coastal gradients were King Eider, Semipalmated Sandpiper, Dunlin, Stilt Sandpiper, Red-necked Phalarope, and Red Phalarope. These gradients were evenly split in both directions; the species most common near the coast were King Eider, Dunlin, and Red Phalarope. The distributions of Stilt Sandpiper, Dunlin, and Red Phalarope were examined in greatest detail as they appeared to be the species with the strongest coastal gradients (Fig. 9). Stilt Sandpiper density trends mirrored those described for the nest data of this species, with low densities (most plots without birds) near the coast but with higher values farther inland. Based on the regression line (Fig. 9), no Stilt Sandpipers would be expected at the coast, but 10.3 birds/km² would be expected 20 km inland. The gradient between these extremes may not be linear, as there is some indication of zonation, with a boundary approximately 7 km from the coast, slightly more coastal than the 10 km estimated based on the nest data. A similar boundary can be discerned in the Dunlin and Red Phalarope data sets but with higher densities shoreward of a distance contour 7 to 8 km from the coast. The regression lines (Fig. 9) indicate expected densities of 13.5 Dunlin/km² on the coast but only 8.5 20 km inland. The corresponding densities of Red Phalaropes are 13.7 on the coast and 2.6 20 km inland.

Brood-Rearing Season. The brood-rearing period is the first portion of the summer when, based on prior studies, coastal habitats are expected to show concentrations in bird use relative to more typical tundra types. Reasons for this expectation are twofold—brood rearing and migration. This portion of the summer is named brood-rearing because it encompasses much of the period when young-of-the-year birds are out of the nest but prior to southbound migration. Waterfowl are generally tending their broods, while many juvenile shorebirds and longspurs are independent of their parents by this time. There is considerable evidence that waterfowl with broods, especially Brant and Snow Geese, make considerable use of coastal habitats at this time. Saline tundra has frequently been identified as being of particular importance to brood-rearing geese (Bergman et al. 1977, Murphy et al. 1988, Burgess and Ritchie 1987). We intended to evaluate how strict this reliance on saline tundra was (i.e., were coastal nonsaline plots also used?). However, in 1991 the major Brant and Snow Goose colonies in the Prudhoe Bay area (primarily Howe Island in the Sagavanirktok River delta) incurred catastrophic nest failure (Johnson 1991, Stickney et al. 1992) resulting in few brood-rear-

ing geese using the plots, and precluded such an evaluation.

Increased reliance on coastal areas was also expected during the brood-rearing season because of the presence of migrant shorebirds. Most migrant shorebirds during this portion of the summer are adults. Post-breeding adult shorebirds of many species tend to aggregate in coastal areas; however, use of strictly coastal habitats is not as extreme as the later movement of juveniles (Connors et al. 1979). Therefore, increased use of more inland tundras such as the PMRA might be expected as well. Post-breeding Dunlin, Semipalmated Sandpiper, and Red Phalarope adults make use of coastal habitats (Connors et al. 1979).

The results of this investigation partially confirm these expectations, although they show more evidence of a shift in habitat use than major influxes of birds into the area. A distinct pulse of Lesser Golden-Plover, mostly adults, occurred during this period (Fig. 4). A pulse of Stilt Sandpiper at the end of the brood-rearing period was also recorded; however, all those that were aged were juveniles, not adults. Shorebirds were apparently on the move, but no major concentrations were recorded. Changes in habitat use were more evident. Tests revealing selection among plot types indicated that the greatest response was still due to a lack of use of dry plots, especially by Semipalmated Sandpiper and Pectoral Sandpiper. The density summaries show shifts in usage compared to earlier in the summer, although these changes are not statistically verifiable. During the breeding season most species had their peak densities in the PMRA, with a few species also occurring in highest densities on the nonsaline plots. During the post-breeding season there was greater separation of species among plot types, indicating movement into coastal areas. Lesser Golden-Plover, Semipalmated Sandpiper, and Red-necked Phalarope made most use of saline plots at this time. The high use of saline plots by Lesser Golden-Plover was unexpected based on Connors et al. (1979), who reported that this species makes little use of coastal habitats at any time during the summer. The late brood-rearing season incursion of Stilt Sandpiper, while occurring in a coastal habitat, was most concentrated in nonsaline plots—although almost as many were found on saline plots. The brood-rearing season was the first part of the summer when any of the study species made much use of the dry plots. Both Buff-breasted Sandpiper and Lapland Longspur reached their highest densities on this type of plot.

Post-Breeding Season. The post-breeding season is the part of the summer when the bird populations may be at their highest (except in years of nesting failure), and use of coastal habitats may be most pronounced. This is particularly true of juvenile shorebirds that tend to aggregate in coastal habitats as they start their outbound migration (Andres 1989, Connors et al. 1979, Martin and Moitoret 1981). This study has confirmed that several species have their peak abundances in coastal habitats during August; these include Lesser Golden-Plover, Pectoral Sandpiper, Dunlin, Stilt Sandpiper, and Buff-breasted Sandpiper (Fig. 4).

The tendency for species to shift into coastal plots, especially saline plots, became even pronounced during the post-breeding season. Five species—Dunlin, Stilt Sandpiper, Red-necked Phalarope, Red Phalarope, and Lapland Longspur—had their highest densities on saline plots, although differences in plot use were significant for only Red Phalarope and Lapland Longspur (Table 10). The tendency for Pectoral Sandpiper to remain on inland tundra (PMRA) and Buff-breasted Sandpiper to aggregate on the dry plots was statistically significant during the post-breeding season.

Geographic gradients continued to be important during the post-breeding season. East-west gradients were found for more species (six) than were coastal gradients (four), and none of the species had only a coastal gradient. The species exhibiting coastal influences were Semipalmated Sandpiper, Dunlin, Red Phalarope, and Lapland Longspur. The three shorebirds were most numerous near the coast, while Lapland Longspur increased in abundance inland. Zonation was moderately distinct, at least for some of the shorebirds (Fig. 10). Encounters with Semipalmated Sandpiper were primarily on plots within 4 km of the coast. The regression line (Fig. 10) indicates expected densities of Semipalmated Sandpipers of 7.1 birds/km^2 at the coast but none 20 km inland. Red Phalarope extended slightly farther inland, but a sharp decrease in encounters occurred approximately 6 km from the coast. The regression-based estimates for Red Phalaropes are 9.6/km^2 on the coast and none 20 km inland. Zonation was less distinct for Lapland Longspur, but there was a tendency for more longspurs to be present (or perhaps more accurately, it was less likely that there would be few longspurs) on plots more than 8 to 9 km inland. Despite the wide variability about the trend line, the expected density of Lapland Longspur increases substantially from 30.0 birds/km^2 at the coast to 297.6 birds/km^2 20 km inland.

Importance of Coastal Habitats
Saline Tundra

Coastal wetlands are generally considered to be important, and relatively rare, habitats along the Beaufort Sea coast. The value of coastal wetlands to birds originates largely from the importance attributed to these habitats by Bergman et al. (1977). Bergman et al. stressed the high use of this habitat by Brant, both during migration and brood-rearing. Their analyses also indicated high use of this habitat by pre-nesting and nesting King Eiders, although other habitats (especially Deep *Arctophila*) were also used extensively. In Bergman's classification, coastal wetlands included aquatic habitats that occupy low areas bordering the Beaufort Sea and within a zone directly influenced by sea water. This type included lagoons, flats, and vegetated areas dominated by *Carex subspathacea* and *Puccinellia phryganodes*. Our saline plots approximate Bergman coastal wetlands, although our sampling was biased to sample more vegetation and less lagoon and barren flat than occur in Bergman's coastal wetland as a whole. Our nonsaline and dry plots certainly would not be included in coastal wetlands as defined by Bergman et al. (1977).

At the Canning River delta, Martin and Moitoret (1981) found saline meadows to be the most heavily used mainland shoreline habitat, especially by shorebirds and Brant during fall migration. Phalaropes and Sanderling, however, used barrier island beaches much more than other shoreline types. The use of gravel beaches by migrant phalaropes has been documented in other studies that sampled barrier islands (Johnson and Richardson 1981, Troy and Johnson 1982) and causeways (Troy and Johnson 1982). Other studies have noted extensive use of saline tundra along the Beaufort Sea coast by post-breeding shorebirds. Andres (1989) studied shorebird use of littoral zone habitats in the Colville delta during the post-breeding season (July and August) of 1987 and 1988. He distinguished five cover types—terminal shoreline silt barrens, subterminal shoreline silt barrens, interior silt barrens, sparse forb-graminoid tundra, and saline wet sedge/grass-sedge tundra. He consolidated these types into two broad classes of silt barrens (first three types) and saltmarsh (the last two types). Andres considered his saltmarsh to be encompassed by Bergman's coastal wetland class. Strictly speaking, Bergman's coastal

wetland definition also included unvegetated flats, but the recognition of distinct classes for flats and saltmarshes is probably more informative. Saltmarsh was the habitat class most similar to that sampled by our saline plots. Andres concluded that Dunlin and Sanderling made extensive use of silt barrens. Other species (Semipalmated Sandpiper, Red-necked Phalarope, Western Sandpiper, Pectoral Sandpiper, and Stilt Sandpiper were the most numerous species encountered by Andres) made much more use of saltmarsh habitats. Extensive silt barrens (mud flats) are infrequent along the Beaufort Sea coast. In the Sagavanirktok delta, Troy (1982) found Semipalmated Sandpiper, Dunlin, and Stilt Sandpiper to be the species making greatest use of mudflats.

To date, our study is in agreement with other studies in failing to identify any special use of saline tundra during the breeding season. Like other investigations, we found increasing use of saline wetlands following nesting during both the brood-rearing and, especially, the post-breeding seasons. Since most of this use is by shorebirds, these periods might best be considered to represent adult and juvenile migrations. The species making most use of the saline plots during these periods were Semipalmated Sandpiper, Dunlin, Stilt Sandpiper, Red-necked Phalarope, and Red Phalarope. There is little doubt that of the areas we sampled, saline tundra may be the most heavily used by migrants of these species; however, the limitations of our sampling may give a false impression as to the relative importance of saline tundra. On the basis of the other investigations reviewed above, it appears that at least Dunlin, Red-necked Phalarope, and Red Phalarope, and perhaps Semipalmated Sandpiper and Stilt Sandpiper, may make greater use of silt barrens and gravel beaches, both of which were present near our study areas but were not sampled. Hence, compared to adjacent tundra types, saline tundra may receive greater use by migrant shorebirds, but on a slightly broader scale it may not be the most important habitat. However, along most of the Beaufort Sea coast, silt barrens are not available; therefore, in most areas saline tundra would likely be the highest use tundra type. No other study has reported the high density of post-breeding Lapland Longspur in saline wetlands. Our 1991 data indicate that this species is the most numerous saltmarsh bird.

Nonsaline Tundra

Nonsaline coastal tundra has, to our knowledge, never been examined in isolation to determine if there is a coastal effect independent of the role of unique coastal vegetation types. The closest approximation—although the analyses were not explicitly conducted for this purpose—can be found in Troy et al. (1983), who analyzed breeding-season plot data in the Prudhoe Bay area to determine if there was a coastal influence on nest and breeding-season bird distributions. The data used in those analyses contained trivial amounts of saline habitats; thus, the analyses compared bird densities of nonsaline tundra sampled from 0.3 to 6.2 km from the coast. The species that occurred in high densities near (<1 km) the coast were Lesser Golden-Plover, Semipalmated Sandpiper, Dunlin, and Buff-breasted Sandpiper (see Fig. 7-7, Troy et al. 1983). Species appearing to occur in lower densities in this area were Oldsquaw and Red-necked Phalarope.

The nonsaline plots were located near the saline plots but largely out of the haline influence. The intent was to determine if the dominant factor affecting bird use of coastal areas was proximity to the coast or the vegetation types restricted to these areas. The results indicate that during the breeding season (including actual nest sites) nonsaline is the most heavily used coastal habitat. For some species, especially Semipalmated Sandpiper and Lapland Longspur, and to a lesser degree both phalaropes, this coastal tundra supports higher densities than inland tundra, at least to the degree that the PMRA is representative of inland tundra. It is possible that nonsaline coastal tundra is a restricted but preferred habitat type because these areas are beyond the saline influence and therefore well vegetated, yet adjacent to saline tundra that may provide better foraging areas (speculation based on attraction to these areas by staging birds).

Dry Coastal Tundra

The dry plots were established because little sampling of dry tundras has occurred, largely because dry tundra is rare and local in the Prudhoe Bay area. Previous sampling has taken place in the Sagavanirktok delta by Troy (1982, 1991). Troy (1982) conducted a small sampling program widely scattered in the central portion of the Sagavanirktok delta. Preliminary analyses indicated that most birds made little use of dry tundra, represented in the sampling by largely stabilized dunes. The only common species that appeared attracted to dry tundra was Lapland Longspur and only during June. Sampling in the Sagavanirktok delta by Troy (1991) emphasized the heavily disturbed peat roads. Sampling was not restricted to dry tundra, but

stabilized dunes were well represented in the areas sampled. This study found high densities of Red-necked Phalarope and Lapland Longspurs using these plots, although the role of increased habitat diversity due to thermokarsting may be more important that the presence of dry tundra in affecting these results.

This study shows the dry plots were little used during the breeding season. However, the dry plots were found to become more important during migration, when high densities of Lesser Golden-Plovers and Buff-breasted Sandpiper were found in these areas. Also of note was the exceptional concentration of Dunlin found in this plot type at the end of August (Fig. 4). This concentration of Dunlin was due to the occurrence of a roost on Heald Point (the birds were observed flocking to the area from the Sagavanirktok delta). Even if future censuses confirm the use of Heald Point as a roost site, it is likely to prove a site-specific phenomenon rather than a characteristic of dry tundra.

Gradients

The magnitude of the gradients documented in the stepwise regression analyses is perhaps the most exciting result of this investigation. The scatter diagrams summarizing the plot data (Figs. 8, 9, and 10) reveal considerable scatter and require study to discern much pattern. However, much of the variability in these plots arises from the fact that these graphs are highlighting only the component of variation attributable to distance from coast, yet we know several other factors affect bird abundance. For example, many of the species exhibiting coastal gradients also had east-west gradients, frequently of greater magnitude. The distribution of our sampling within the Prudhoe Bay region has been such that the locations of plots on the coastal and east-west gradients are dependent (linear regression of distance from coast on distance east $F_{[1, 208]} = 91.246$, p = 0.0001); i.e., sampling in the east (Sagavanirktok delta) has been predominantly near the coast, and sampling in the west has been primarily inland. The tendency for our plots to have been located along the diagonal of these two gradients makes visual examination of either gradient in isolation difficult. Figure 11 shows patterns of variation of breeding-season Dunlin and Stilt Sandpiper, and post-breeding-season Lapland Longspur in relation to both gradients. Dunlin and Stilt Sandpiper have trends in increasing abundance in the west, but Dunlin is more numerous near the coast, whereas Stilt Sandpiper is more numerous inland. Lapland Longspur exhibit a different pattern, increas-

ing to the east and inland.

At least three other sources of variation add to the variability in bird densities on plots: year (TERA 1992a), habitat (Troy 1986), and anthropogenic disturbances (TERA 1992b). Some species exhibit marked among-year variability in abundance (TERA 1992a). The ideal way to control for this variability is to sample all plots simultaneously, but this is impractical. Averaging densities over all years sampled minimizes this source of variation. It is conceivable that some of the plots that were sampled only one or two years may have been sampled when a species was at an extreme limit in abundance and have biased our results. Fortunately, most major highs and lows in abundances have occurred during multi-year studies; therefore, this is probably not a major concern.

Geobotanical characteristics of the tundra (habitat) are known to have a large influence on bird use of the study plots (Troy 1986, TERA 1992b). Troy (1986) estimated that differences in vegetation and surface form accounted for up to 70 percent of the variability in bird use among plots. Incorporation of geobotanical information into the regression models developed in this report would be expected to account for much of the residual variation not accounted for by plot location. Indeed, for most species, habitat type would probably emerge as the primary variable in the regressions. Some of the geographic gradients detected in the analyses presented here may have their basis in habitat availability. For example, the east-west gradient of post-breeding Buff-breasted Sandpiper may be due to the high availability of dry habitats in the Sagavanirktok River delta rather than the actual geographic location.

Although geobotanical characteristics will no doubt prove important in explaining the gradients we have detected, in some cases their influence is either subtle or secondary to other factors. For example, one might hypothesize that the gradients we observe reflect the availability of wet and aquatic tundras on the basis that drier tundra (moist and dry vegetation types) would be more frequent in the east (due to the dunes associated with the Sagavanirktok River) and inland (due to greater relief). However, birds associated with wet habitats (wet and aquatic vegetation) reach their peak abundances near the coast (King Eider and Red Phalarope) and inland (Stilt Sandpiper and Red-necked Phalarope); in the west (King Eider, Stilt Sandpiper, and Red Phalarope); and in the east (Red-necked Phalarope) (Fig. 12).
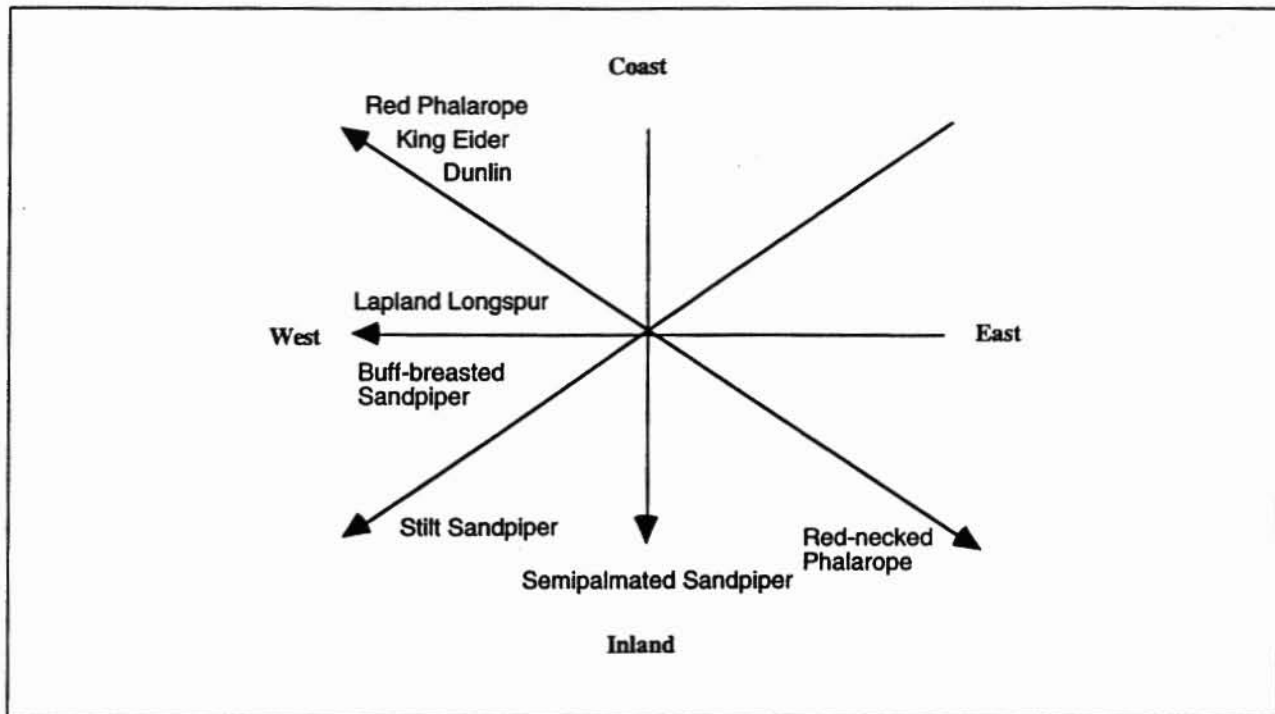
Figure 12. Summary of abundance gradients based on breeding-season bird densities. Densities increase in the direction of the arrows.

Table 14. Summary of number of significant gradients selected in multiple regression analyses indicating the presence of coastal gradients, east-west gradients, or both. A total of ten species was included in each analysis.

Data Set	Distance From Coast	East-West	Both Gradients
Nests	2	1	3
Breeding-Season	1	2	5
Post-Breeding Season	0	2	4

The final source of variation is the effect of habitat alterations and other disturbance associated with the oil field roads and pads and exploration activities (e.g., peat roads). Considerable research has shown changes in bird use of areas close to facilities (Troy 1986, TERA 1992b). In most cases, nest and breeding season abundances are lower than expected close to roads; however, some types of disturbances, such thermokarsting, may result in increased bird use of altered tundra (Troy 1991). In all these cases the densities differ from what would have been expected in unaffected tundra. The plots that formed the basis of these studies are included in the preliminary gradient analyses presented here. As these analyses are refined, we intend to incorporate a variable for distance to facilities to factor in this effect. This approach will offer

a new tool to evaluate the relative importance of oil field influence in comparison to habitat and geographic location.

Coastal influences have long been known or suspected of influencing bird distribution and abundance. The gradient analyses confirm the presence of coastal influences in affecting bird distribution on the Arctic Coastal Plain. However, in reviewing the frequency of gradients detected in the analyses (summarized in Table 14), we found coastal gradients were slightly less frequent than east-west gradients. During the post-breeding season the importance of coastal gradients would have been expected to be most pronounced due to the presence of migrant birds; however, it was during this period that east-west gradients were most frequent relative to coastal gradients. Whatever the
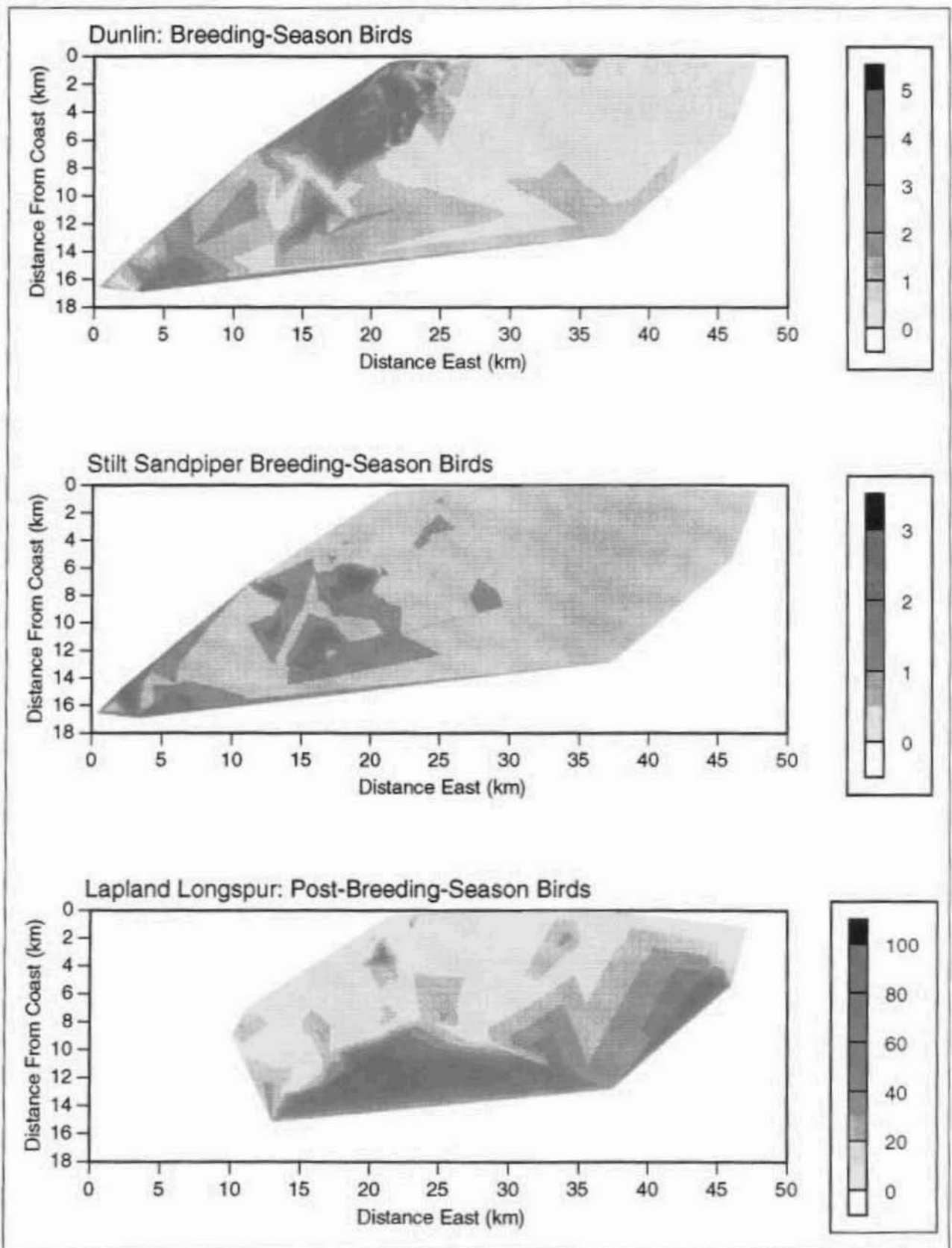
Figure 11. Surface contour charts showing breeding-season densities of Dunlin and Stilt Sandpiper in relation to distance from coast and location on an east-west axis.

ultimate cause of these gradients, it is apparent that there is substantial spatial variability in the distribution of tundra birds that needs to be understood in order to assess the tundra habitat values.

The presence of the gradients demonstrated in this report provides some insight into impact assessment useful in interpreting some recent studies. Meehan (1986) found differences in densities of some shorebirds on plots within developed portions of the Prudhoe Bay oil field and some of the PBU Waterflood bird plots (several of which are the PMRA study plots). This was interpreted as possible evidence of an oil field impact indicating avoidance of tundra areas within the oil field. TERA (1992b) confirmed these differences between the two study areas, finding lower densities of Dunlin and Red Phalaropes in the oil field but also the opposite trend for Stilt Sandpiper and Red-necked Phalarope. We hypothesized that these trends were not oil field influences but were probably attributable to broader-scale abundance gradients. The PMRA plots and the oil field plots used by TERA (1992b) do not differ significantly in their east-west locations, but the oil field plots were significantly farther inland than the PMRA. The results of the gradient analyses presented here support the hypothesis that the major differences in densities between the PMRA and the oil field plots were because of underlying gradients. The major differences between the two areas involved the species exhibiting the strongest coastal gradients, and the density differences were in the same direction as predicted by these gradients; i.e., species increasing in abundance near the coast were most numerous in the PMRA, while species increasing in abundance inland were more numerous in the oil field.

CONCLUSIONS

Proximity to the coast was found to have an influence on bird use of the Prudhoe Bay area. Using a narrow definition of coastal to include all tundra adjacent to the Beaufort Sea (<1 km), the coastal effect was subtle. The species composition of coastal plots differed slightly from the Prudhoe Bay area in general. Some species that are rare in the Prudhoe Bay area, such as Ruddy Turnstone and Baird's Sandpiper, were more common in coastal areas; however, there was still considerable similarity in the species composition of coastal and other portions of the Prudhoe Bay area.

Considerable species and seasonal variability was found in the use of the three types of coastal plots sampled. The highest nesting densities (especially Semipalmated Sandpiper and Lapland Longspur) occurred in nonsaline tundra. Saline tundra received high use by breeding-season phalaropes, but overall there were more birds in nonsaline tundra. Saline tundra was the single most important habitat during the post-breeding season, especially for Lapland Longspur, Red-necked Phalarope, and Dunlin. Dry coastal habitats received low use for nesting and by breeding-season birds, while Lesser Golden-Plover and Buff-breasted Sandpiper made considerable use of these habitats during the post-breeding season. Thus, habitat type was found to play an important role in determining bird use of coastal areas. Some habitat types, such as saline tundra, are by definition restricted to coastal areas and are heavily used by some species during select periods of the summer. In general, there was low use of dry areas and high use of nonsaline tundra, but the species composition in coastal areas was not as diverse as in the PMRA. During the post-breeding season, coastal habitats, especially saline tundra, supported the highest relative densities of the study species, except King Eiders and Pectoral Sandpipers.

The strongest coastal associations were detected by analyses looking for broad-scale gradients in abundance. By combining the results of this study with those of similar plot-based studies from the Prudhoe Bay area, we documented the presence of abundance gradients along east-west and distance-from-coast axes. Depending on the species, the geographic location of a study plot could account for up to 30 percent of the variability in bird and nest densities. Species exhibiting responses to these geographic gradients were Semipalmated Sandpiper, Dunlin, Stilt Sandpiper, Red-necked Phalarope, Red Phalarope, and Lapland Longspur. Coastal gradients could go in either direction; for some species, densities were highest near the coast, but for others the converse was true. For example, during the breeding season, densities of Semipalmated Sandpiper, Stilt Sandpiper, and Red-necked Phalarope increased with distance from the coast, whereas densities of King Eider, Dunlin, and Red Phalarope decreased with increasing distance from the coast. There was little indication of a narrowly defined coastal zone receiving high use for any species. Where the analyses did indicate high use of coastal areas, the zone tended to be 4 to 10 km wide.

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