendix D). Foraging behavior also dominated the activity of shorebirds in all habitats. Differences in the proportion of birds feeding varied from 97% on irregular terminal shorelines to 58% in moist grass-sedge tundra (Appendix D).

Twenty-four hour observations made in early July, 1987 demonstrated that shorebirds foraged throughout the diel period during continuous daylight (Figure 6). Although nocturnal feeding by shorebirds has been noted in temperate areas (e.g. Goss-Custard et al. 1977) and more recently in the tropics (Robert et. al 1989), birds in these studies were inactive for long periods during high tides. Other authors have noted that breeding arctic species show a semblance of circadian rhythm with periods of nocturnal inactivity (Amlaner and Ball 1983). In this study, where foraging was not constrained by water level or darkness, shorebirds fed continuously.

Sleeping accounted for only 3% of a shorebird's time when in the littoral habitats of the delta. If all non-classified birds (flushed) were considered sleeping, the estimate is raised to 6%. This is still well below values of 10% to 15% reported in other arctic species (Amlaner and Ball 1983). Because these higher values were reported for breeding birds, it might be expected that individuals that need to accumulate fat stores for migration would spend less time in inactive modes. From field observations, it appeared that the pattern of shorebird sleep was to catch frequent (1/hour), short duration naps. In two years, only one large flock of birds (250) was observed sleeping on a subterminal shoreline. This flock was observed nestled down amidst the driftwood strand. Occasional occurrences of individual birds resting in the driftwood strand were noted throughout the two summers.

Preening was also a rare behavior and may be associated with arrival on the delta. In one instance, a flock of 37 red phalaropes was observed landing on a shoreline and immediately began preening.

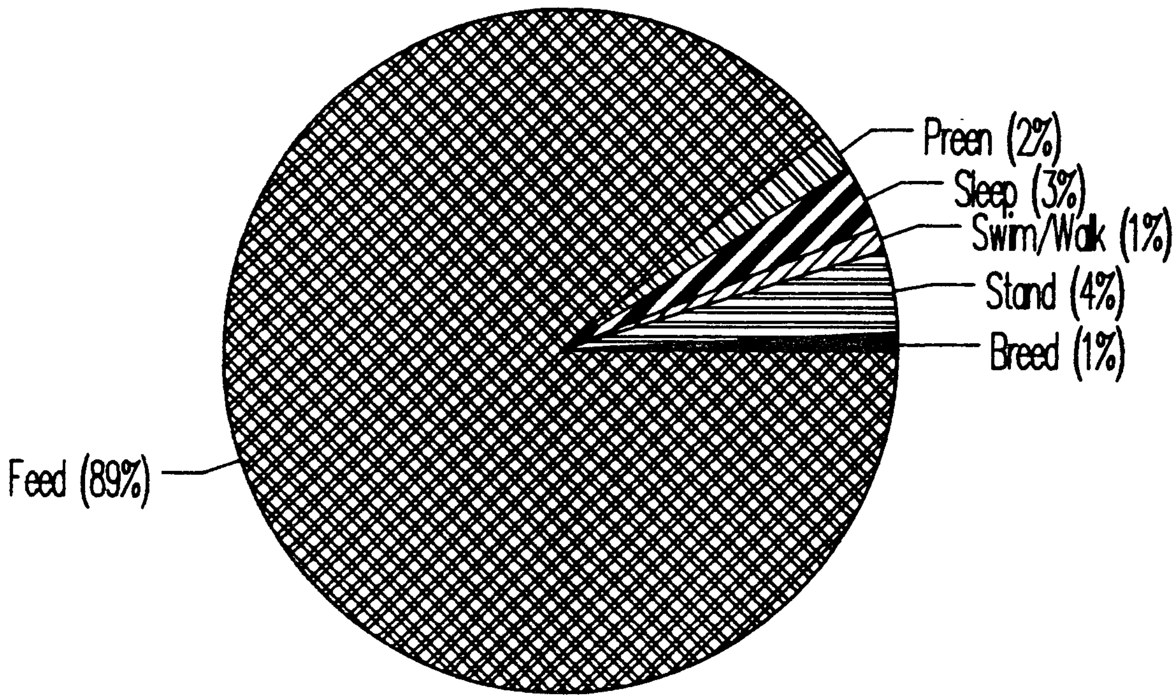

Figure 5. Activity of shorebirds (proportions of observations) recorded in the littoral zone of the Colville River delta - 1987, 1988 (n=30,754).

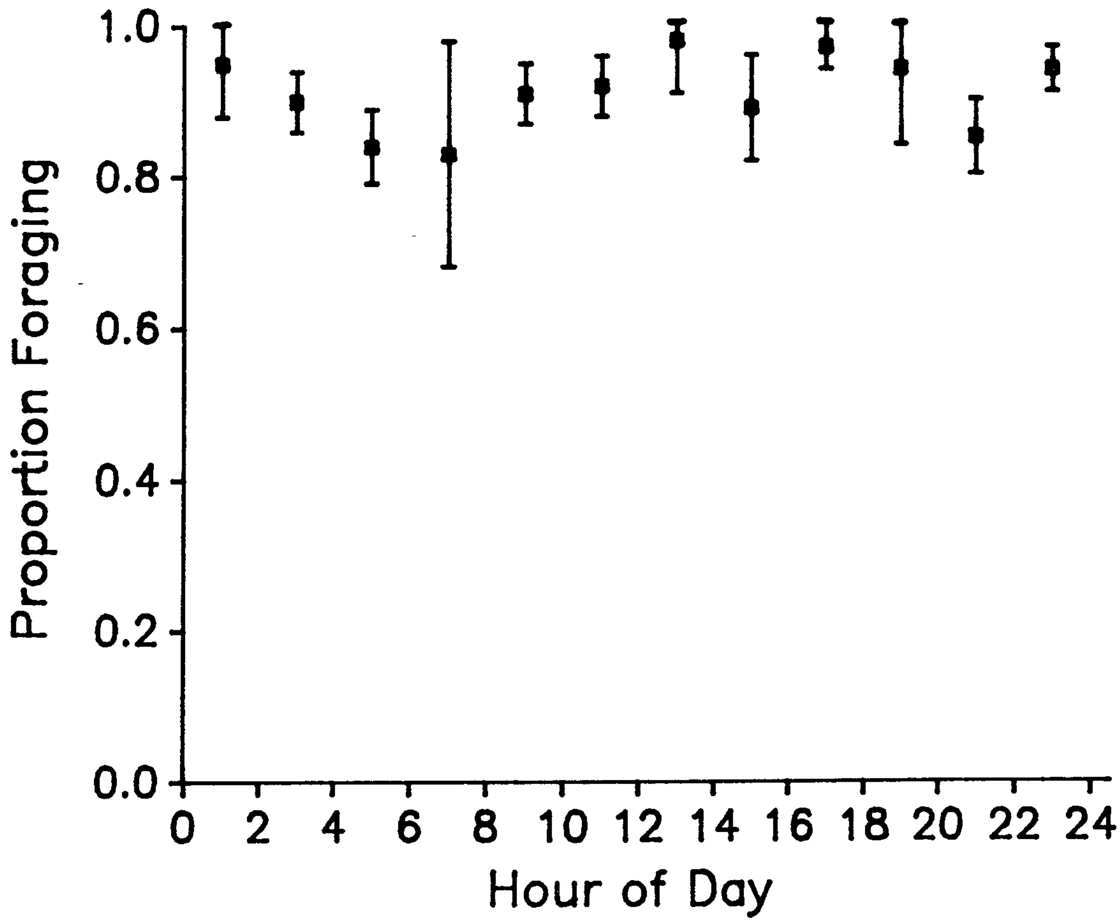

Figure 6. Proportion of shorebirds foraging in sparse forb-graminoid habitats of the Colville River delta during a twenty-four hour period in early July, 1987.

Directional Movements of Shorebirds

For analysis of migratory direction, headings of shorebirds obtained during stratum and point-count surveys were classified into four directions: north (315^{o}-44^{o}), east (45^{o}-134^{o}), south (135^{o}-224^{o}), and west (225^{o}-314^{o}). The dominant direction of migrating shorebirds passing through the delta appeared to be east. Only the dunlin, and to a lesser degree, the western sandpiper, were primarily seen heading to the west. Proportions of individuals heading in four major directions along with 95% confidence intervals of the highest value (based on the binomial distribution) for each species are presented in Table 16. Prominent migratory direction is underlined, where it is apparent (confidence interval excludes p=0.5), for each species.

Table 16. Directional proportions, numbers observed, and 95% confidence bounds of highest values of birds observed migrating through the Colville River delta-1987, 1988.

SPP	North 315-44	East 45-134	South 135-224	West 225-314	n	Lower Limit	Upper Limit
BBPL	0.14	0.73	0.06	0.07	86	0.63	0.83
LGPL	0.08	0.84	0.02	0.06	149	0.77	0.89
SESA	0.11	0.56	0.15	0.18	211	0.50	0.63
PESA	0.02	0.70	0.06	0.21	203	0.64	0.77
LBDO	0.00	0.82	0.03	0.15	126	0.74	0.88
RNPH	0.04	0.71	0.03	0.22	178	0.64	0.77
WESA	0.18	0.25	0.11	0.46	28	0.25	0.64
STSA	0.23	0.54	0.04	0.19	26	0.31	0.73
REPH	0.01	0.55	0.07	0.37	97	0.43	0.64
RUTU	0.03	0.45	0.10	0.42	31	0.26	0.61
DUNL	0.08	0.22	0.03	0.67	562	0.63	0.71

CHAPTER 4

INFLUENCE OF PREY ON HABITAT USE BY AND ACTIVITY OF POST-BREEDING SHOREBIRDS

Sampling and Experimental Procedures

Invertebrates were sampled in sparse forb-graminoid covertypes during July, 1988. Eight plots of one hectare each were randomly placed in sparse forb tundra (2 plots), moist, sparse forb-graminoid tundra (3 plots), and wet, sparse forb-graminoid tundra (3 plots). The original intention was to use four emergence traps randomly placed in each hectare plot to collect adult insects. However, numbers were so low in traps, primarily due to the fact that peak hatch occurred two days before all the traps were out, that a second method was employed to assess adult insect abundance in the different forb-graminoid habitat types. A standing crop measure of adult dipterans was obtained by counting the individuals within a 95 cm^2 circle. Each hectare plot was divided into three strata: sparsely vegetated land, well vegetated land, and water. A randomly selected cluster sample of four points, totaling 16 counts per plot) was taken from each stratum in approximate proportion to the representation of that stratum in the plot on July 15, 1988. For detection consistency, only adult dipterans larger than 3 mm were counted. Estimates of dipteran density for each habitat type were obtained using three-stage stratified cluster sampling procedures (Cochran 1977). Changes in adult density were measured 3 times during July, 1988 by taking 4 random surface samples per plot per visit. Two-stage cluster sampling procedures were used to obtain estimates for these data (Cochran 1977).

Benthic invertebrate abundance on shorelines was assessed in 1988 by collecting twenty-two 19.63 cm^2 x 3 cm cores at 200 meter intervals along the irregular terminal shoreline of section 4 (Figure 1). At each sampling site shorebird use was assessed by classifying shorebird track abundance into one of three categories: no tracks, moderate tracks, abundant tracks. Use class was assigned prior to (and independently of) determining invertebrate density. A qualitative measure of silt grain size (fine or coarse) was also made. Cores containing oligochaetes and midge larvae (Chironomidae) were manually counted in the field.

In 1988, to test the effect that shorebirds may have on depleting benthic shoreline invertebrate prey as the season progressed, ten predator-exclosures (1 m^2) were paired with an exposed area of the same size along the terminal shoreline of section 4 (Figure 1). Originally, samples were to be gathered at weekly intervals to detect time-dependent differences in invertebrate densities between the pairs. However, high water prevented this schedule and only one set of randomly selected cores (15 x 15 x 3 cm) was taken from each pair near the end of the field season. Benthic samples were examined after returning from the field.

Shorelines

Use on terminal silt barrens is largely restricted to a narrow shoreline band along the water. The large interior portion of these extensive barrens dried out as the summer progressed and was unattractive to foraging shorebirds. Use was particularly linear along subterminal and regular terminal shorelines. On irregular terminal shorelines, use extended further inland due to the development of an "intertidal" community in irregular pockets of the shoreline. These areas were characterized by patches of Puccinellia, abundant algae, finer grain size of the silt, and higher abundances of invertebrates in the substrate. Invertebrates (oligochaetes and midge larvae) in areas of fine grain size were more abundant ($9531/m^2 \pm 1238$) than in areas of coarse grain size ($3194/m^2 \pm 576$). Almost all benthic organisms were found in the top 2 cm of the substrate. The non-uniform distribution of shorebirds, as illustrated by numbers of dunlins on a single survey during August of 1987 (Figure 7), on irregular shorelines often matched the distribution of these intertidal patches. Indeed, high shorebird use (as assessed by classifying tracks counts as low, medium, or high while taking a core sample, n=22) corresponded with high invertebrate density (Figure 8). Although it seems a 5 mm prey item would not offer much to a bird that needs to accumulate large fat reserves for migration, the high caloric value of these items compared to other invertebrates (averaging over 5000+ calories/gram dry weight, Cummins and Wuycheck 1971) and their high abundance must be sufficient to accommodate migrating dunlins. Although dunlins were not collected to verify prey selection during this study, Connors et al. (1984) found that dunlins do feed on oligochaetes and chironomid larvae.

The exclosure experiment did not detect any depletion of the invertebrate resource by foraging dunlins on terminal shorelines ($p \geq 0.05$, paired t-test). Because high water levels on the shorelines during the experiment rendered prey unavailable, a phenomenon that did not occur in 1987, the generality of these conclusions is questionable. Resource depletion by migrant shorebirds has been found in temperate North America (Schneider and Harrington 1981) and is thought to control the timing of migration.

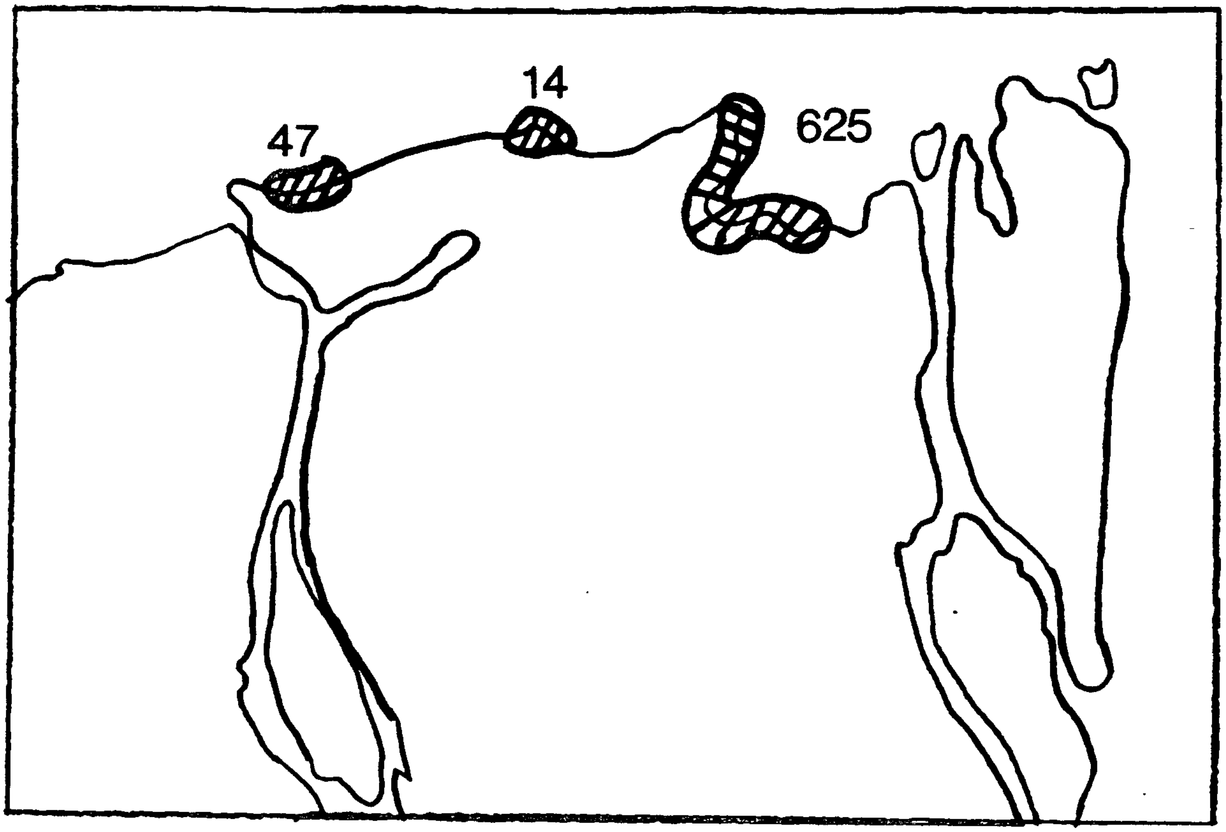

Figure 7. Distribution of shorebirds along the irregular terminal shoreline of section 2 of the Colville River delta on August 17, 1987.

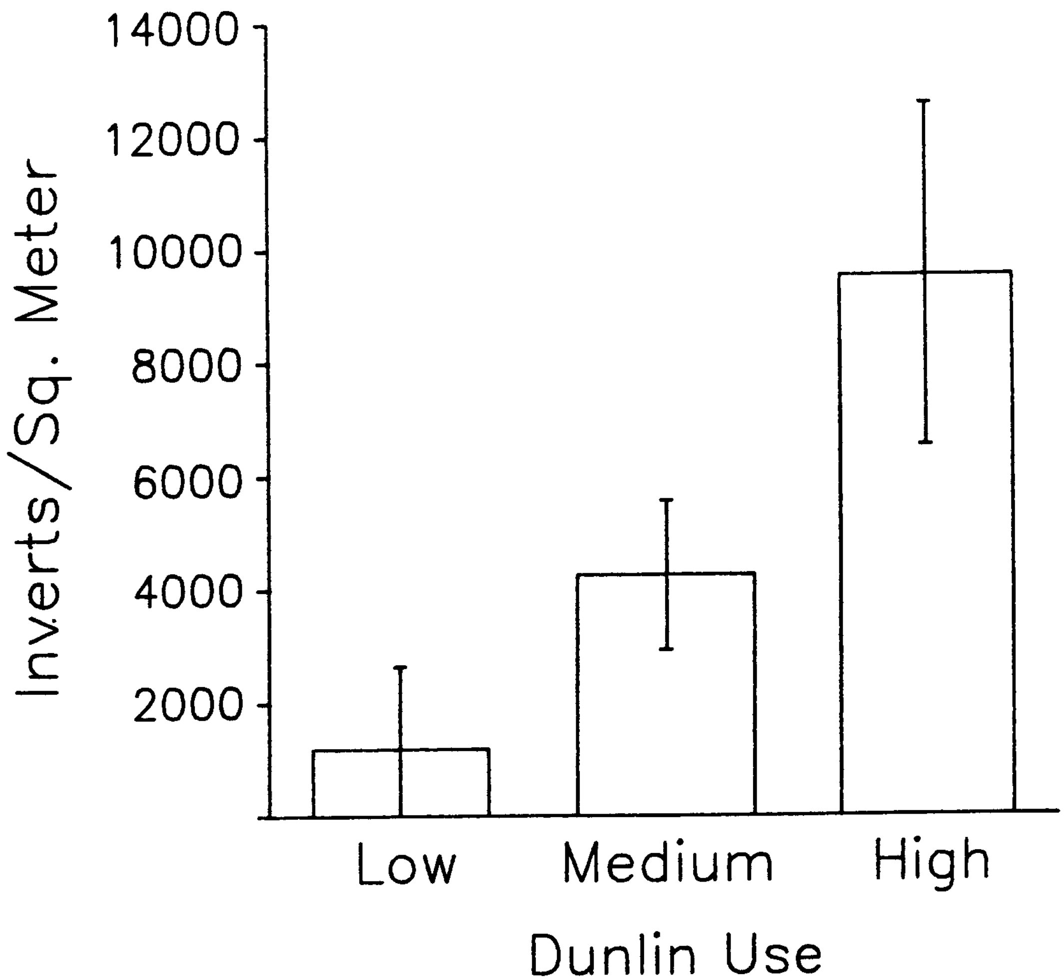

Figure 8. Invertebrate density (inverts/m^2) and shorebird use (track class) on an irregular terminal shoreline of the Colville River delta, 1988.

Saltmarshes

The heaviest use of vegetated saltmarshes by post-breeding shorebirds occurred in the wettest sites. A gradient in abundance of adult dipterans, measured as standing crop, from sparse forb tundra to wet sparse forb-graminoid tundra corresponded with an increasing change in shorebird density (Figure 9). During early July, shorebirds largely fed on emerging dipterans. Prey were secured by visually-directed pecks. The pecking rate of pectoral sandpipers in these areas was found to be 77.4 ± 2.57 pecks/minute (mean±SE, n=10). Also during this time, windrows of dead adult dipterans amassed along pond and lake edges forming 0.5 meter swaths numbering over 33 insects/cm^2. Besides shorebirds, northern pintails (Anas acuta) and Sabine's gulls (Xema sabini) were observed feeding on this super-abundant resource. As the season progressed and adult dipterans disappeared, shorebird predators switched to a probing foraging behavior (Figure 10). Because benthic larvae have multi-year lifecycles and were present while shorebirds fed on adult dipterans, the sheer abundance of adults must have compensated for their somewhat lower profitability on a per unit scale. Breeding shorebirds also switched from feeding on adult dipterans on upland tundra to probing for benthic larvae in exposed channel sediments when adult flies became inactive under heavy wind conditions. Although benthic samples were not collected in the various forb-graminoid covertypes, it is probable that high adult numbers in wet areas correlated with high numbers of benthic larvae.

Despite prey considerations for shorebirds occurring in wetter sites, birds still occurred in what appeared to be quite sub-optimal, dry, sparse forb tundra. In particular, semipalmated sandpipers were found in these areas during the height of migration. Either a small minority of birds was attracted to this area or they were displaced from wetter, more optimal sites as numbers increased. If the former were the case, then the proportion of birds present in dry areas would remain constant through the season. In the latter case, the proportion of birds in drier habitats should increase as numbers in the delta increase. Goss-Custard (1977) noted a density-dependent response in habitat selection in red knots migrating through England. As numbers increased, the population became more dispersed and the proportion of individuals in the optimal habitat declined and sub-optimal habitats were occupied. Competition for food resources at this time probably drove the dispersion. A similar density-dependent habitat selection response was observed in semipalmated sandpipers in the delta during 1988 (Figure 11). As numbers increased, the proportion of sandpipers in wet, sparse forb-graminoid tundra decreased as the proportion in sparse forb tundra increased.

Shorebirds in saline-sedge/grass-sedge areas were generally found foraging on the edges and in the basins of shallow ponds. Use of pond edges or basins comprised 63% of the shorebird observations in saline-sedge/grass-sedge habitats in 1987 (n=1667). As water evaporated from these ponds, a ring of sediment was exposed along the edge. Late in the season, sediments of coastal ponds may offer more prey than the surrounding tundra (Connors et al. 1979). Consequently, 57% of Calidris sandpipers observed in saline-sedge/grass-sedge areas during August of 1987 were found on barren substrates of drying ponds (n=1318) where access to prey was unhindered. The remaining Calidrid shorebirds were distributed between sparsely vegetated (16%) and well vegetated (27%) substrates. As might be expected, phalaropes were usually found in flooded basins (73%, n=280). Plovers, dowitchers and turnstones were found on the well-vegetated mat of Carex and Dupontia (72%, n=144).

Species occurring together in saline-sedge/grass-sedge habitats were often observed in varying water depths. Within Calidris, species ranged from the pectoral and Baird's sandpiper that seldom occurred in areas with standing water to the stilt sandpiper that was predominantly found in water above the tibiotarsal joint (Figure 12). Plovers (98%, n=251) and turnstones (100%, n=91) were also found on substrates with no standing water. As previously noted, the majority of phalaropes (78%, n=683) were observed swimming in the basins of ponds. Because the diet of shorebirds, particularly *Calidris*, overlaps to a high degree in mid-summer (Holmes and Pitelka 1968), foraging in different water depths may aid in reducing competition when species occur in the same habitat.

Foraging strategies in saline-sedge/grass-sedge areas consisted of substrate probing and water column jabs. Phalaropes primarily fed in the water column whereas *Calidris* sandpipers fed in the benthos (Figure 13). Perhaps surprising, was the number of sandpipers mimicking the water-jabbing strategy of the phalaropes. Semipalmated sandpipers were also observed feeding on copepods in small pools that formed as a result of the high storm surge during August of 1988. This species was also noted alighting on tents and capturing adult midges.

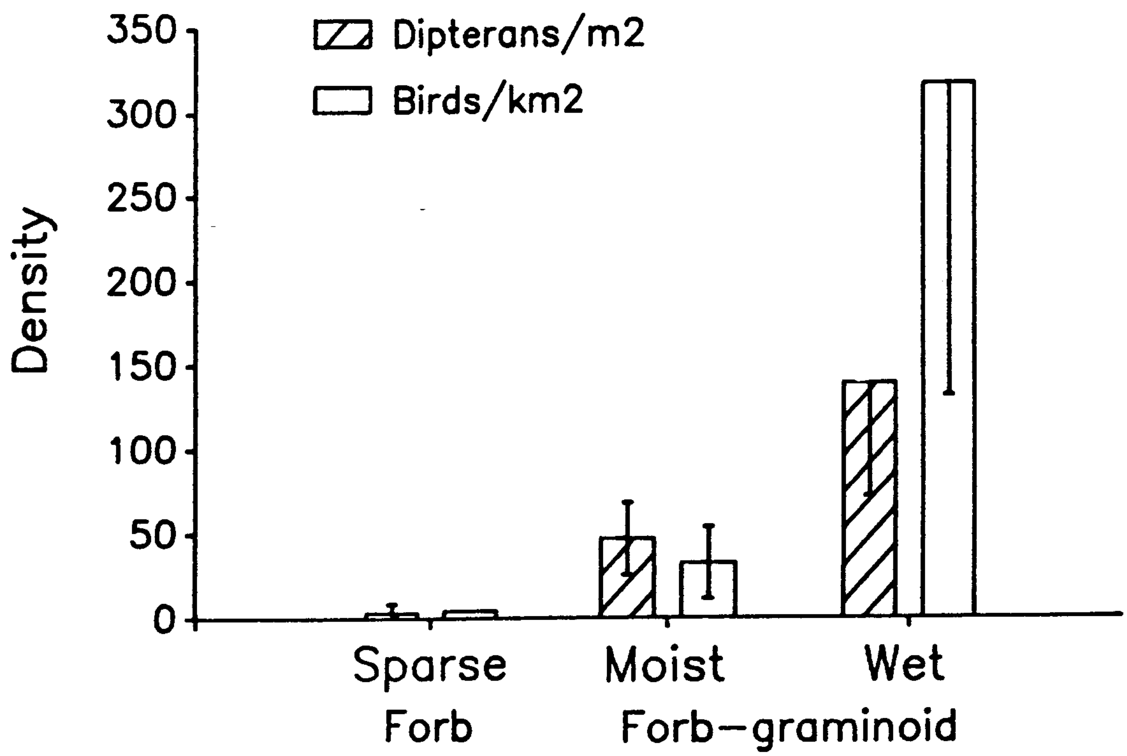

Figure 9. Density of adult dipterans (flies/m^2) and density of shorebirds (birds/km^2) in sparse forb (dry), moist sparse forb-graminoid and wet sparse forb-graminoid tundra of the Colville River delta during July, 1988.

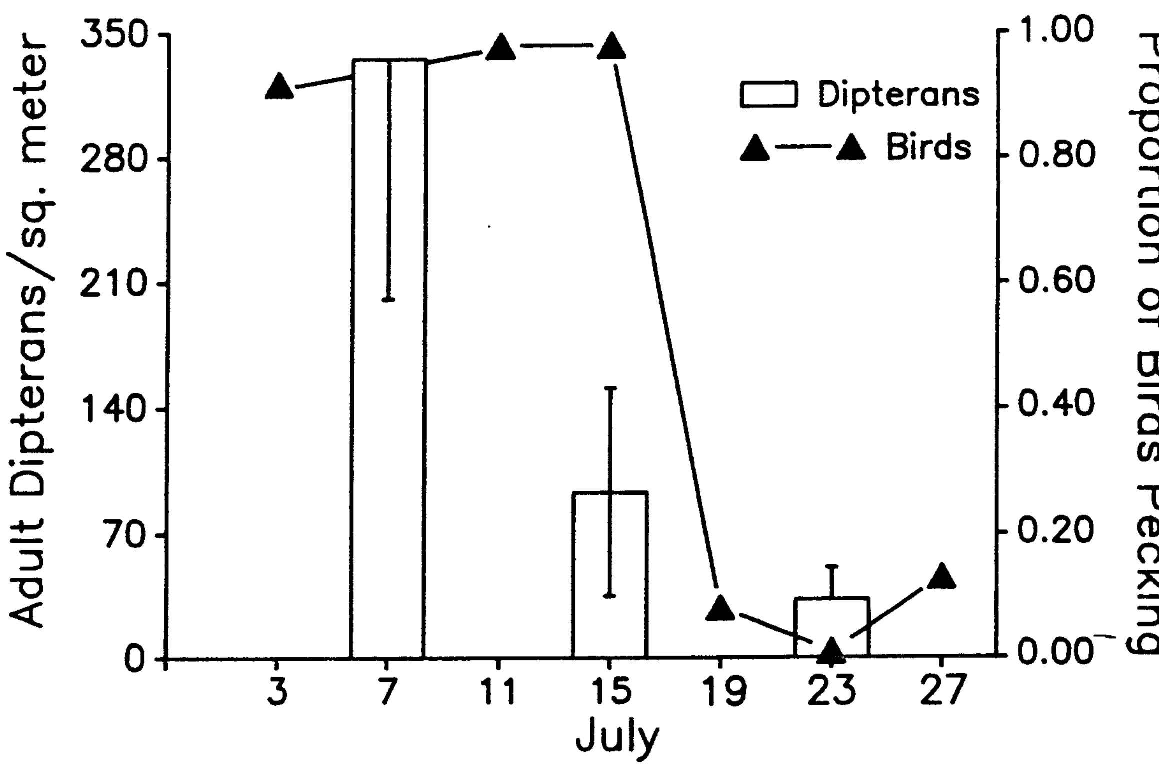

Figure 10. Proportion of pecking and probing foraging behavior of shorebirds and density of adult dipterans (flies/m^2) in sparse forb-graminoid tundra of the Colville River delta during July, 1988.

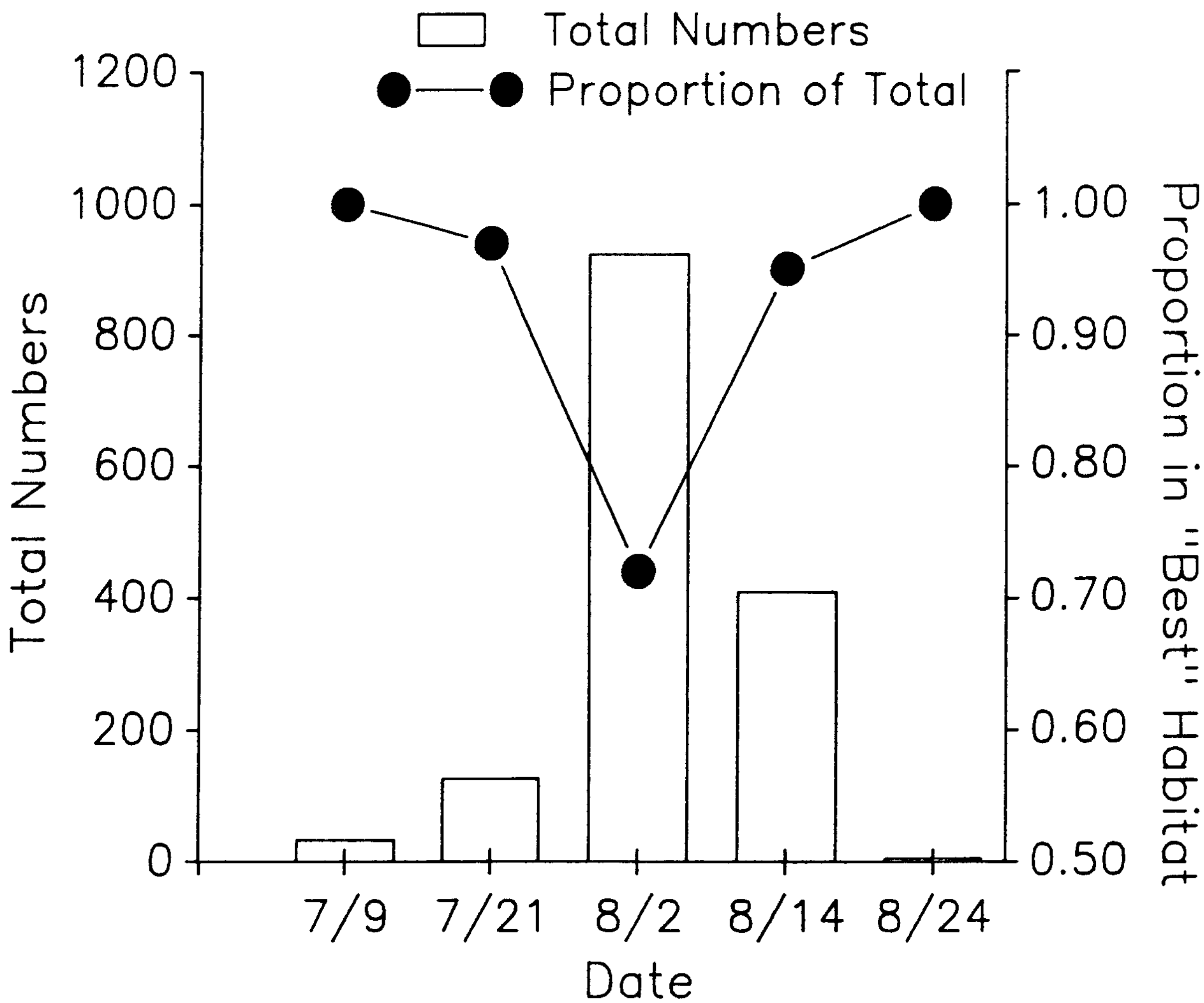

Figure 11. Change in proportion of semipalmated sandpipers occurring in wet sparse forb-graminoid tundra ("best") versus sparse forb tundra of the Colville River delta as numbers change from July to September, 1988.

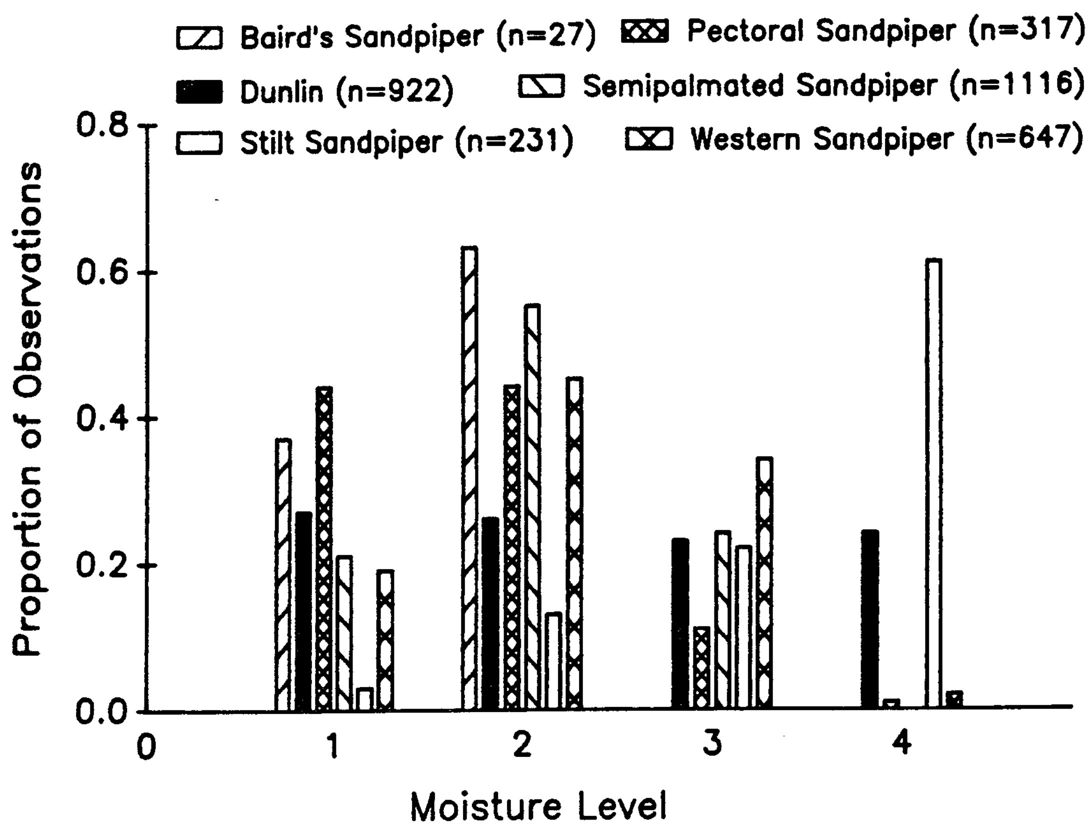

Figure 12. Distribution of Calidris sandpipers with respect to moisture level (1 = moist; 2 = film; 3 = water level between the digits and the distal end of the tibiotarsus; 4 = water level from the distal end of the tibiotarsus to the abdomen).

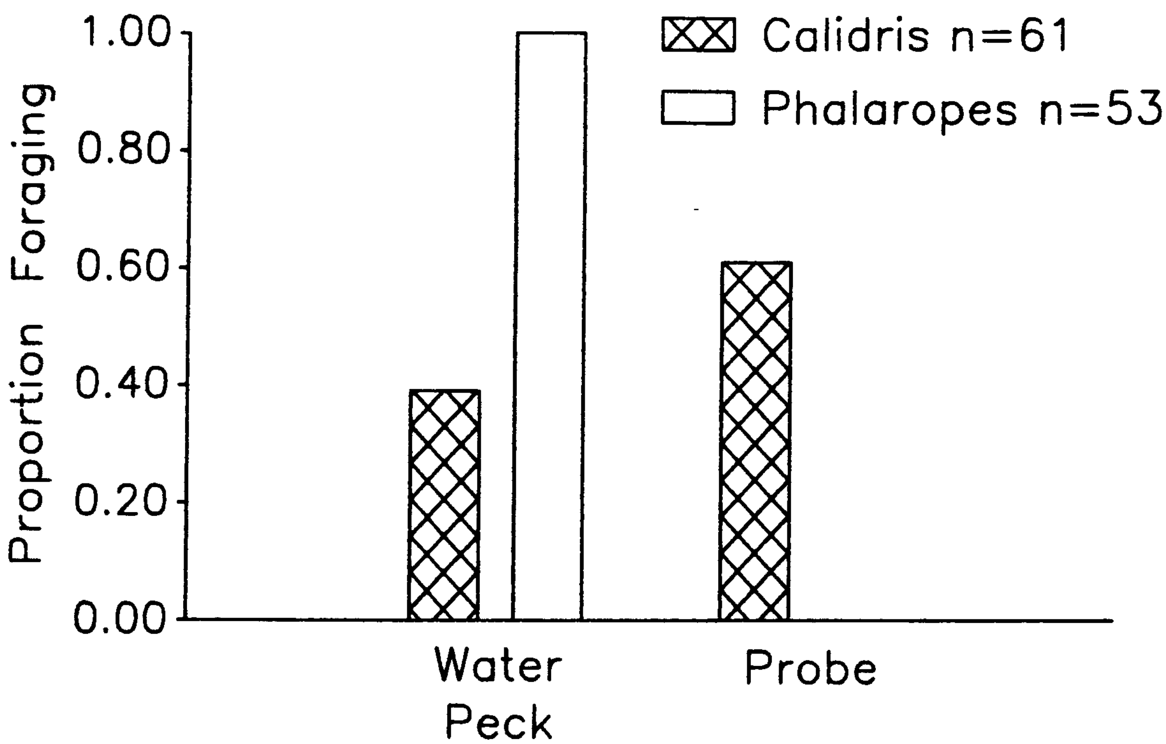

Figure 13. Foraging techniques of <u>Calidris</u> sandpipers and phalaropes found in wet saline sedge tundra of the Colville River delta during August of 1988.

SUMMARY

The dunlin was the most common species observed in littoral zone of the Colville River delta. At no other site on the North Slope was the dunlin as prevalent. Other prevalent species included the semipalmated sandpiper, red-necked phalarope, western sandpiper and pectoral sandpiper.

Two groups of shorebirds emerged with respect to littoral habitat use. Dunlins and sanderlings occurred primarily in shoreline habitats while all other species occurred primarily in saltmarshes. Of these latter species, the semipalmated sandpiper was the most common. Highest abundance was recorded on irregular terminal shorelines while highest density (birds/km^2) occurred on subterminal shorelines. Saltmarsh-dominant species used only wet, sparse forb-graminoid tundra disproportionately more than predicted. Drier habitats were significantly under-used by all species except for the golden plover. Wet saline sedge tundra supported the highest numbers of shorebirds using saltmarsh covertypes.

The abundance of dunlins on the Colville was attributed to the presence of terminal shoreline silt barrens. Connors et al. (1984) listed the dunlin as being only moderately susceptible to littoral zone disturbances at Barrow. At Barrow, dunlins did not always make a dramatic shift to the littoral zone (Connors et al. 1979). The dependence of dunlins on the terminal shorelines of the Colville River delta make the species highly susceptible to oil spills that could occur in Harrison Bay.

Maximum use of littoral habitats occurred during August. The early migrant population (pectoral sandpipers and lesser golden plovers) was composed of adults while later populations mainly consisted of immatures. An exception was the late-August occurrence of adult dunlin.

Despite a large component of spatial heterogeneity within vegetation covertypes, a sampling plan based on habitat strata appeared to be more efficient than a temporally-based plan. Further gains in precision might be made by further temporal stratification and restricting spatial inferences.

Assuming a complete 7-day turnover of the migrant shorebird population, the average annual number of post-breeding shorebirds that passed through the Colville River delta was about 41,000.

Feeding, to the point of virtual exclusion of all other behavior, was the dominant activity of shorebirds in the delta. Shorebirds were found to forage throughout the diel period and were able to switch foraging techniques as prey availability changed.

Habitat selection on shorelines and in sparse forb-graminoid tundra was related to prey abundance. Selection of sites with the highest prey densities was mediated by a density-dependent response. Foraging shorebirds chose microsites in saltmarsh where high numbers of prey would be expected. *Calidris* sandpipers appeared to partition these areas by foraging in different water depths.

The magnitude and intensity of feeding observed in all species, coupled with the correlation of high invertebrate abundance and high shorebird abundance, point to the critical role that the littoral zone of the Colville River delta plays in a shorebird's annual cycle. The dependence of dunlins on coastal shorelines is further illustrated by the delayed appearance of dunlin on the delta in 1988 which corresponded to the retreat of flood water off the silt barrens. These results drastically differ from the conclusions reached by Meehan and Jennings (1988) about the value of coastal barrens to large waterbirds (barrens were ranked last in all considerations). Direct effects of development on shorelines as well as indirect effects of pollutants on benthic invertebrates could largely impact the migrant dunlin population. Not only were areas of high concentration important to shorebirds migrating through the delta, but also important were buffer areas that were needed during times of environmental or competitive stress. Thus, management decisions must include considerations of maintaining areas beyond those which support the highest numbers of birds.

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APPENDICES

APPENDIX A

STRATUM SIZES AND SAMPLING INTENSITY OF AREAS SURVEYED IN 1988

Table 17. Section, area, length (shorelines), and sampling intensity for each stratum sampled in 1988. Strata are grouped by habitat covertype (total area occurring in the delta). See Figure 1 for location examples and Figure 2 for section boundries.

Stratum	Section	Km^2	Km	Surveys
A. Shoreline Silt Barren (127 km, 2.42 km^2)				
1. Irregular terminal shoreline (43 km, 1.87 km^2)				
1	1	0.364	7.71	3
2	1	0.137	8.58	3
3	1	0.263	8.78	3
4	2	0.205	6.82	6
5	4	0.180	5.99	7
6	5	0.640	2.49	4
2. Regular terminal shoreline (6.2 km, 0.06 km^2)				
7	3	0.026	2.56	6
8	4	0.025	2.52	6
9	5	0.012	1.16	3
3. Subterminal shoreline (78 km, 0.49 km^2)				
10	1	0.044	5.76	3
11	1	0.066	4.29	3
12	1	0.116	14.9	3
13	2	0.018	3.62	6
14	3	0.025	4.98	6
15	4	0.015	2.97	6
16	4	0.024	4.81	7
17	5	0.011	2.13	3
18	6	0.042	8.42	3
19	6	0.006	1.26	2

Table 17. (cont.)

Stratum	Section	Km^2	Surveys
B. Interior Silt Barren (37.7 km^2)			
20	1	3.445	3
21	1	2.068	3
22	1	4.442	3
23	2	5.356	6
24	3	5.952	6
25	4	8.515	6
26	4	2.749	7
27	5	0.952	3
28	6	0.144	3
29	6	3.490	2
C. Sparse Forb-graminoid Tundra (11.32 km^2)			
1. Sparse forb (1.86 km^2)			
30	3	0.903	3
31	3	0.953	3
2. Moist forb-graminoid (6.62 km^2)			
32	2	0.582	3
33	2	0.763	3
34	3	0.927	3
35	3	0.482	3
36	3	0.420	3
37	4	0.400	3
38	4	0.321	3
39	4	0.430	3
40	5	0.501	3
41	5	0.574	3
42	6	0.076	3
43	6	0.070	3
44	6	0.187	2
45	6	0.241	2
3. Wet forb-graminoid (1.75 km^2)			
46	2	0.303	3
47	2	0.247	3
48	3	0.248	3
49	3	0.376	3
50	4	0.574	2

Table 17. (cont.)

Stratum	Section	Km^2	Surveys
C. Sparse Forb-graminoid Tundra (cont.)			
4. Polygonal forb-graminoid (1.10 km^2)			
51	2	0.243	3
52	5	0.134	3
53	5	0.140	2
54	6	0.099	2
55	6	0.276	3
56	6	0.209	3
D. Saline Sedge Tundra (10.98 km^2)			
1. Wet saline sedge (9.12 km^2)			
57	2	0.318	3
58	2	0.806	3
59	2	0.054	3
60	2	0.086	3
61	3	0.580	3
62	3	0.297	3
63	3	1.065	3
64	3	0.794	3
65	3	0.091	3
66	4	0.385	3
67	4	0.411	3
68	4	0.216	3
69	4	0.458	3
70	5	0.724	3
71	5	1.150	2
72	6	0.493	3
73	6	0.304	2
74	6	0.503	3
75	6	0.236	2
2. Polygonal saline sedge (1.86 km^2)			
76	5	0.693	2
77	5	0.374	3
78	6	0.439	2
79	6	0.352	3

Table 17. (cont.)

Stratum	Section	Km^2	Surveys
E. Saline Grass-sedge Tundra (5.86 km^2)			
1. Moist saline grass-sedge (3.77 km^2)			
80	2	0.148	3
81	3	0.146	3
82	3	0.700	3
83	3	0.261	3
84	3	0.150	3
85	4	0.177	3
86	4	0.075	3
87	5	0.188	3
88	5	0.532	2
89	6	0.171	2
90	6	0.049	2
91	6	0.162	2
92	6	0.442	3
93	6	0.233	3
94	6	0.140	3
95	6	0.049	2
2. Polygonal saline grass-sedge (2.09 km^2)			
96	3	0.025	3
97	4	0.413	3
98	5	0.576	3
99	5	0.623	2
100	6	0.301	2
101	6	0.154	3

APPENDIX B

ESTIMATES OF DENSITIES, TOTAL NUMBERS, PROPORTION OF THE TOTAL NUMBER AND THEIR ASSOCIATED VARIANCES

Formulae for Stratified Random Sampling (from Cochran 1977)

Notation:

A	total littoral area of the delta (km^2)
a	total sampled littoral area of the delta
A_k	area for the k^{th} combination of strata
a_h	area of the h^{th} stratum
y_{hi}	the i^{th} number of birds/area in the h^{th} stratum
$w_h = a_h / \sum_{h=1}^{\ell} a_h$	the weight of stratum h for (the total number of strata)
n_h	the number of surveys (times) the h^{th} stratum was covered
$y_h = \sum_{i=1}^{n_h} y_{hi}/n_h$	sample mean of stratum h
$s_h^2 = \sum_{i=1}^{n_h}(y_{hi} - y_h)^2/n_h - 1$	sample variance of the stratum

The sample estimate for the mean density for any species or group of species in an instant in time for stratified sampling is equal to the population estimate of the mean assuming that approximately 100% of the spatial area of the delta was sampled. The sample estimate is,

$$y_{st} = \sum_{h=1}^{\ell} w_h y_h$$

In estimating the variance of y_{st}, covariance arose because a distinct set of strata together was sampled on each predetermined survey-day. Including the covariance between strata, the estimate of the variance is

$$var(y_{st}) = \sum_{h=1}^{\ell} w_h^2 s^2/n_h(y_h) + 2\sum_{h=1}^{\ell}\sum_{j<h}^{\ell} w_h w_j cov(y_h y_j)/n_h$$

where,

$$cov = \frac{\sum_{i=1}^{n_h}(y_{hi} - y_h)(y_{ji} - y_j)}{n_h - 1} \quad \text{and } SE(y_{st}) = \sqrt{var(y_{st})}$$

To obtain an estimate of total number (abundance), density is multiplied by the area (A_k) of any combination of strata desired (a covertype habitat) or the entire delta (A).

$$T_k = A_k y_{st} \text{ and the } var(T_k) = A_k^2 s^2(y_{st})$$

Lastly, conditioning on the estimate of the abundance of any species or group of species occurring in the littoral zone of the delta in an instant of time, the estimate of the proportion of the total number occuring in habitat k is,

$$P(T_k) = A_k(y_{st})/A(y_{st}) \text{ and } SE(P) = SE(T_k)/A(y_{st})$$

<u>Formulae for Ratio Estimation</u> (from Cochran 1977)

Because estimates were desired for a shorter period of time (and n=1 for any strata as defined above), strata were combined to produce estimates for super-strata (covertype habitat). Instantaneous average density, totals and variances in time within a more protracted time period were obtained using ratio estimation. Stratified procedures were then employed to obtain estimates for combinations of habitats. Notation is as above with the following exceptions:

a_{hi}	area in the i^{th} sample
a_h	average area in the h^{th} stratum
y_{hi}	the i^{th} number of birds in the h^{th} stratum
$W_h = A_h/A$	weight of the h^{th} stratum

Here, the primary point estimate of interest was the stratum ratio,

$$r_h = \sum_{i=1}^{n_h} y_{hi}/\Sigma a_{hi} \quad \text{where the variance of } r_h \text{ is}$$

$$\text{var}(r_h) = (1/na^2)[(\sum_{i=1}^{n_h} y_{hi} - r_h a_{hi})^2/n_h - 1]$$

To obtain density and total estimates for combinations of strata, stratified procedures would followed as presribed above, where,

$$r_{st} = \sum_{h=1}^{\ell} W_h r_h \text{ and } \text{var}(r_{st}) = \sum_{h=1}^{\ell} W_h{}^2 s^2(r_h)$$

To obtain an estimate of total number (abundance), density is multiplied by the area (A_h) of any stratum, any combination of strata (A_k), or the entire delta (A).

$$T_k = A_k r_{st} \text{ and the } \text{var}(T_k) = A_k{}^2 s^2(r_{st})$$

Table 18. Estimated average densities (birds/km^2), total number, and standard errors (SE) of shorebirds occurring in littoral habitats of the Colville River delta. Included are estimates for 1987, 1988 (habitat classes defined in 1987).

		Shorelines				Sparse		Saline-sedge	
		Terminal		Subterminal		Forb-grass		/Grass-sedge	
Species	Year	Den SE	Tot SE	Den SE	Tot SE	Den SE	Tot SE	Den SE	Tot SE
All Species	87	868 208	1675 401	717 189	353 93	100.2 12.8	1133 145	58.2 6.9	979 116
	88	858 236	1655 456	1187 309	584 152	131.1 32.7	1484 371	77.7 12.6	1308 212
DUNL	87	755 223	1457 430	587 185	289 91	14.8 4.4	167 50	15.1 3.5	254 59
	88	670 244	1292 470	984 303	484 149	23.6 5.5	268 62	11.4 2.9	193 49
SESA	87	60 21	117 41	35 13	17 6	31.0 5.8	351 66	11.4 2.6	191 44
	88	150 97	290 187	150 84	74 41	55.5 23.2	629 263	24.4 6.5	411 109
RNPH	87	6.7 5.0	13 10	- -	- -	16.4 4.5	185 52	8.2 2.3	138 38
	88	3.5 2.7	7 5	1.7 1.1	1 1	22.8 5.2	258 58	21.3 5.4	359 90
WESA	87	25 6	48 11	29 13	14 6	18.2 7.6	206 86	6.8 1.5	115 25
	88	11 4	20 8	29 15	14 7	5.7 3.1	64 36	2.6 1.1	43 19
PESA	87	1.7 1.3	3 3	0.8 0.8	0 0	7.0 2.8	79 31	3.5 0.6	59 10
	88	2.5 1.8	5 4	- -	- -	9.4 3.0	107 33	7.0 1.9	118 32

Table 18. (cont.)

Species	Year	Shorelines Terminal Den SE	Shorelines Terminal Tot SE	Shorelines Subterminal Den SE	Shorelines Subterminal Tot SE	Sparse Forb-grass Den SE	Sparse Forb-grass Tot SE	Saline-sedge /Grass-sedge Den SE	Saline-sedge /Grass-sedge Tot SE
STSA	87	0.3	0	-	-	0.9	10	4.5	76
		0.3	0	-	-	0.3	3	1.4	24
	88	-	-	-	-	7.0	80	3.4	57
		-	-	-	-	2.6	30	1.2	20
REPH	87	7.2	14	-	-	2.4	27	1.9	32
		6.8	13	-	-	1.0	11	0.7	12
	88	3.4	7	0.4	0	1.7	19	1.6	27
		1.5	3	0.4	0	0.7	8	0.6	10
BBPL	87	2.0	4	31	15	2.5	29	1.4	24
		0.7	2	18	9	0.8	9	0.4	6
	88	2.5	5	3.6	2	1.8	21	1.1	18
		1.4	2	2.6	1	0.5	6	0.4	6
LGPL	87	0.7	1	-	-	3.0	34	1.2	20
		0.4	1	-	-	1.1	13	0.5	8
	88	0.5	1	0.8	0	0.5	6	2.0	34
		0.2	1	0.6	0	0.2	3	0.5	9
RUTU	87	0.9	2	19	9	2.1	24	1.0	17
		0.4	1	11	6	0.6	7	0.3	5
	88	-	-	2.7	1	1.7	19	1.8	30
		-	-	1.9	1	0.4	4	0.4	7
LBDO	87	1.0	2	-	-	1.1	12	1.7	29
		1.0	2	-	-	0.6	7	1.1	18
	88	1.1	2	-	-	0.7	8	0.9	14
		1.1	2	-	-	0.4	5	0.3	6
SAND	87	1.0	2	1.9	1	-	-	0.1	2
		0.4	1	1.4	1	-	-	0.1	1
	88	10	20	11	5	0.0	0	-	-
		3	6	5	3	0.0	0	-	-

Table 18. (cont.)

Species	Year	Shorelines Terminal Den SE	Shorelines Terminal Tot SE	Shorelines Subterminal Den SE	Shorelines Subterminal Tot SE	Sparse Forb-grass Den SE	Sparse Forb-grass Tot SE	Saline-sedge /Grass-sedge Den SE	Saline-sedge /Grass-sedge Tot SE
Other Species	87	6.4	12	16.9	8	0.8	9	1.3	22
		3.8	7	7.0	3	0.2	3	0.3	5
	88	3.3	6	5.4	3	0.5	5	0.2	4
		1.4	3	3.9	2	0.3	3	0.1	1

Table 19. Estimated average density (birds/km), number, and standard errors (SE) of shorebirds occurring in shoreline habitat types of the Colville River delta defined in 1988.

Species	Irregular Terminal Shoreline		Regular Terminal Shoreline		Subterminal Shoreline	
	Density	Total	Density	Total	Density	Total
All	36.88	1585	11.21	70	7.49	584
Species	10.59	456	5.44	34	1.93	152
DUNL	28.66	1232	9.67	60	6.20	484
	10.41	447	5.41	34	1.91	149
SESA	6.65	286	0.62	4	0.95	74
	4.32	186	0.60	4	0.53	41
RNPH	0.14	6	0.08	1	0.01	1
	0.12	5	0.08	1	0.01	1
WESA	0.48	20	-	-	0.18	14
	0.19	8	-	-	0.09	7
PESA	0.11	5	-	-	-	-
	0.08	4	-	-	-	-
STSA	-	-	-	-	-	-
	-	-	-	-	-	-
REPH	0.11	5	0.29	2	0.00	0
	0.06	3	0.22	1	0.00	0
BBPL	0.07	3	0.28	2	0.02	2
	0.05	2	0.19	1	0.02	1
LGPL	-	-	0.16	1	0.00	0
	-	-	0.10	1	0.00	0
RUTU	-	-	-	-	0.02	1
	-	-	-	-	0.02	1
LBDO	0.05	2	-	-	-	-
	0.05	2	-	-	-	-
SAND	0.46	20	0.05	0	0.07	5
	0.13	6	0.05	0	0.03	3
Other	0.14	6	0.05	0	0.03	3
Species	0.08	3	0.05	0	0.02	2

Table 19. (cont.)

Species	Sparse Forb		Moist, Forb-Graminoid		Wet, Forb-Graminoid		Polygonal Forb-graminoid	
	Den.[a] SE	Total SE	Den. SE	Total SE	Den. SE	Total SE	Den. SE	Total SE
All	28.21	52	75.11	495	450.96	791	133.27	146
Species	22.35	41	26.47	175	109.38	191	29.26	32
DUNL	1.08	2	7.87	52	116.39	204	9.23	10
	0.40	1	3.76	25	29.06	51	3.75	4
SESA	24.80	46	40.85	270	146.22	256	51.64	57
	22.70	42	19.95	132	64.05	112	25.92	29
RNPH	0.54	1	10.32	68	91.32	160	26.50	29
	0.54	1	4.64	30	24.59	43	9.89	11
WESA	0.18	0	2.43	16	25.07	44	3.94	4
	0.18	0	1.32	9	16.11	28	3.65	4
PESA	-	-	4.78	32	30.03	53	20.29	22
	-	-	1.68	11	12.83	22	11.96	13
STSA	-	-	3.96	26	22.40	39	13.02	14
	-	-	2.98	20	9.94	17	7.00	8
REPH	-	-	0.59	4	8.01	14	1.51	2
	-	-	0.35	2	3.44	6	0.80	1
BBPL	0.36	1	1.62	11	3.72	7	2.72	3
	0.36	1	0.53	4	1.83	3	1.79	2
LGPL	0.72	1	0.67	4	-	-	-	-
	0.72	1	0.33	2	-	-	-	-
RUTU	0.36	1	1.23	8	3.34	6	4.09	5
	0.36	1	0.41	3	0.92	2	1.64	2
LBDO	-	-	0.67	4	1.91	3	-	-
	-	-	0.62	4	1.38	2	-	-
SAND	-	-	0.06	0	-	-	-	-
	-	-	0.06	0	-	-	-	-
Other	0.18	0	0.06	0	2.57	5	0.03	0
Species	0.18	0	0.06	0	1.77	3	0.03	0

[a] density = birds/km^2

Table 19. (cont.)

Species	Wet Saline Sedge Den.[a] SE	Wet Saline Sedge Total SE	Polygonal Saline Sedge Den. SE	Polygonal Saline Sedge Total SE	Moist Grass-sedge Den. SE	Moist Grass-sedge Total SE	Polygonal Grass-sedge Den. SE	Polygonal Grass-sedge Total SE
All	89.85	820	122.18	227	24.53	92	81.04	169
Species	19.73	180	22.73	42	5.98	23	13.96	30
DUNL	17.11	156	3.77	7	2.67	10	9.32	20
	5.18	47	1.64	3	0.92	3	3.19	7
SESA	27.80	254	36.60	68	9.91	37	24.78	52
	8.39	77	12.56	23	3.75	14	8.63	18
RNPH	21.70	198	46.02	86	3.37	13	30.04	63
	6.46	59	12.89	24	1.56	6	9.89	21
WESA	3.81	35	1.08	2	-	-	3.03	6
	2.09	19	1.08	2	-	-	1.66	3
PESA	7.58	69	13.55	25	3.64	14	5.02	11
	1.87	17	8.64	16	1.47	6	2.13	4
STSA	3.92	36	8.07	15	0.09	0	2.87	6
	1.61	15	4.20	8	0.09	0	2.44	6
REPH	1.21	11	7.36	14	0.09	0	0.96	2
	0.52	5	4.45	8	0.09	0	0.96	2
BBPL	1.17	11	1.61	3	0.28	1	1.51	3
	0.50	5	1.61	3	0.28	1	1.24	3
LGPL	2.10	19	1.79	3	3.09	12	0.16	0
	1.01	9	1.38	3	1.86	7	0.16	0
RUTU	1.91	17	1.88	4	1.29	5	1.83	4
	0.44	4	0.87	2	0.47	2	1.24	3
LBDO	1.34	12	-	-	-	-	1.04	2
	0.61	6	-	-	-	-	0.48	1
SAND	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-
Other	0.20	2	0.45	1	0.09	0	0.48	1
Species	0.11	1	0.32	1	0.09	0	0.34	1

[a] density = birds/km^2

Table 20. Estimated proportions of average numbers and standard errors (SE) of shorebirds occurring in littoral habitats (defined in 1987) of the Colville River delta for 1987 and 1988.

		Terminal Shorelines		Subterminal Shorelines		Sparse Forb-grass		Saline Sedge /Grass-sedge		
	87	P	SE	P	SE	P	SE	P	SE	Total
Spp.	88	P	SE	P	SE	P	SE	P	SE	Total
All		0.40	0.10	0.09	0.02	0.27	0.03	0.24	0.03	4140
Species		0.33	0.09	0.12	0.03	0.29	0.07	0.26	0.04	5031
DUNL		0.67	0.20	0.13	0.04	0.08	0.02	0.12	0.03	2167
		0.58	0.21	0.22	0.07	0.12	0.03	0.09	0.02	2237
SESA		0.17	0.06	0.03	0.01	0.52	0.10	0.28	0.06	676
		0.21	0.13	0.05	0.03	0.45	0.18	0.29	0.06	1404
RNPH		0.04	0.03	0.00	0.00	0.55	0.15	0.41	0.11	336
		0.01	0.01	0.00	0.00	0.41	0.08	0.57	0.14	625
WESA		0.13	0.03	0.04	0.02	0.54	0.22	0.30	0.07	383
		0.14	0.06	0.10	0.05	0.45	0.25	0.30	0.13	141
PESA		0.02	0.02	0.00	0.00	0.56	0.22	0.42	0.07	141
		0.02	0.02	0.00	0.00	0.47	0.14	0.51	0.14	230
STSA		0.00	0.00	0.00	0.00	0.12	0.03	0.88	0.28	86
		0.00	0.00	0.00	0.00	0.58	0.22	0.42	0.15	137
REPH		0.19	0.18	0.00	0.00	0.37	0.15	0.44	0.16	73
		0.13	0.06	0.00	0.00	0.37	0.13	0.50	0.20	53
BBPL		0.06	0.01	0.21	0.13	0.40	0.13	0.33	0.08	72
		0.11	0.04	0.04	0.02	0.46	0.11	0.39	0.13	46
LGPL		0.02	0.02	0.00	0.00	0.61	0.23	0.35	0.14	55
		0.02	0.02	0.00	0.00	0.15	0.07	0.83	0.22	41
RUTU		0.04	0.02	0.18	0.12	0.47	0.14	0.33	0.10	52
		0.00	0.00	0.02	0.02	0.38	0.08	0.60	0.14	50
LBDO		0.05	0.05	0.00	0.00	0.28	0.16	0.67	0.42	43
		0.09	0.09	0.00	0.00	0.32	0.20	0.59	0.23	24
SAND		0.40	0.20	0.20	0.20	0.00	0.00	0.40	0.20	5
		0.80	0.24	0.20	0.12	0.00	0.00	0.00	0.00	25

Table 21. Estimated proportions of average numbers and standard errors (SE) of shorebirds occurring in littoral habitats (defined in 1988) of the Colville River delta for 1988.

	Irregular Terminal Shoreline		Regular Terminal Shoreline		Subterminal Shoreline	
Species	P(Total)	SE	P(Total)	SE	P(Total)	SE
All Spp.	0.315	0.091	0.014	0.007	0.116	0.030
DUNL	0.552	0.200	0.027	0.015	0.217	0.067
SESA	0.204	0.133	0.003	0.003	0.053	0.029
RNPH	0.010	0.008	0.001	0.001	0.001	0.001
WESA	0.144	0.059	-	-	0.010	0.051
PESA	0.021	0.015	-	-	-	-
STSA	-	-	-	-	-	-
REPH	0.088	0.049	0.035	0.026	0.000	0.000
BBPL	0.071	0.043	0.037	0.027	0.039	0.028
LGPL	-	-	0.024	0.015	0.010	0.007
RUTU	-	-	-	-	0.027	0.019
LBDO	0.086	0.086	-	-	-	-
SAND	0.766	0.217	0.013	0.013	0.209	0.103
Other Spp	0.324	0.070	0.018	0.018	0.143	0.103

Table 21.(cont.)

Spp.	Sparse Forb		Moist, Forb-Graminoid		Wet, Forb-Graminoid		Polygonal Forb-Graminoid	
	P(Tot)	SE	P(Tot)	SE	P(Tot)	SE	P(Tot)	SE
All Spp.	0.010	0.008	0.099	0.034	0.157	0.038	0.029	0.007
DUNL	0.001	0.000	0.023	0.011	0.091	0.023	0.005	0.002
SESA	0.033	0.030	0.193	0.094	0.182	0.080	0.041	0.020
RNPH	0.002	0.002	0.109	0.048	0.256	0.069	0.047	0.017
WESA	0.002	0.002	0.113	0.062	0.308	0.198	0.031	0.028
PESA	-	-	0.138	0.048	0.228	0.097	0.097	0.057
STSA	-	-	0.192	0.144	0.286	0.127	0.105	0.057
REPH	-	-	0.073	0.043	0.263	0.113	0.031	0.017
BBPL	0.015	0.015	0.236	0.077	0.143	0.070	0.066	0.046
LGPL	0.032	0.032	0.106	0.051	-	-	-	-
RUTU	0.013	0.013	0.162	0.051	0.116	0.032	0.090	0.045
LBDO	-	-	0.183	0.168	0.138	0.099	-	-
SAND	-	-	0.014	0.014	-	-	-	-
Other Spp.	0.018	0.018	0.020	0.020	0.242	0.167	0.018	0.018

Table 21. (cont.)

Spp.	Wet Saline Sedge P(Tot)	SE	Polygonal Saline Sedge P(Tot)	SE	Moist Grass-sedge P(Tot)	SE	Polygonal Grass-sedge P(Tot)	SE
All Spp.	0.163	0.036	0.045	0.008	0.018	0.004	0.034	0.006
DUNL	0.070	0.021	0.003	0.001	0.005	0.001	0.009	0.003
SESA	0.181	0.053	0.049	0.017	0.027	0.010	0.037	0.013
RNPH	0.317	0.094	0.137	0.038	0.020	0.009	0.101	0.033
WESA	0.245	0.139	0.014	0.014	-	-	0.045	0.025
PESA	0.301	0.075	0.109	0.070	0.060	0.024	0.046	0.019
STSA	0.261	0.112	0.110	0.057	0.003	0.003	0.044	0.037
REPH	0.207	0.088	0.257	0.155	0.007	0.007	0.038	0.038
BBPL	0.235	0.099	0.066	0.066	0.023	0.023	0.070	0.057
LGPL	0.460	0.220	0.080	0.062	0.279	0.165	0.008	0.008
RUTU	0.348	0.080	0.070	0.032	0.097	0.033	0.077	0.052
LBDO	0.504	0.231	-	-	-	-	0.089	0.042
SAND	-	-	-	-	-	-	-	-
Other Spp.	0.101	0.053	0.045	0.032	0.019	0.019	0.054	0.038

Table 22. Proportions of the average number of dunlins and sanderlings and proportion of the littoral zone coverage by sections (Figure 1) of Colville River delta surveyed in 1988.

Section Habitat	1 P(Km²)/P(Tot)	2 P(Km²)/P(Tot)	3 P(Km²)/P(Tot)	4 P(Km²)/P(Tot)	5 P(Km²)/P(Tot)	6 P(Km²)/P(Tot)
Irregular Terminal	2.50	0.93	-	0.59	2.09	-
Shoreline	19.13	20.01	-	18.08	1.44	-
Regular Terminal	-	-	0.09	0.08	0.04	-
Shoreline	-	-	0.31	2.11	0.24	-
Subterminal	1.15	0.06	0.08	0.13	0.03	0.16
Shoreline	14.33	1.42	1.21	1.51	1.52	1.25
Sparse Forb/	-	6.20	14.09	5.64	3.51	3.98
Forb-graminoid	-	2.66	6.88	0.64	1.00	0.05
Polygonal Sparse	-	0.79	-	-	0.89	1.91
Forb-graminoid	-	0.07	-	-	0.04	0.33
Saline Sedge/	-	4.62	13.35	5.63	8.48	9.59
Grass-sedge	-	1.14	1.73	0.66	1.47	2.47
Polygonal Saline	-	-	0.08	1.35	7.41	4.07
Sedge/Grass-sedge	-	-	0.00	0.04	1.13	0.00

Table 22. (cont.) Other species.

Section Habitat	1 $P(Km^2)$ P(Tot)	2 $P(Km^2)$ P(Tot)	3 $P(Km^2)$ P(Tot)	4 $P(Km^2)$ P(Tot)	5 $P(Km^2)$ P(Tot)	6 $P(Km^2)$ P(Tot)
Irregular Terminal Shoreline	2.50 5.04	0.93 0.60	- -	0.59 1.12	2.09 4.94	- -
Regular Terminal Shoreline	- -	- -	0.09 0.04	0.08 0.87	0.04 0.23	- -
Subterminal Shoreline	1.15 1.20	0.06 0.06	0.08 0.28	0.13 0.20	0.03 1.08	0.16 0.17
Sparse Forb/ Forb-graminoid	- -	6.20 13.98	14.09 14.93	5.64 4.39	3.51 2.96	3.98 2.52
Polygonal Sparse Forb-graminoid	- -	0.79 0.69	- -	- -	0.89 0.61	1.91 3.63
Saline Sedge/ Grass-sedge	- -	4.62 3.91	13.35 6.99	5.63 4.79	8.48 6.27	9.59 5.03
Polygonal Saline Sedge/Grass-sedge	- -	- -	0.08 0.04	1.35 0.40	7.41 5.92	4.07 7.16

Table 23. Weekly average numbers and (SE's) for species occurring on the Colville River delta - 1987.

	Periods							
Species	1	2	3	4	5	6	7	8
All	1065	1893	3350	4969	8283	5878	5909	5549
Species	(285)	(364)	(971)	(1171)	(1234)	(1316)	(1536)	(2791)
DUNL	82	147	495	2211	5243	3904	4354	5288
	(33)	(58)	(300)	(946)	(1210)	(1163)	(1396)	(2779)
SESA	325	643	1026	1804	904	237	54	0
	(116)	(149)	(372)	(361)	(244)	(70)	(43)	(0)
RNPH	0	202	871	128	410	307	816	172
	(0)	(116)	(459)	(82)	(154)	(107)	(286)	(91)
WESA	0	40	661	321	785	700	350	32
	(0)	(22)	(249)	(75)	(279)	(309)	(144)	(25)
PESA	308	385	45	106	116	87	0	3
	(155)	(127)	(18)	(41)	(36)	(22)	(0)	(2)
STSA	0	24	8	106	285	190	0	0
	(0)	(12)	(8)	(25)	(126)	(83)	(0)	(0)
REPH	10	28	8	72	149	167	98	0
	(10)	(14)	(6)	(57)	(80)	(81)	(46)	(0)
BBPL	60	143	73	60	100	32	61	32
	(29)	(52)	(23)	(20)	(27)	(17)	(28)	(13)
RUTU	107	51	94	31	120	13	29	8
	(38)	(19)	(23)	(13)	(62)	(6)	(21)	(6)
LGPL	137	160	8	6	48	19	24	0
	(45)	(51)	(7)	(6)	(31)	(10)	(15)	(0)
LBDO	0	0	0	0	18	186	81	0
	(0)	(0)	(0)	(0)	(12)	(69)	(47)	(0)
SAND	12	2	6	1	5	4	18	13
	(10)	(2)	(6)	(1)	(5)	(2)	(10)	(12)

Table 24. Ten-day average numbers and (SE's) for species occurring on the Colville River delta - 1988.

Species	Periods 1	2	3	4	5	6
All Species	1264 (291)	1738 (422)	6091 (932)	6968 (1469)	12232 (3500)	5341 (1888)
DUNL	54 (33)	277 (58)	919 (300)	2229 (946)	9759 (1210)	4534 (1163)
SESA	518 (90)	359 (101)	3451 (584)	2821 (763)	302 (127)	8 (7)
RNPH	191 (0)	47 (116)	1058 (459)	906 (82)	1271 (154)	455 (107)
WESA	2 (2)	11 (10)	30 (15)	186 (53)	536 (227)	181 (86)
PESA	306 (133)	592 (132)	167 (76)	141 (30)	51 (16)	14 (8)
STSA	2 (2)	73 (47)	150 (94)	373 (123)	123 (55)	8 (6)
REPH	14 (8)	11 (6)	104 (36)	166 (59)	30 (11)	11 (11)
BBPL	18 (6)	94 (27)	83 (27)	26 (13)	5 (4)	10 (6)
RUTU	99 (19)	76 (18)	60 (17)	19 (10)	19 (12)	5 (4)
LGPL	50 (41)	97 (30)	1 (1)	53 (30)	15 (9)	0 (0)
LBDO	5 (5)	24 (24)	4 (4)	2 (2)	33 (19)	100 (59)
SAND	3 (3)	49 (43)	36 (25)	35 (19)	76 (41)	14 (5)

Table 25. Estimated total numbers and standard errors for all species occurring in saltmarsh and shoreline habitats of the Colville River delta by 7-day periods - 1987.

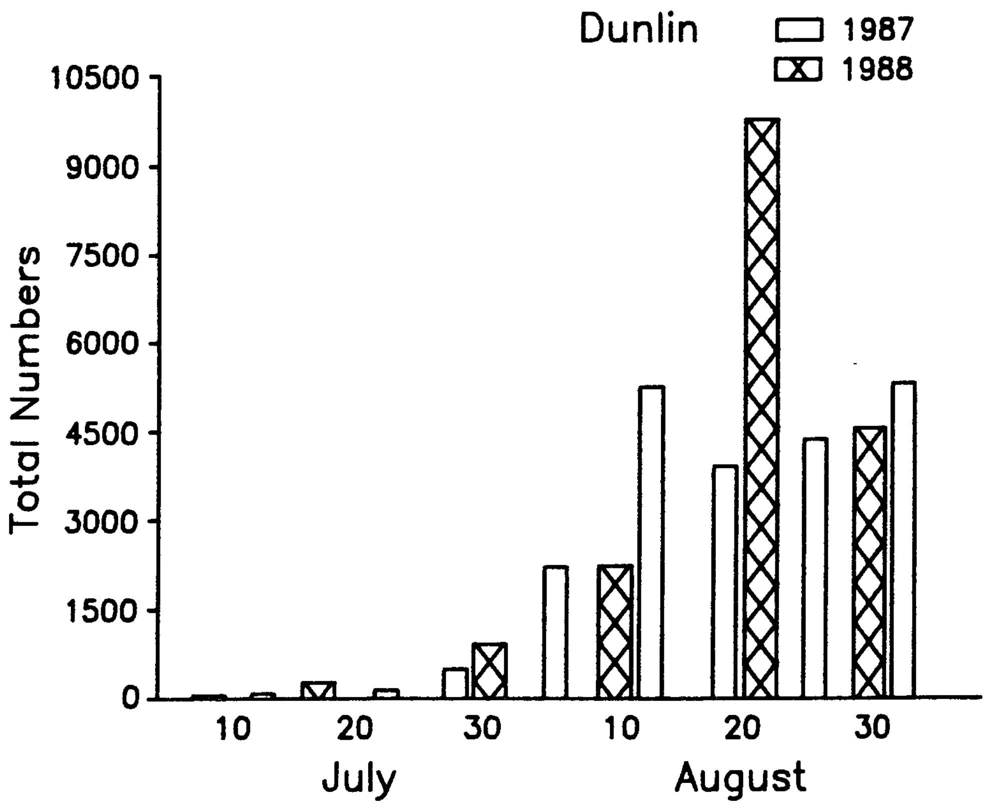
Habitat	Periods 1	2	3	4	5	6	7	8
Shorelines	88	349	533	2841	5667	3147	2889	4373
	28	126	302	1103	1055	1152	1386	2788
Saltmarsh	977	1545	2818	2134	2629	2738	3027	1187
	284	341	923	401	646	642	668	245
Delta	1065	1894	3351	4975	8296	5885	5916	5560
	285	364	971	1171	1234	1316	1536	2791

Table 26. Estimated average numbers and standard errors for all species occurring in saltmarsh and shoreline habitats of the Colville River delta by 10-day periods - 1988.

Habitat	Periods 1	2	3	4	5	6
Shorelines	15	181	2000	1711	9252	4054
	7	113	301	606	3425	1826
Saltmarsh	1264	1558	4096	5261	3003	1297
	291	407	882	1339	757	494
Delta	1279	1739	6096	6972	12255	5351
	291	422	932	1469	3500	1888

APPENDIX C

TEMPORAL ABUNDANCE OF SHOREBIRD SPECIES OCCURRING IN THE LITTORAL ZONE



Dunlin
1987
1988
Total Numbers
10500
9000
7500
6000
4500
3000
1500
0
10
20
30
10
20
30
July
August

Figure 14.

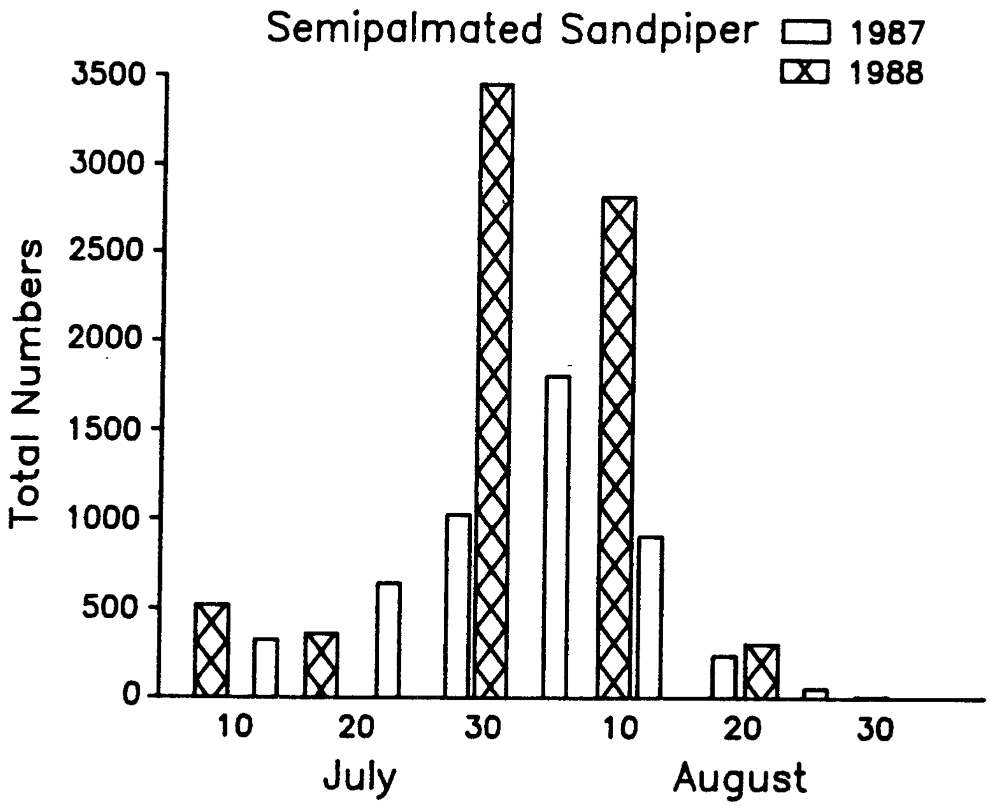

Semipalmated Sandpiper
1987
1988
3500
3000
2500
2000
1500
1000
500
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 15

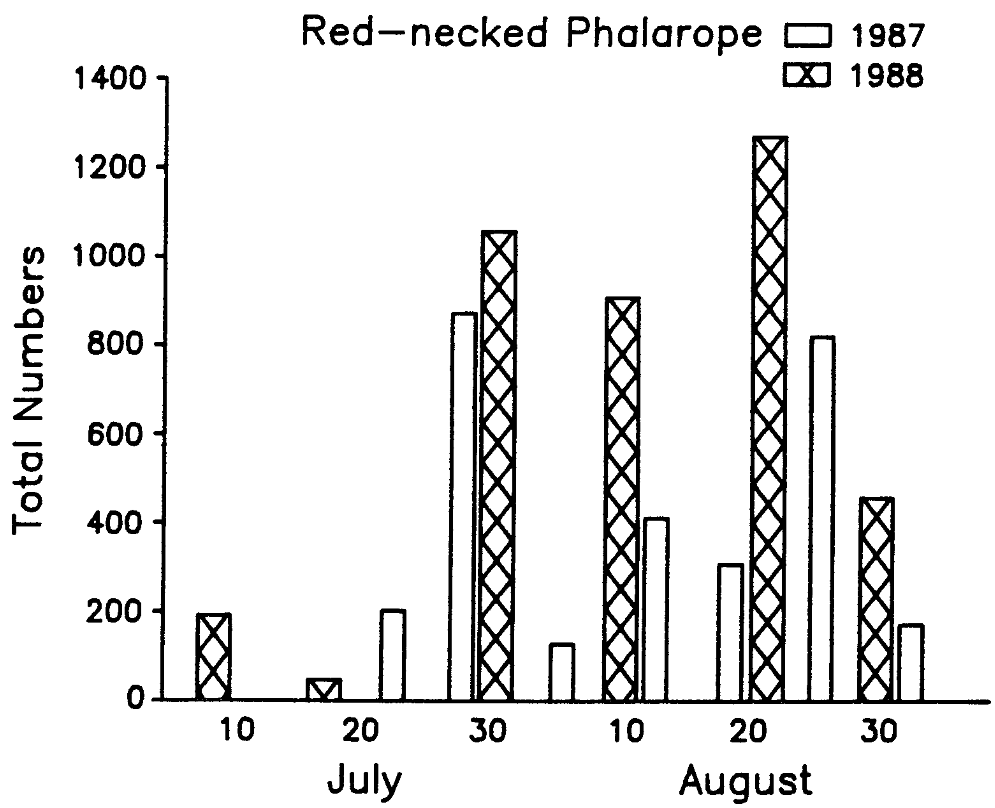

Red—necked Phalarope
1987
1988
1400
1200
1000
800
600
400
200
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 16.

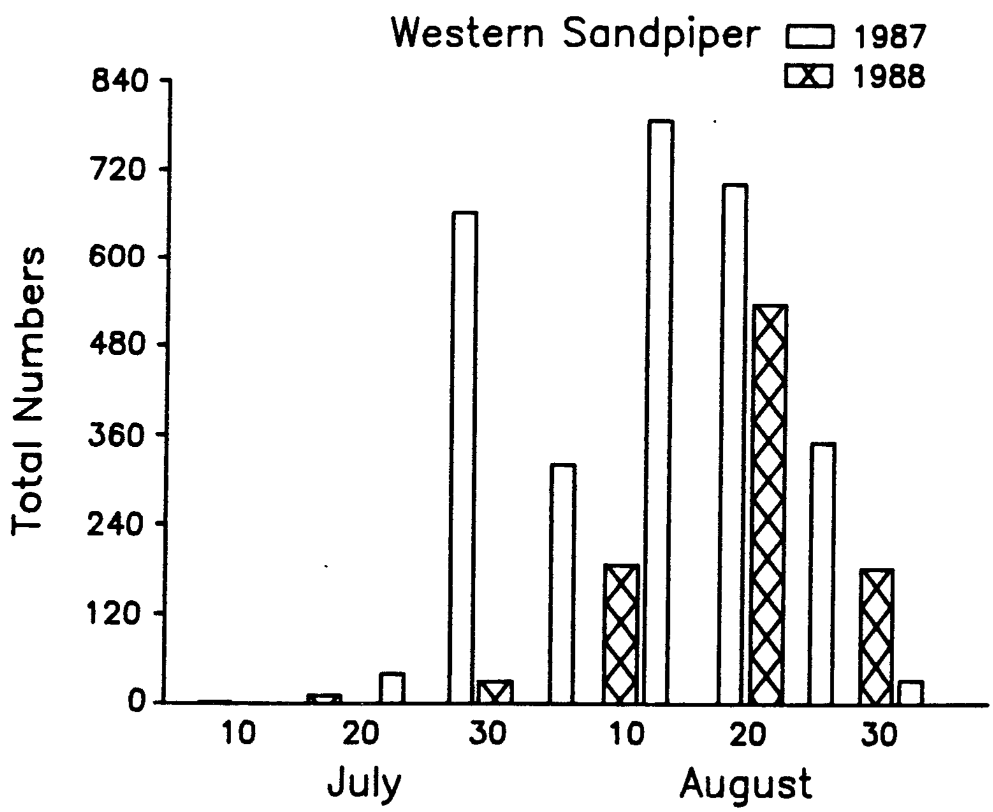
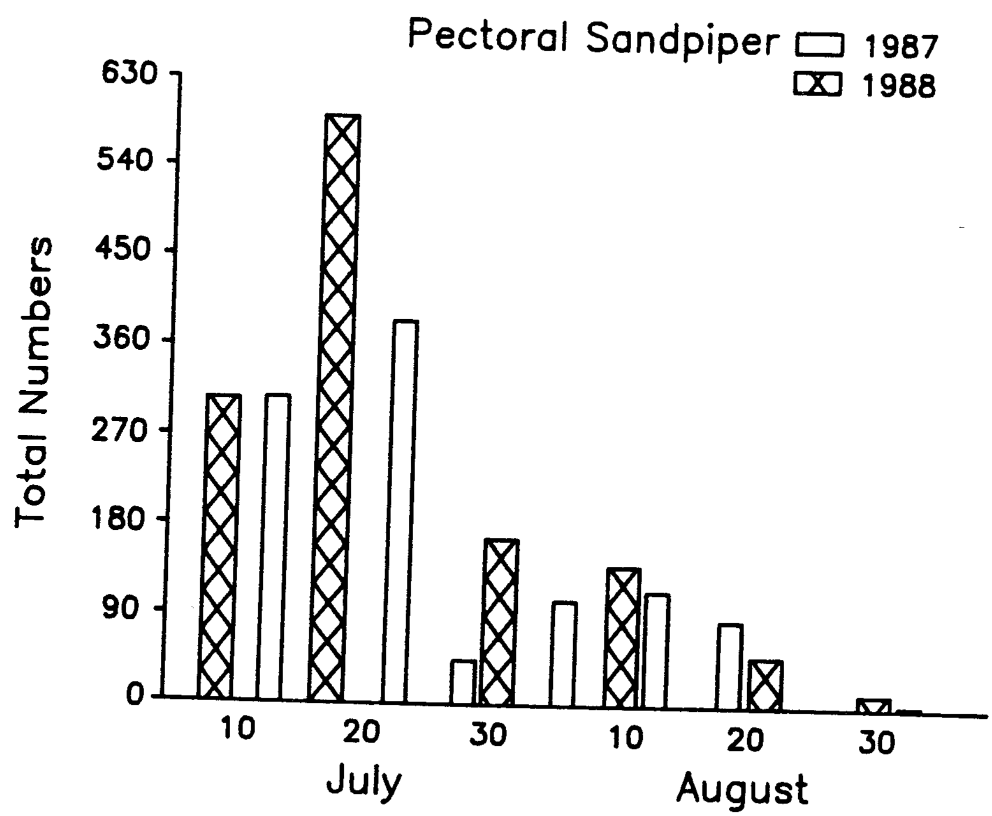

Western Sandpiper
1987
1988
840
720
600
480
360
240
120
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 17.



Pectoral Sandpiper
1987
1988
Total Numbers
630
540
450
360
270
180
90
0
10
20
30
10
20
30
July
August

Figure 18.

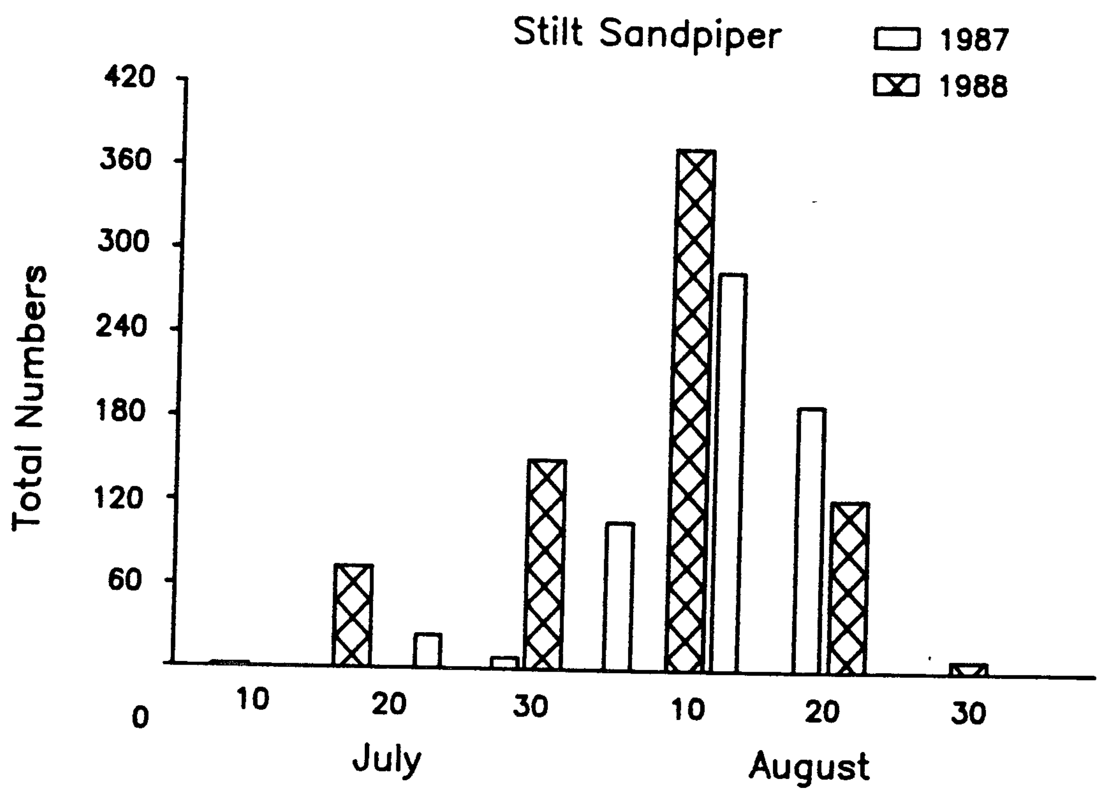

Stilt Sandpiper
1987
1988
420
360
300
240
180
120
60
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 19.

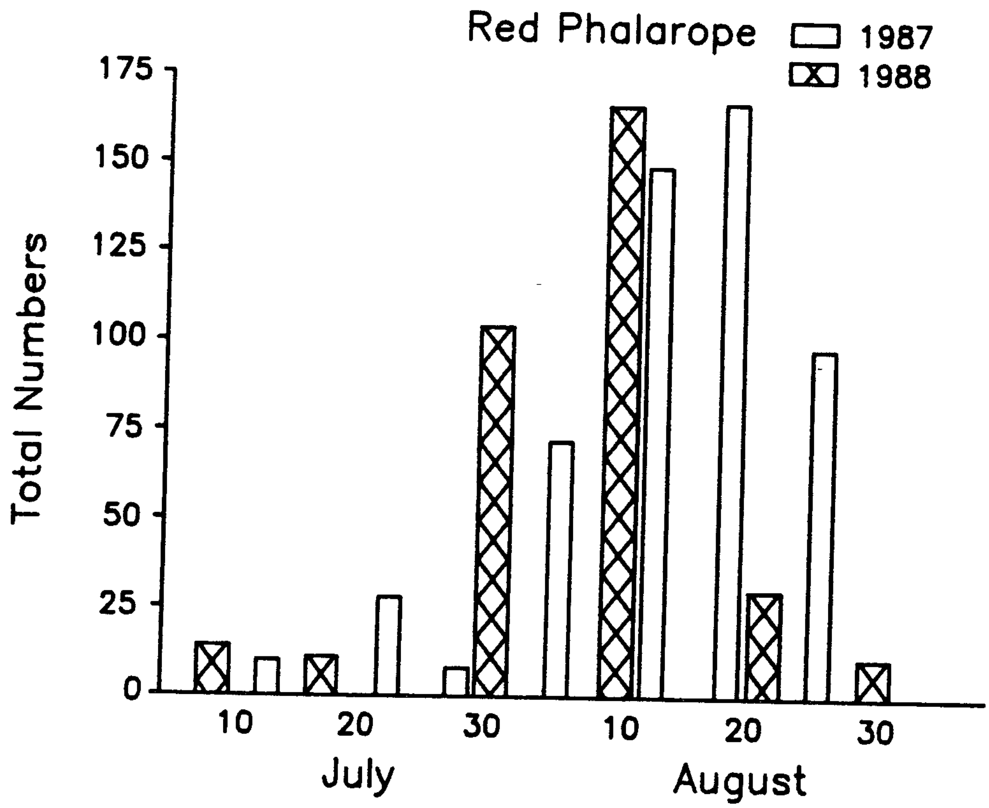

Red Phalarope
1987
1988
175
150
125
100
75
50
25
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 20.

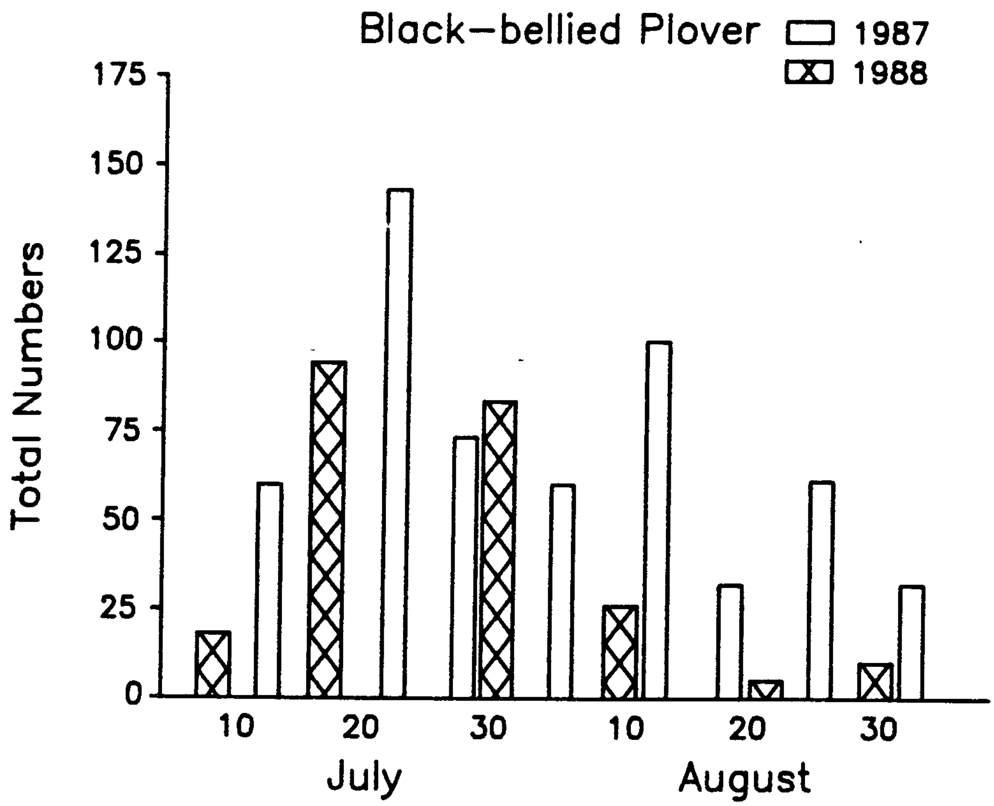
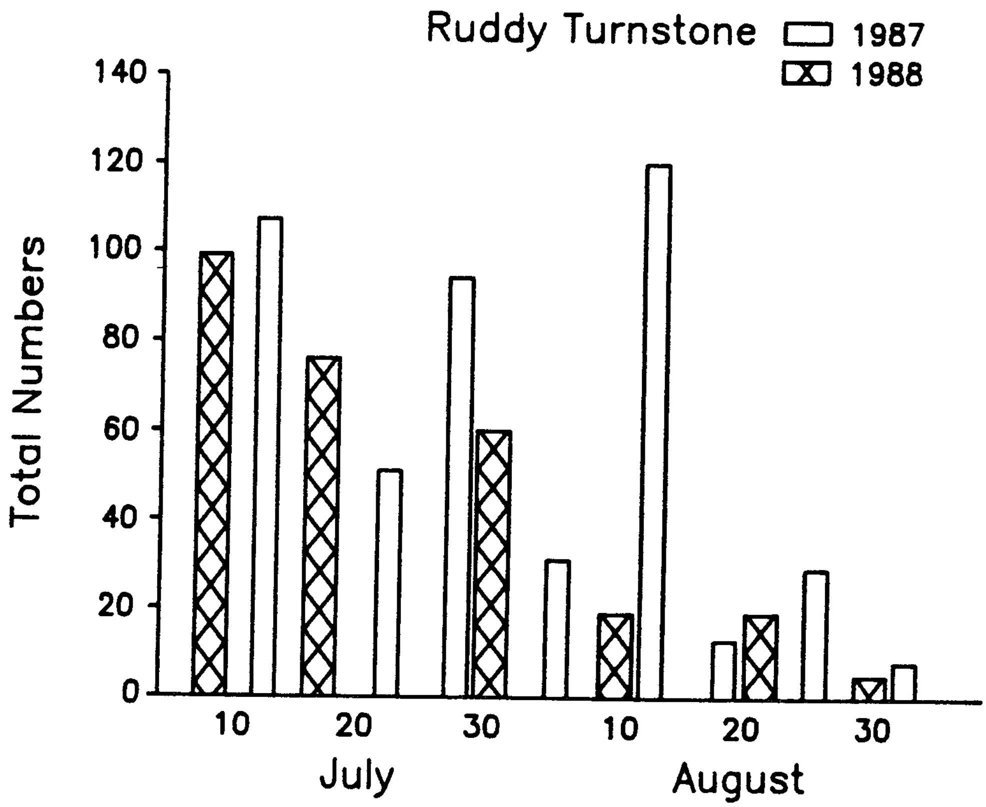

Black-bellied Plover
1987
1988
Total Numbers
175
150
125
100
75
50
25
0
10
20
30
10
20
30
July
August

Figure 21.



Ruddy Turnstone
1987
1988
Total Numbers
140
120
100
80
60
40
20
0
10
20
30
10
20
30
July
August

Figure 22.

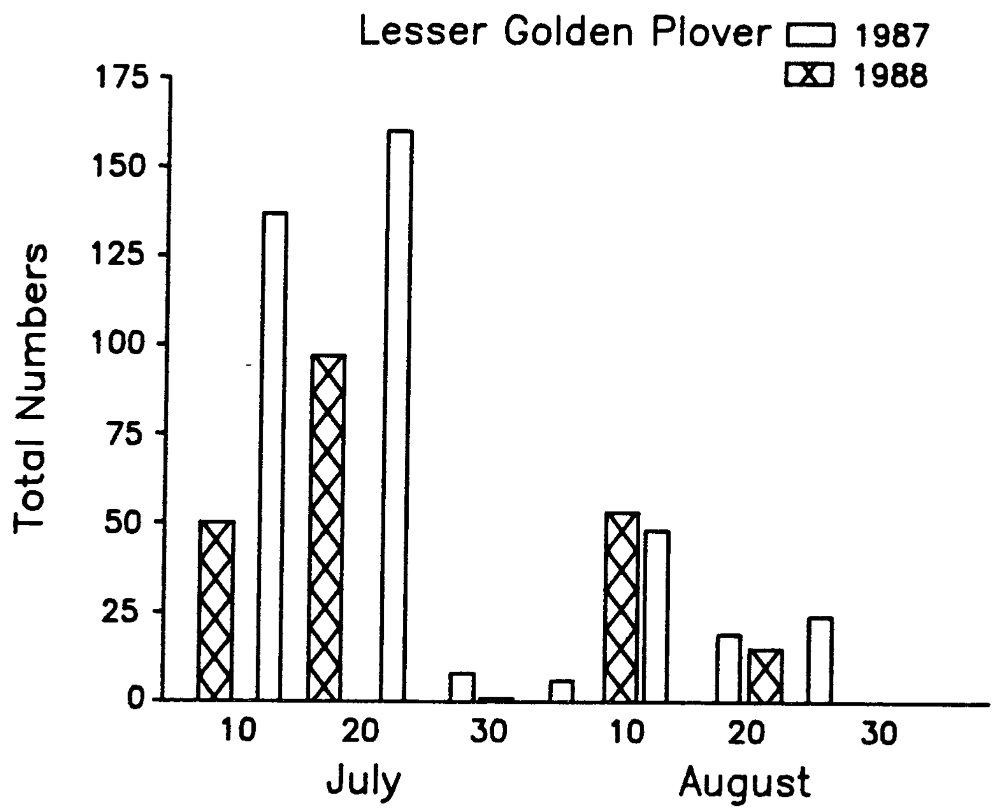
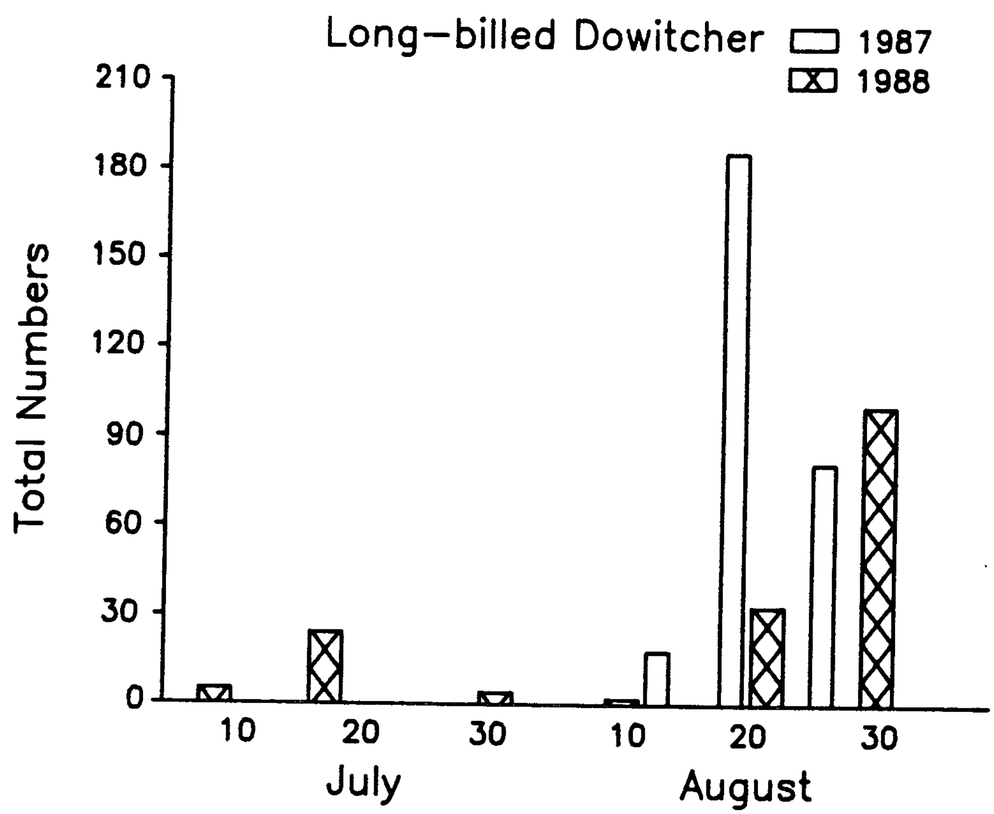
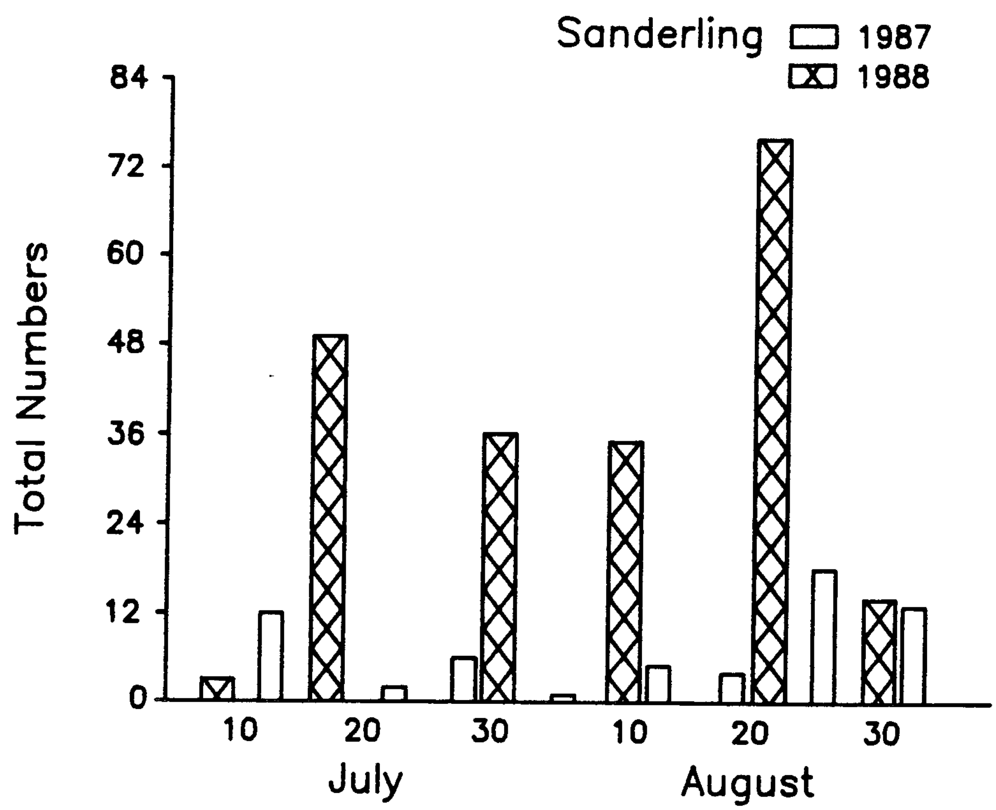

Lesser Golden Plover
1987
1988
Total Numbers
175
150
125
100
75
50
25
0
10
20
30
10
20
30
July
August

Figure 23.



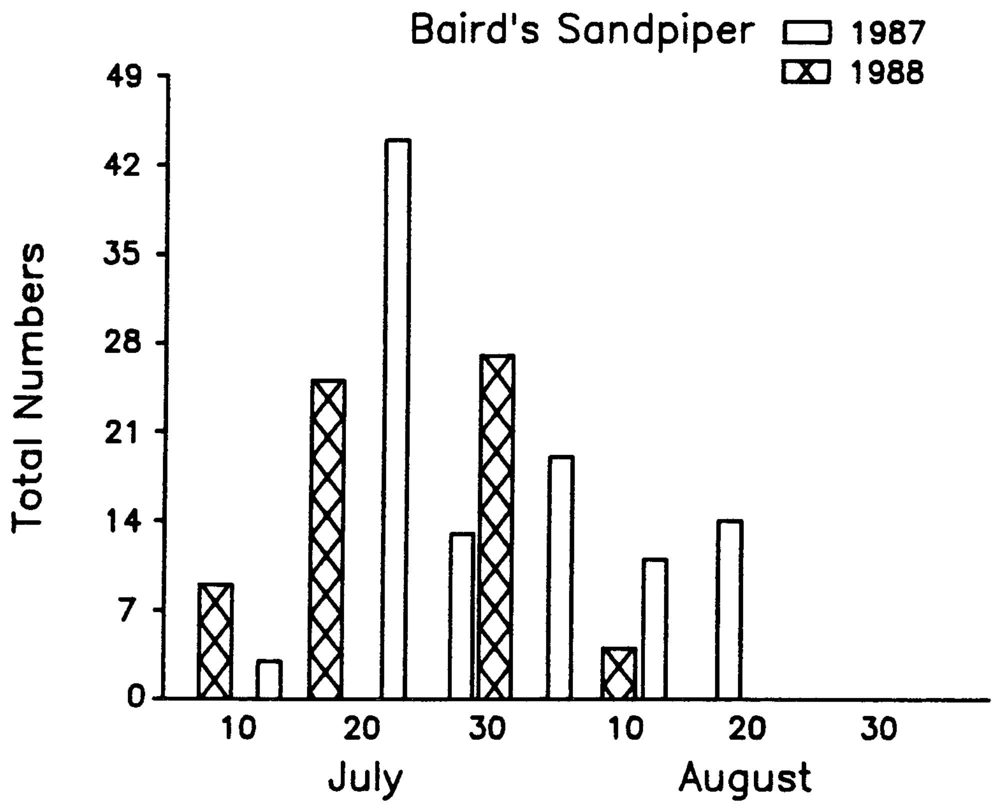
Long-billed Dowitcher
1987
1988
Total Numbers
210
180
150
120
90
60
30
0
10
20
30
10
20
30
July
August

Figure 24.



Sanderling
1987
1988
Total Numbers
84
72
60
48
36
24
12
0
10
20
30
10
20
30
July
August

Figure 25.



Baird's Sandpiper
1987
1988
Total Numbers
49
42
35
28
21
14
7
0
10
20
30
10
20
30
July
August

Figure 26.

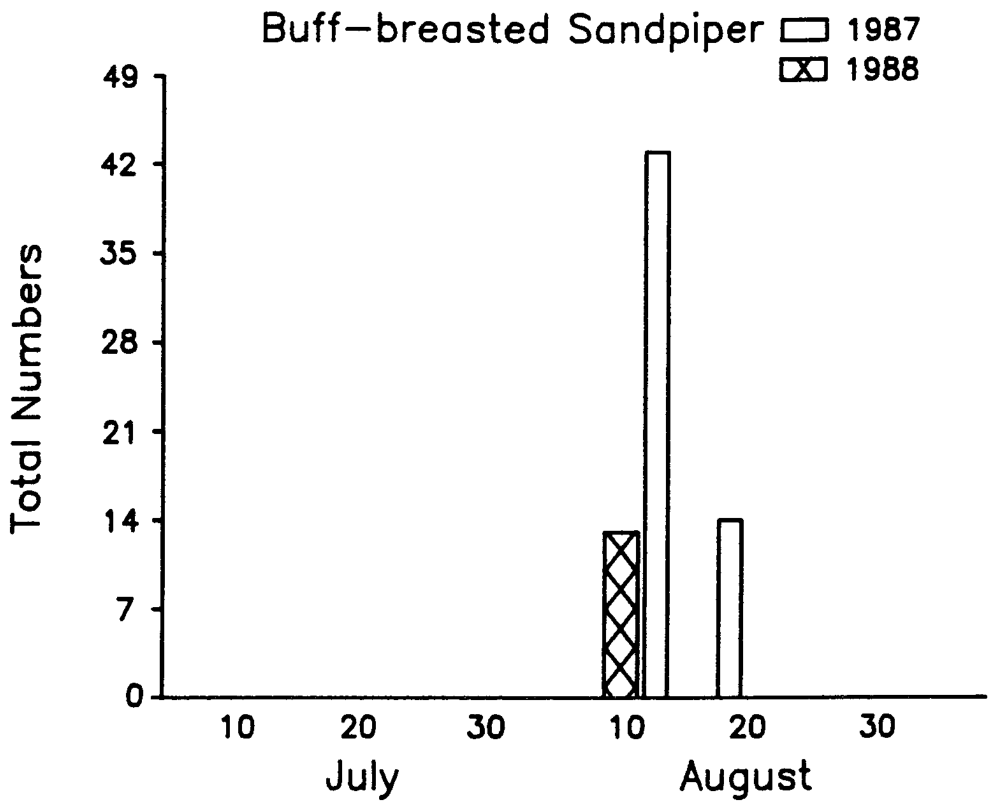

Buff-breasted Sandpiper
1987
1988
49
42
35
28
21
14
7
0
Total Numbers
10
20
30
10
20
30
July
August

Figure 27.

APPENDIX D

ACTIVITY OF POST-BREEDING SHOREBIRDS

Table 27. Frequency distribution of shorebird activity observed during littoral zone surveys - 1987, 1988.

	Activity							
Species	Feed	Stand	Sleep	Preen	Swim/ Walk	Breed	Total Known	Total Unknown
ALL	0.89	0.04	0.03	0.02	0.01	0.01	30754	1830
DUNL	0.89	0.04	0.05	0.02	0.00	0.00	19450	395
SESA	0.88	0.05	0.01	0.03	0.00	0.03	5840	688
RNPH	0.72	0.07	0.01	0.01	0.17	0.01	2624	184
WESA	0.89	0.03	0.06	0.01	0.00	0.00	1629	75
PESA	0.65	0.29	0.02	0.02	0.00	0.01	948	259
STSA	0.86	0.06	0.05	0.02	0.00	0.01	588	24
REPH	0.64	0.05	0.00	0.15	0.16	0.01	369	21
BBPL	0.65	0.18	0.00	0.01	0.08	0.08	313	20
LGPL	0.71	0.28	0.00	0.00	0.00	0.01	245	23
RUTU	0.57	0.16	0.00	0.00	0.00	0.26	293	23
LBDO	0.67	0.33	0.00	0.00	0.00	0.00	187	103
SAND	0.68	0.27	0.05	0.00	0.00	0.00	149	8

Table 28. Frequency distribution of activity by habitat type for all species of shorebirds observed during littoral zone surveys of the Colville River delta - 1987, 1988.

	Activity							
Species	Feed	Stand	Sleep	Preen	Swim/ Walk	Breed	Total Known	Total Unknown
Irregular Shoreline	0.97	0.00	0.01	0.02	0.00	0.00	7424	90
Regular Shoreline	0.96	0.00	0.01	0.01	0.03	0.00	368	4
Subterminal Shoreline	0.91	0.01	0.03	0.05	0.00	0.00	1593	56
Sparse Forb	0.79	0.04	0.15	0.01	0.01	0.01	154	3
Moist Forb-graminoid	0.84	0.06	0.04	0.02	0.01	0.03	1042	182
Wet Forb-graminoid	0.91	0.02	0.00	0.02	0.05	0.06	2151	116
Polygonal Forb-graminoid	0.76	0.11	0.03	0.03	0.01	0.06	330	47
Wet Saline Sedge	0.82	0.05	0.05	0.03	0.01	0.04	1809	374
Polygonal Saline Sedge	0.83	0.05	0.03	0.03	0.02	0.04	467	72
Moist Grass-sedge	0.58	0.15	0.02	0.01	0.03	0.22	158	61
Polygonal Grass-sedge	0.78	0.05	0.05	0.03	0.00	0.10	389	56

Table 29. Species and numbers of individuals banded on the Colville River delta - 1988.

Species	Number
Semipalmated Sandpiper	75
Dunlin	1
White-rumped Sandpiper	1
Red-necked Phalarope	1
Red Phalarope	1
Yellow Wagtail	1
Savannah Sparrow	2
Lapland Longspur	128