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# The Use of Remote Sensing to Evaluate Shorebird Habitats and Populations on Prince Charles Island, Foxe Basin, Canada

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ABSTRACT. Landsat-5 Thematic Mapper imagery was used to produce a 17-habitat classification of Prince Charles Island, Foxe Basin, Northwest Territories, through a combination of supervised and unsupervised approaches. Breeding shorebirds and habitats were surveyed at 35 study plots in July 1989. Habitat-specific breeding densities calculated from these observations were used to estimate total populations of breeding shorebirds on the island based on areas of habitat derived from the classified image. Breeding densities were further modelled in two ways: first, to adjust for distance from the coast, where regression analyses found a significant relationship between distance and density, and second, to include only those pixels of areas considered suitable for breeding, using results of a proximity analysis to determine habitat associations between known breeding locations (pixels) and other habitats. Six species of shorebirds were found breeding on Prince Charles Island, with a combined population (after modelling) estimated at 294 000 pairs. Comparison of breeding densities and estimated populations of shorebirds with those recorded at other arctic locations indicated that Prince Charles Island supports highly significant numbers of shorebirds, especially white-rumped sandpipers and red phalaropes. Comparison of reference areas of known habitat with those on the classified image indicated classification accuracy averaged over 90%. Remote sensing appears to offer a reliable method for assessing habitats and regional breeding populations of birds in at least some areas, providing that classification methods are carried out in a carefully controlled manner. Use of the method over broad areas of the Arctic would require considerable work to recalibrate imagery for different geographic regions.

Key words: shorebirds, Landsat TM, remote sensing, Foxe Basin, habitats

RÉSUMÉ. On a utilisé des images de cartographie thématique obtenues avec le Landsat-5 pour répartir en 17 classes les divers habitats de l'île du Prince-Charles, située dans le bassin de Foxe (Territoires du Nord-Ouest), et ce, en faisant appel à des méthodes dirigées et non dirigées. En juillet 1989, on a procédé à un relevé des oiseaux de rivage nicheurs et de leur habitat à 35 parcelles-échantillons. On s'est servi des densités de nidification spécifiques à l'habitat tirées de ces observations pour évaluer la population totale des oiseaux nicheurs de l'île, à partir des zones d'habitat tirées de l'imagerie classifiée. On a procédé de plus à une modélisation des densités de nidification, et ce, à deux fins: d'abord, pour tenir compte de la distance depuis la côte, dans les cas où l'analyse de régression faisait apparaître un rapport significatif entre distance et densité, ensuite, pour n'inclure que les pixels des zones jugées appropriées pour la nidification, en utilisant les résultats d'une analyse de proximité visant à déterminer les associations d'habitats entre les sites de nidification connus (les pixels) et d'autres habitats. On a trouvé que six espèces d'oiseaux de rivage nichaient dans l'île du Prince-Charles, avec une population globale (après modélisation) évaluée à 294 000 paires. La comparaison des densités de nidification et des populations d'oiseaux de rivage estimées avec celles enregistrées à d'autres endroits de l'Arctique a révélé que l'île du Prince-Charles accueille un nombre important d'oiseaux de rivage, surtout de bécasseaux à croupion blanc et de phalaropes roux. La comparaison entre les zones de référence d'habitat connu et celles de l'imagerie classifiée révèle que la précision de la classification atteignait en moyenne 90 p.cent. La télédétection semble offrir une méthode fiable d'évaluation des habitats et des populations régionales d'oiseaux nicheurs dans au moins certaines zones, à condition que les méthodes de classification soient appliquées avec soin et sous contrôle. L'utilisation de la méthode sur de grandes surfaces de l'Arctique exigerait un travail considérable de réétalonnage de l'imagerie pour différentes régions géographiques.

Mots clés: oiseaux de rivage, capteur TM, télédétection, bassin de Foxe, habitats

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## INTRODUCTION

The Canadian Arctic provides breeding grounds for many species of migratory birds, of which shorebirds form an important and prominent component. Identification of key breeding areas for such species presents many problems, since their breeding ranges often cover enormous geographical areas, in some cases stretching from Alaska to Baffin

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Island (Hayman et al., 1986), and many species breed at low densities, which makes their detection difficult and complicates assessment of the numbers breeding in a wide area. Remote sensing offers a potential method for mapping migratory bird breeding habitats, since it is capable of identifying different habitats and land types over large geographical areas. In the Arctic and Subarctic, satellite imagery (both Landsat and SPOT) has been used successfully to map wetlands and habitats used by muskox, bison, and waterfowl (Tomlins and Boyd, 1988; Wakelyn, 1990; Ferguson, 1991; Matthews, 1991; Pearce, 1991; Markon and Derksen, 1994). The extent to which regional studies can be extrapolated to cover wider areas, however, is usually uncertain, since results of habitat classification will depend on both the nature of the terrain covered and the methodology used. For instance, changing vegetation patterns and characteristics, varying moisture regimes, different landforms and geological substrates, and possible phenological differences in plant development are likely to produce spectral differences in ground reflectance that will require extensive ground truthing of classified images in different parts of the Arctic and may restrict the applicability of habitat maps to particular regions. George et al. (1977) encountered problems with consistent delineation of plant communities over large areas in mapping reindeer habitat in Alaska, and Wickware et al. (1980) noted problems with misclassification in mapping snow goose habitats in Hudson Bay. Gratto-Trevor (1994, 1996) reported that reliability of identification of shorebird habitats in the Mackenzie Delta decreased as distance increased from the location on which the original ground truth studies had been centred.

The present work assesses the capability of remote sensing to map shorebird and other wildlife habitats on Prince Charles Island, the largest island in Foxe Basin. Relatively little was known about the avifauna of the island. Its low-lying topography, involving areas of raised beach ridges and marshy habitats, indicated that the area could hold important breeding habitats for migratory shorebirds and other birds and that it would be suitable for remote sensing studies. Classification methodology was developed to utilize the maximum amount of spectral information that could be extracted from the scene. The classified imagery was then combined with results from ground surveys of nesting birds to identify key habitats used by different species of shorebirds and, after modelling habitat-specific breeding densities to adjust for the effects of distance from the coast and proximity to other habitat types, to estimate the number of shorebirds breeding on Prince Charles Island.

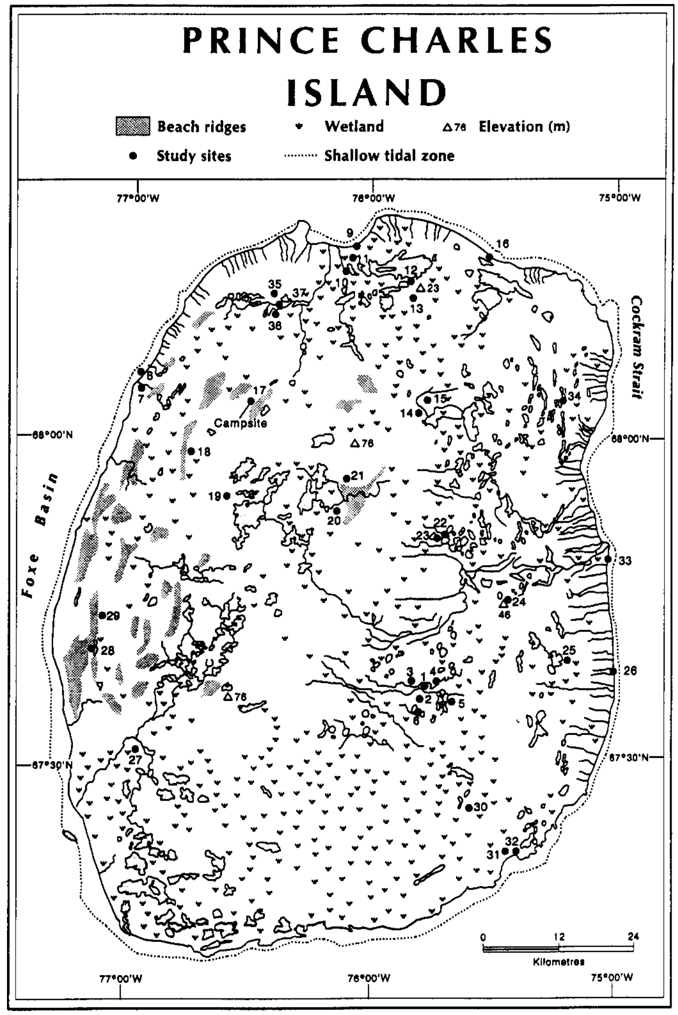


FIG. 1. Map of Prince Charles Island, showing location of study areas.

## STUDY AREA

Prince Charles Island (67°47′N, 76°12′W) lies in the eastern part of Foxe Basin and is approximately 122 km long and 95 km wide (Fig. 1). The terrain is generally flat or gently rolling, reaching maximum elevations of 76 m in the central sectors. The island has been isostatically uplifting since the last glaciation (some 6–7000 years ago), and has emerged from the sea over the past 2000 years at a rate of approximately 0.75 m/century (Dyke and Prest, 1987). The higher west central sections, which were the first to emerge from the sea, consist mostly of barren bedrock and gravel. Long series of raised beach ridges extend along the west coast. In the east, broad coastal grasslands lead inland to vast areas of poorly drained marshy terrain covered with characteristic round lakes (Morrison and Martini, unpubl. results). Two isolated hills are found in the northwestern and east central parts of the island. Bedrock consists of horizontally lying, thinly bedded Paleozoic carbonates, which outcrop in several places. The surficial sedimentary cover is composed mostly of a thin, discontinuous Pleistocene diamict and, in the east, of thin Quaternary sands and silts. Fairly extensive tidal flats occur around much of the island, especially on the east coast. Tidal ranges are probably intermediate between the extremes of 0.5 m and 4.5 m recorded elsewhere in Foxe Basin (Prinsenberg, 1986). Sea ice is persistent and may pile up against the shores at any time during the summer (Markham, 1986; Prinsenberg, 1986).

The climate is arctic, with July monthly means of 5.4°C and 6.7°C at Hall Beach and Longstaff Bluff, on the northwest and northeast sides of Foxe Basin, respectively (AES, 1982a). At Hall Beach, annual average precipitation is 21.8 cm (12.1 cm as snow), and winds are predominantly northwesterly, averaging 21.3 km/h (AES, 1982a, b). Permafrost has an active layer up to 1 m deep. Much of the low-lying terrain is very wet during the early summer melt, but dries rapidly during July and part of August.

Relatively little is known about the avifauna or geomorphology of Prince Charles Island or of the Foxe Basin area in general. Early avifaunal reports include those of Manning (1950), who made wildlife and geographical observations from Prince Charles Island, and Ellis and Evans (1960), whose observations were centred on Rowley Island. King (1969) reported geomorphological analyses of Foley Island, and Bird (1967) classified the coasts of the basin. More recent work includes aerial surveys for birds by Reed et al. (1980) and Gaston et al. (1986), and a general review of birds of the area by Morrison and Gaston (1986).

## METHODS

Field studies were carried out on Prince Charles Island from 5 to 13 July 1989 from a camp (68˚03′N, 76˚32′W) established in the northwestern part of the island. Work was scheduled to take place during the incubation phase of the shorebird nesting cycle, before hatching occurred; the schedule was based on results of three years (1986–88) of fieldwork on Rowley Island to the northwest (Morrison, unpubl. data). During the study period, all parts of the island were visited by helicopter, and a series of 35 study plots was laid out to obtain information on breeding bird densities, habitat characteristics, and geomorphology (Fig. 1). Sites were selected to represent as wide a range of habitats and landforms as possible. Site selection was based on examination of air photographs, reference to a preliminary remote sensing classified image of Prince Charles Island derived from similar habitats and terrain encountered on Rowley Island (Morrison, unpubl. results), and information from reconnaissance flights conducted immediately after arrival on the island. At each site, a well-defined plot of ground was identified which could be located readily on air photographs and remote sensing images. Plots averaged 17.1 ha in area (SD = 20.4, range = 1.6–70.8 ha, total area = 598 ha).

Breeding bird surveys were conducted in a consistent manner by a team of 1–4 people walking in parallel lines throughout the plot, coverage being to within approximately 20 m of all parts of the area. Observations of birds' nests and of birds showing territorial behaviour were marked on field maps, and their locations were later identified on air photos and on the classified remote sensing image. All records used in the work involved birds considered to be actively nesting (as judged by standard criteria: nest found, alarm behaviour, etc.); records of non-nesting birds (wandering groups or individuals) were excluded from the analysis. No nests were found to be hatching, and no broods were encountered during the surveys. In all cases it was possible to assign nests or active territories to individual pixels on the image. At each study site, major habitats were plotted on the field maps, using air photos as a reference. Habitats were divided into four major types based on vegetation cover, substrate characteristics, and wetness; the major objective was to provide a method for rapid field categorization of habitats in a manner relevant to potential wildlife use and to aid habitat delineation during remote sensing analysis. The four major types were: *Water* habitats, such as ponds, lakes, rivers, etc.; *Barren* ground habitats, with vegetation cover generally less than 10–15% and varying in degree of wetness; *Tundra* habitats, with moderate vegetation cover of 15–65%, typically consisting principally of *Dryas* species, *Saxifraga* species, *Salix* species, lichens, sedges, and mosses, and generally occurring in better-drained areas; and *Marsh* habitats, with extensive (50–100%) vegetation cover dominated by graminoid species (grasses and sedges) and mosses, usually occurring in poorly drained areas. Each principal habitat was further divided into subcategories in the field on the basis of the principal vegetation and the substrate or wetness properties that gave the subhabitat its characteristic appearance (e.g., Tundra-*Dryas,* Marsh-saturated). For each habitat, a visual estimate was made of the percentage cover of the major types and of the principal vegetation and substrate types, and the slope, aspect, topographic variation (average vertical variation in ground relief), and water type were noted. Additional information on habitats and birds was obtained during helicopter flights in 1989 and on an aerial survey of the island carried out using a Twin Otter aircraft on 23 July 1990. Such information was used in ground-truthing and error assessment of the classified image.

### *Remote Sensing*

Landsat TM data for Prince Charles Island were acquired through the Canada Centre for Remote Sensing (CCRS) as computer-compatible tapes. Coverage of the entire island and parts of neighbouring Air Force Island (Path 25, Row 12) was recorded on 19 July 1985, a day that was essentially cloud-free. Digital analyses were performed using Easi/Pace software (version 5.3.1, PCI Inc., Richmond, Ontario) on a Sun SPARC10/51 system running under the Solaris operating system at CCRS. Image striping, evident around some parts of the coast of the island, probably resulted from sensor saturation over the high-reflectance areas of sea ice lying adjacent to the coast. Destriping procedures were tested and were most effective when carried out on masked-off land areas to avoid processing of high-contrast areas of sea ice. This involved masking off areas of land, setting sea areas to a reflectance or Digital Number (DN) value of 0, running the destriping procedure, and resetting sea areas to DN = 0 to remove the slight striping introduced during the processing. Setting the sea areas to a single DN value (of 0) is also advantageous for subsequent classification procedures, since it removes the considerable variation in DN values occurring in the sea and ice parts of the image. The image contained one strip of degraded data some 22 pixels wide (pixel size = 30 × 30 m) and this "noise" was corrected by replacing the affected lines with adjacent lines immediately above and below the affected area. Twenty-five ground control points from all parts of the island were selected from the 1:250 000 National Topographic System maps (Sheets 37B, 37A, 36N, and 36O, the most detailed available for this area). Assessment of the root mean square (RMS) errors of the points under different polynomial models led to the adoption of 22 ground control points and a second-order polynomial model to produce a correction with RMS error of 2.51, 0.98 (x,y) pixel units, which was considered acceptable at the mapping scale in use. The image was then resampled to a 25 × 25 m pixel size using a nearest-neighbour interpolation (considered the most appropriate for subsequent classification procedures since it does not alter grey levels of pixels (PCI, 1993)), resulting in a fully geocoded image. Land masks for Prince Charles Island and Air Force Island were transferred to the new image file after geometric correction.

Initially, various three-band combinations were examined to determine which produced the most visually interpretable habitat delineations on the image. Channels 3, 4, and 5 were chosen for further analysis; other useful combinations included (3, 4, 7), (2, 4, 5), (2, 4, 7), and (2, 5, 7). Channel 3 (red, 0.63 – 0.69 μm), Channel 4 (near-infrared, 0.76 – 0.90 μm) and Channel 5 (short-wave infrared, 1.55-1.75 μm) are accepted as being particularly useful for delineation of combinations of geological features (Channel 3), vegetation differences, water, and moisture content (Channels 4 and 5) (EMR, 1986; Rees, 1990). Channel 7 is useful as an alternative to Channel 5, but the higher signal-to-noise ratio and excellent haze penetration of the latter generally make its use preferable (EMR, 1986). Altogether, six of the seven channels available on Landsat-TM are useful for terrain analysis (Channels 1 – 5 and 7), and all six were used for habitat classification analysis. Image classification is based on the fact that similar types of terrain have similar spectral reflectances (expressed as Digital Numbers, DN). Various methods of aggregating or clustering pixels with similar reflectances are available. One can either start with known reference areas and use them to define groups into which unknown pixels are assigned (supervised classification), or simply start with a computer analysis of all pixels to produce as many groups as required whose identities are later determined (unsupervised classification). The method used in the present work involved a combination of both. An unsupervised classification was initially conducted to produce as many clusters as possible (maximum number possible = 255), and thus extract the maximum possible amount of spectral information from the scene. The initial groups were then aggregated one by one into categories of known habitat by reference to areas of known habitat on the image. This procedure was continued until all groups had been assigned to a habitat class. The fine scale of division produced by the initial maximum clustering allows for the best possibility of separating different habitats that are otherwise spectrally similar. Several clustering methods were tested in the present work, including K-Means clustering, isodata clustering, and the nonparametric multidimensional NGCLUS algorithm developed by Narendra and Goldberg (Tou and Gonzalez, 1974; PCI, 1992a, 1993). K-Means clustering resulted in the most effective separation of habitat classes when the maximum of 255 was requested, producing 242 groups (versus 203 for the Isoclus procedure and 51 for the NGCLUS procedure). Of the 255 - 242 = 13 groups that were not separable by K-Means clustering, 11 appeared to be located within groups subsequently identified as Water: lakes category, one was a "zero" comprising the areas of sea surrounding the island, and one was an overlap category comprising 18 pixels (out of an image total of 16 777 216 land pixels), indicating that a highly effective separation had been achieved. The 242 initial groups were aggregated into 17 habitat categories by reference to known habitats at the 35 ground survey sites and to other observations made during aerial flights.

### *Accuracy Assessment of Classification*

A second series of separate areas was used to assess the accuracy of the classification scheme. These test sites were chosen to contain apparently homogeneous habitat to which the classified image could be compared. Accuracy assessment therefore involved a comparison of the classified image to ground areas of a single known habitat type rather than a pixel-by-pixel assessment of a mosaic of mixed habitats. Reference areas did, however, include both large areas of homogeneous habitat and smaller but clearly identifiable and locatable areas of the same habitat occurring within a wider area of heterogeneous habitats. Each test site was located on the image by reference to known ground features and comparison with air photographs, and the area was saved as a bitmap with a grey level corresponding to the appropriate habitat category. Sites were chosen to include representative samples of all habitats used in the classification scheme. The habitat bitmaps were then compared to the classified image to produce an error or "confusion" matrix.

### *Assessment of Breeding Densities and Breeding Shorebird Populations*

Habitat-specific estimates of shorebird breeding densities at each study site were obtained by registering field survey maps with the classified image and assigning all nests and active territories to the habitat category pixel occurring at that location. The extent of each habitat category within the survey area was determined by outlining the survey areas as bitmaps and counting pixels, to enable the number of breeding pairs of each species in a given area of habitat at each site to be estimated. Initial estimates of populations of each species on Prince Charles Island were made by determining the weighted mean density in each habitat over the 35 study sites and extrapolating numbers based on the extent of each habitat category occurring over the entire island.

Estimates of breeding population size based on simple extrapolation from a single estimated density value applied to all pixels of that habitat category are not likely to be accurate for several reasons. For instance, some species of shorebirds are thought to nest in higher densities near the coast than at inland locations. This possibility was investigated by running linear regression analyses on habitat-specific densities found at the 35 different study sites with distance of the site from the coast. Where statistically significant relationships were found, these relationships were applied to all pixels of that habitat throughout the island. This was achieved by replacing grey levels of the 17 habitat categories on the classified image with the weighted mean density of the shorebird species in those habitats as determined during surveys of the 35 survey sites. After determining distances of all pixels to the coast, breeding densities were adjusted by applying the regression relationship, using the modelling facility within the image analysis system (PCI, 1992b). Revised population estimates were obtained through summation of pixels in each of the modelled density categories.

Standard errors for the simple and modelled extrapolations were derived through extension of the variance equation for ratio and regression estimators, respectively (Cochran, 1963; Collins and Morrison, unpubl. results).

The suitability of an area for nesting by a particular species may depend not only on the presence of the habitat used specifically for nesting, but also on the presence nearby of other habitats used by the species for other purposes, such as feeding. High-quality nesting areas may therefore contain particular combinations of habitats rather than a single habitat type. The hypothesis that a species is selecting patches of a particular habitat A on the basis of their proximity to another habitat B may be tested by comparing the mean distances (1) to habitat B of those pixels of habitat A containing a known nest and (2) to habitat B of the entire population of pixels of habitat A. This type of analysis was carried out using the modelling capabilities of the Easi/Pace software (PCI, 1992b). Pixels known to contain nests were identified on the classified image and saved as bitmaps. The proximities (i.e., distance to the nearest pixel) of pixels with known nests to the various other classes of habitat pixels were then computed and compared with proximities of all pixels of the nesting habitat to the various other habitats.

The results of these analyses were used to carry out further modelling of nesting distributions. Where a species was found to be nesting significantly closer in one habitat to another habitat (compared to the overall population of habitat), pixels of the nesting habitat were considered to be potential nesting pixels only if they occurred within the mean plus 2.326 standard deviations distance (the analysis was carried out in pixel units) of the second habitat; this distance should include 98% of the known distribution of nesting pixels. Pixels not within this distance were not considered as suitable habitat and were removed from the image using the Easi/Pace modelling software. This analysis was carried out after the regression analysis that adjusted densities for distance from the coast. Updated population estimates for the island were obtained by summing pixels in the remaining density categories. Standard errors were calculated by adjusting those errors derived in the regression step for the decrease in area of habitat resulting from the proximity analysis.

## RESULTS

### *Habitat Classification*

The habitat classification procedure resulted in the delineation of 17 habitat categories, including three categories of *Water*, five of *Marsh*, three of *Tundra*, and six of *Barren* ground (Fig. 2). Brief descriptions of these categories are found in Table 1, and their spectral characteristics are shown in Table 2. For the *Water* categories, "Sea" included all areas considered to be below the low water mark, and this area was masked off and set to a DN of 0 prior to proceeding with the rest of the classification: this eliminated the variation in the image occurring over the sea (consisting of open water and ice) so that the classification procedures dealt only with spectral variability of land habitats. "Lakes" involved permanent fresh water bodies of all sizes and depths, whereas "Other Water" involved river courses, shallow areas under standing water, and wet areas immediately adjacent to streams and watercourses, thus representing a mixed but wet habitat category, and distinguished by higher reflectance values in TM Bands 4, 5, and 7. Five categories of *Marsh* habitats were recognized. A distinctive "Saltmarsh" zone, characterized by colonizing patches of *Puccinellia phryganodes*, occurred along the upper intertidal zone, especially on flat, silty coastlines. Two categories of "grassland" were distinguished: both were characterized by extensive swards of graminoid vegetation and mosses and occurred at both coastal and inland sites. "Grassland 1" consisted of an unbroken cover of graminoids (78%) and mosses (22%) and was generally rather wet, the terrain often being dotted with small pools. Where standing water persisted in both coastal and inland areas, a completely "Saturated Marsh" developed, dominated by mosses (71%) rather than graminoids (28%). "Grassland 2" appeared to be a dried-out version of the saturated marsh: it was found in areas where better drainage led to a drying out of the substrate after the spring melt. Such areas were again dominated by mosses (66%) rather than graminoids (27%), but were mostly damp rather than completely saturated when visited in early July. Sedge "Marshes" were found in areas that remained wet but not saturated and contained more graminoids (54%) than mosses (31%), though there tended to be more open areas of silt or organic crust. This category included marsh types with an overall vegetation cover somewhat lower (81%) than the saturated marsh/grasslands, and a more diverse range of plants (e.g., *Salix*, lichens and even *Dryas*) and some hummock development. *Tundra* types were divided into one well-vegetated and two poorly vegetated categories. Well-vegetated tundra ("Tundra: veg") averaged about 65% vegetation cover, consisting mostly of *Dryas* and/or lichens, and was found on well-drained slopes or ridge flanks. "Tundra: unveg" had a lower vegetation cover, and was situated in wetter areas, leading to a more prominent

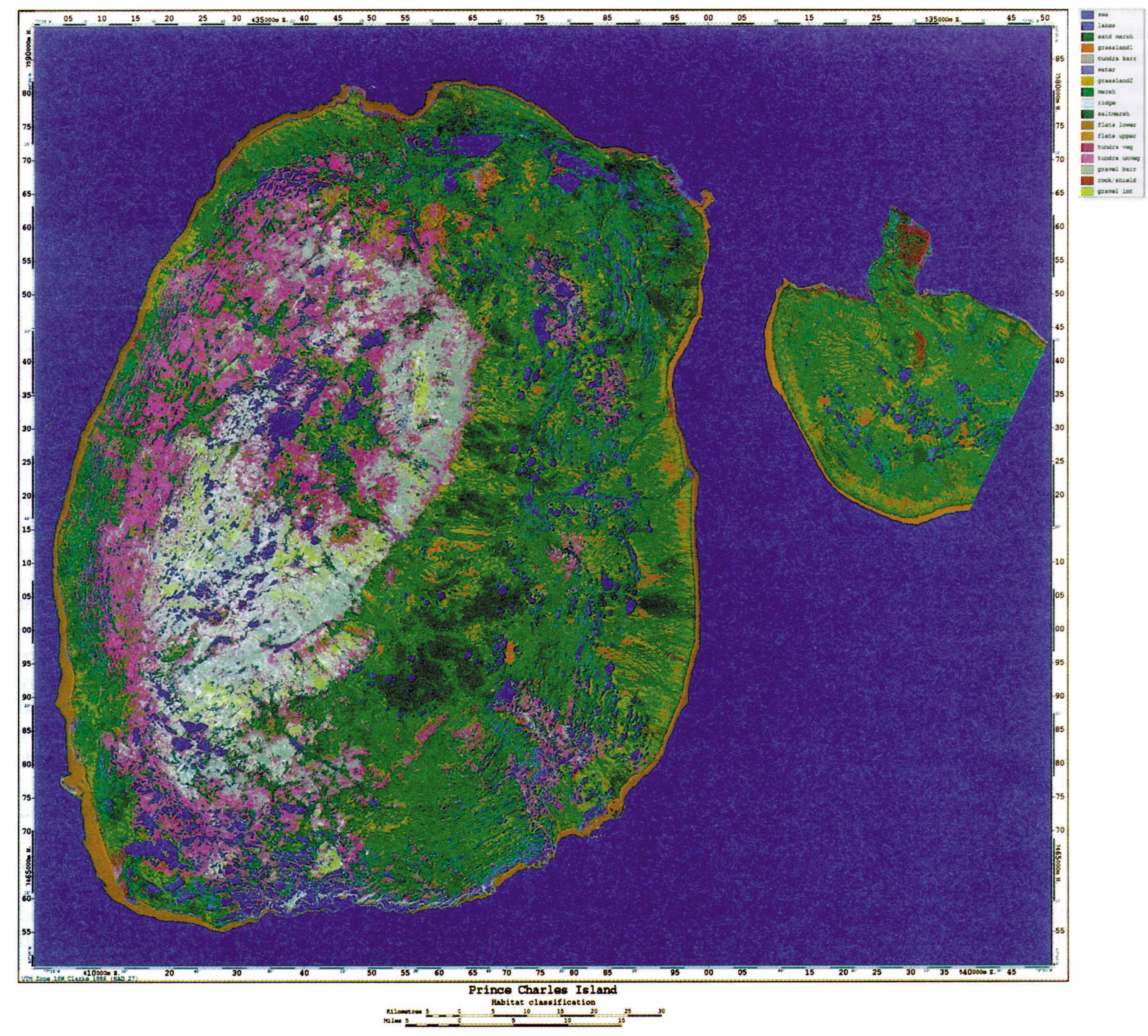


FIG. 2. Classified image of Prince Charles Island and part of Air Force Island, showing 17 habitat categories produced by a combination of unsupervised and supervised classification methods.

moss component or, where this had dried out, a cover of organic crust. "Tundra: poor" also had a relatively low plant cover. Several types were probably included in this category, including a wet type of gravelly or rocky slope with moderate *Dryas* cover (21%) and silty outcrops with sedgy cover. Among the six *Barren* categories, two categories of intertidal flats were distinguished. The lower flats ("Flats: lower") were generally wetter and consisted of coarser substrates than the upper flats ("Flats: upper"), which were siltier and in some places covered by a distinctive algal mat. "Ridge" habitats represented the poorly vegetated tops of raised beach ridges. They were usually flat and dry and dominated by gravel (54%) and sand (27%), with a sparse cover of *Dryas* and purple saxifrage. "Barren gravel" was very similar to the ridge-top habitats, though it covered more extensive open areas. "Interior gravel" habitats, which occurred on the higher inland parts of the island, were drier and tended to consist of frost-shattered rocks and gravel.

*Nesting Densities of Shorebirds*

Six species of shorebirds were found breeding on the survey plots of Prince Charles Island. Estimated nesting densities in each habitat category are shown in Table 3. Based on a total of 230 nests/territories found during coverage of a total of 598 ha at all study plots, they represent the weighted

TABLE 1. Habitat categories resulting from classification of the remotely sensed image of Prince Charles Island, Foxe Basin, Northwest Territories.

| No[1] | Habitat | | Area | Approximate % Cover | | | | Description |
|---|---|---|---|---|---|---|---|---|
| | Type | Category | ha | % total | Veg | Barren | Water | |
| 1 | Water 18.1% | Sea | - | - | 0 | 0 | 100 | Sea: all areas below low water mark as judged from satellite image |
| 2 | | Lakes | 114010 | 11.5 | 0 | 0 | 100 | Lakes: permanent fresh water bodies of all depths and sizes |
| 6 | | Other water | 65373 | 6.6 | 0 | 0 | ±100 | River courses, shallow areas under standing water, and wet areas immediately adjacent to streams and watercourses |
| 10 | Marsh 40.5% | Saltmarsh | 2473 | 0.3 | 35 | 65 | + | Areas bordering the upper intertidal flats characterized by patches of *Puccinellia phryganodes* interspersed with mud |
| 4 | | Grassland 1 | 67534 | 6.8 | 100 | 0 | (++) | Extensive swards of graminoid (78%) and mossy (22%) vegetation, generally rather wet |
| 7 | | Grassland 2 | 50854 | 5.1 | 100 | 0 | (+) | Extensive swards of marshy vegetation, with mosses (66%) rather than graminoids (27%) predominating; rather damp, but resembling a dried-out version of a saturated marsh |
| 8 | | Wet marsh | 178867 | 18.0 | 80 | 20 | + | Areas typically of sedge marsh, remaining wet but not saturated, some hummock development, wider range of vegetation than in grasslands; more graminoids than mosses. |
| 3 | | Saturated marsh | 102503 | 10.3 | 99 | 1 | ++ | Completely saturated marshy area, remaining wet throughout the summer: usually with complete vegetation cover and dominated by mosses (71%) rather than graminoids (28%) |
| 5 | Tundra 22.0% | Tundra: poor | 85272 | 8.6 | 40 | 60 | 0 | Tundra with very sparse vegetation cover, sometimes with minimal barren dried out sedge cover, includes open rocky tundra |
| 14 | | Tundra: unveg | 73110 | 7.4 | 30 | 70 | 0 | Poorly vegetated tundra, damper than tundra:veg, with more prominent moss or organic crust cover |
| 13 | | Tundra: veg | 59528 | 6.0 | 65 | 35 | 0 | Moderately vegetated tundra, cover about 65%, typically with combinations of *Dryas*, *Saxifraga*, *Salix*, some sedges and lichens; occurring on well-drained slopes and ridge flanks |
| 11 | Barren 19.7% | Flats: lower | 23552 | 2.4 | 0 | 100 | 0 | Lower intertidal areas: usually with coarser sediments than on the upper flats |
| 12 | | Flats: upper | 10324 | 1.0 | 0 | 100 | 0 | Upper intertidal areas: typically with rather fine sediments, sometimes with an algal mat |
| 9 | | Ridge | 46360 | 4.7 | 10-15 | 85-90 | 0 | Barren poorly vegetated (5 – 10%) gravelly or sandy ridge tops, typically comprising raised beach ridges found along coastal areas |
| 15 | | Gravel: barren | 96029 | 9.7 | 5 | 95 | 0 | Open areas of barren gravel, coarser than 9; similar to 17, but usually nearer the coast |
| 17 | | Gravel: interior | 18530 | 1.9 | <5 | >95 | 0 | Interior areas of frost-nipped gravel and shattered loose rocks |
| 16 | | Rock | 447 | 0.04 | 0 | 100 | 0 | Areas of bare bedrock (on neighbouring Air Force Island Canadian Shield outcrops); uncommon on Prince Charles Island |

[1] Numbers are those assigned to habitat categories during the remote sensing analyses.

TABLE 2. Spectral signatures (Mean Digital Number (SD)) for 17 habitats in classified image derived from Landsat TM data acquired 19 July 1985, Prince Charles Island, Northwest Territories, Canada.

| No. | Habitat description | Spectral signature [Mean DN(SD)] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Band 1 | | Band 2 | | Band 3 | | Band 4 | | Band 5 | | Band 7 | |
| 1 | Sea | 0* | | 0* | | 0* | | 0* | | 0* | | 0* | |
| 2 | Lakes | 81.1 | (8.7) | 38.2 | (7.4) | 38.2 | (10.0) | 19.0 | (10.3) | 13.0 | (10.0) | 5.56 | (4.2) |
| 6 | Other water | 86.5 | (11.2) | 38.0 | (8.2) | 44.8 | (11.3) | 56.0 | (7.1) | 84.1 | (23.6) | 32.1 | (9.9) |
| 10 | Saltmarsh | 100.0 | (7.1) | 47.2 | (5.0) | 60.8 | (7.8) | 77.9 | (5.4) | 113.5 | (7.3) | 43.9 | (4.4) |
| 4 | Grassland 1 | 82.8 | (3.1) | 34.3 | (1.9) | 40.3 | (2.7) | 57.3 | (5.4) | 99.8 | (11.7) | 36.7 | (5.2) |
| 7 | Grassland 2 | 85.9 | (5.5) | 35.9 | (3.3) | 42.2 | (4.6) | 55.4 | (6.5) | 107.7 | (9.9) | 41.3 | (5.1) |
| 8 | Wet marsh | 83.5 | (3.9) | 35.3 | (3.1) | 40.9 | (4.0) | 52.5 | (6.9) | 84.7 | (20.8) | 32.1 | (7.7) |
| 3 | Saturated marsh | 77.3 | (3.8) | 31.3 | (2.6) | 34.8 | (3.8) | 49.2 | (7.3) | 58.3 | (14.9) | 21.7 | (5.7) |
| 5 | Tundra: poor | 95.7 | (8.8) | 41.2 | (5.3) | 48.9 | (7.5) | 56.3 | (5.8) | 115.9 | (14.1) | 50.3 | (9.9) |
| 14 | Tundra: unveg | 104.0 | (7.1) | 46.0 | (4.2) | 55.5 | (6.2) | 59.4 | (5.1) | 124.5 | (14.4) | 57.9 | (9.8) |
| 13 | Tundra: veg | 107.8 | (9.3) | 48.8 | (5.8) | 59.7 | (8.8) | 61.7 | (5.4) | 125.5 | (16.4) | 59.3 | (11.5) |
| 11 | Flats: lower | 138.0 | (15.2) | 71.8 | (10.7) | 89.5 | (16.6) | 61.2 | (20.0) | 44.3 | (27.6) | 17.9 | (11.3) |
| 12 | Flats: upper | 131.1 | (11.9) | 70.6 | (7.8) | 94.0 | (12.0) | 77.5 | (9.5) | 115.5 | (23.9) | 52.0 | (12.8) |
| 9 | Ridge | 135.7 | (12.7) | 67.2 | (8.3) | 87.5 | (12.5) | 78.6 | (7.9) | 169.5 | (24.2) | 87.9 | (15.5) |
| 15 | Gravel: barren | 130.7 | (10.1) | 63.1 | (7.1) | 81.1 | (10.9) | 73.7 | (7.4) | 171.2 | (17.8) | 88.9 | (10.6) |
| 17 | Gravel: interior | 153.7 | (7.4) | 82.4 | (5.3) | 111.6 | (8.3) | 95.2 | (6.0) | 198.1 | (9.9) | 105.1 | (5.8) |
| 16 | Rock | 95.2 | (5.4) | 39.4 | (3.1) | 44.7 | (3.9) | 39.8 | (4.4) | 105.8 | (5.4) | 53.9 | (3.7) |

* Habitat 1 = Sea set to 0.

means of the habitat-specific estimates at each of the 35 study plots. Red phalaropes (n = 99), white-rumped sandpipers (n = 94) and semipalmated sandpipers (n = 7) tended to nest predominantly in marshy habitats, though white-rumped sandpipers also regularly made use of tundra habitats. Red phalaropes and white-rumped sandpipers were the most abundant species overall, nesting in densities up to an estimated 64 and 40 pairs/km$^2$, respectively, in marsh habitats. Ruddy turnstones (n = 21), black-bellied plovers (n = 7) and lesser golden-plovers (n = 2) were found principally in tundra habitats, often situated along flanks of raised beach ridges; nesting densities were generally lower, reaching about 24 pairs/km$^2$ for ruddy turnstones nesting in well-vegetated tundra. Nesting densities were highest in marshy habitats, ranging between 40–110 pairs/km$^2$ for all species combined, compared to 11–37 pairs/km$^2$ in tundra habitats. Statistically significant differences in shorebird densities both for individual species across different habitats and between different species within the same habitat are indicated in Table 3.

*Estimates of Population Sizes of Shorebirds*

Table 4 shows estimates of shorebird population sizes, before and after modelling. Estimates were derived by extrapolating habitat-specific nesting densities to the total area of that habitat on the island as determined by remote sensing. Initial estimates based on simple extrapolations of weighted mean densities range from 1700 pairs for the lesser golden-plover to some 189 000 pairs of red phalaropes, with a total estimated population for all species of shorebirds of some 364 000 pairs.

Regression analyses showed that nesting densities were related to distance from the coast for at least some habitats, often the principal one used for nesting, for all species but the lesser golden-plover (where sample sizes were small) (Table 5). In all but one case, nesting densities decreased away from the coast; the only exception was the positive relationship for red phalaropes breeding in Grassland 1 habitats, which perhaps reflects the suitability of this nesting habitat for this species in the interior of the island. For ruddy turnstones, the strong negative relation between densities on ridge habitats and distance to coast reflected the preference of this species for nesting on raised beach ridges in coastal areas; there was a weaker relationship of borderline statistical significance for densities in other tundra habitats. Black-bellied plovers showed a general decrease in density (habitats combined) away from the coast, and semipalmated sandpipers, white-rumped sandpipers, and red phalaropes all showed declining densities inland in various types of marshy habitats.

Population estimates for shorebirds after the habitat-specific distance modelling are shown in the second column of Table 4. Estimated populations of ruddy turnstones and red phalaropes decreased by about 23% and 6%, respectively, reflecting a general preference for coastal areas of raised beach ridges and marshy grasslands, respectively. The population estimate for semipalmated sandpipers increased somewhat (13%), reflecting this species' preference for marsh habitats in coastal locations. The estimate for white-rumped sandpipers changed rather little: possibly this result reflects the broad distribution of the species in both marsh and tundra habitats, so that calculated increases in coastal locations apparently balance decreases in interior areas. Densities of black-bellied plovers and lesser golden-plovers were not modelled, as habitat-specific regression relationships were not statistically significant.

The proximity analysis determined whether a species was selecting nesting pixels that were closer to or farther from a given habitat than those that were available overall. Results indicated that many species tended to select nesting pixels that were closer to water and marsh habitats and farther from barren ground habitats than the general pixel population (Table 6). Sample sizes of nesting pixels were small in comparison with the overall population of pixels on the image, and comparisons were made using t-tests, assuming unequal variances and calculating appropriate degrees of freedom as described by Bailey (1981). For the marsh-nesting red phalaropes and white-rumped sandpipers, for instance, nesting pixels were located closer to water and marsh habitats than average, reflecting their close association with these habitats, farther from a number of barren ground habitats, reflecting their avoidance of these areas, and there was no difference in mean distance from the sea, reflecting their wide distribution throughout the island. Semipalmated sandpipers, ruddy turnstones, and black-bellied plovers all nested closer to the sea than average, reflecting their tendency to nest in coastal areas, and all nested closer to water, marsh, and tundra habitats than average, reflecting their association with these habitats for nesting and feeding. The results also generally imply that birds were selecting associations of habitats or were preferring "edge" situations where a number of habitats were available in close proximity. For ruddy turnstones, for instance, this selection reflects their use of beach ridges and tundra habitats for nesting and their use of nearby marshy areas for feeding and loafing. The results also emphasize the importance of water and moisture in influencing the distribution of birds amongst the various habitats.

The results of the proximity analysis were then used to eliminate pixels of breeding habitat that could be considered unsuitable for nesting on the basis of their being too far away from other significantly associated habitat types. The criterion adopted was that a pixel of a given breeding habitat should be within a distance not greater than the mean for the species plus 2.326 standard deviations of the significantly associated habitat to be considered suitable for breeding, based on the association between known breeding pixels and the associated habitat. This distance should include 98% of known nesting pixels. These distances are shown in Table 7, and indicate, for instance, that 98% of ruddy turnstones nested within 7 pixel units ($7 \times 25 = 175$ m) of marsh habitats.

A number of restrictions were placed on the proximity modelling process in order that the overall criteria for defining a suitable nesting habitat pixel did not become unduly restrictive. First, only those habitats that showed a statistically significant difference from the overall pixel population

TABLE 3. Nesting densities of shorebirds (pairs per km², Mean (SD)) for 17 habitats in classified image derived from Landsat TM data acquired 19 July 1985, Prince Charles Island, Northwest Territories, Canada.

| No. | Habitat description (sample size) | Nesting density pairs per km² [Mean (SD)]: Black-bellied plover | Lesser golden-plover | Ruddy turnstone | Semipalmated sandpiper | White-rumped sandpiper | Red phalarope | All species | ANOVA (within habitats) |
|---|---|---|---|---|---|---|---|---|---|
| 2 | Lakes (15) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 6 | Other water (24) | 0 | 0 | 0 | 0 | 0 | 2.7(8.3) | 2.7(8.3) | ** |
| 10 | Saltmarsh (5) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 4 | Grassland 1 (27) | 0 | 0 | 0 | 0 | 36.2(76.1) | 29.0(32.5) | 65.2(83.8) | *** |
| 7 | Grassland 2 (23) | 0 | 0 | 0 | 1.6(26.9) | 24. 2(62.4) | 14.5(39.2) | 40.3(119.7) | *** |
| 8 | Wet marsh (25) | 0 | 0 | 0 | 6.3(36.7) | 39.7(91.4) | 63.7(98.5) | 109.6(182.5) | *** |
| 3 | Saturated marsh (20) | 0 | 0 | 0 | 0 | 3.7(11.7) | 44.9(51.4) | 48.7(59.6) | *** |
| 5 | Tundra: poor (22) | 1.2(6.0) | 1.2(15.3) | 3.5(24.6) | 0 | 10.4(41.6) | 0 | 16.2(50.1) | * |
| 14 | Tundra: unveg (20) | 3.0(15.3) | 1.0(8.0) | 1.0(5.1) | 0 | 6.1(20.6) | 0 | 11.1(30.8) | ** |
| 13 | Tundra: veg (18) | 5.0(15.7) | 0 | 23.5(47.5) | 0 | 8.4(23.3) | 0 | 36.9(59.6) | *** |
| 11 | Flats: lower (3) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 12 | Flats: upper (5) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 9 | Ridge (11) | 0 | 0 | 15.9(26.0) | 0 | 0 | 0 | 15.9(26.0) | *** |
| 15 | Gravel: barren (10) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 17 | Gravel: interior (6) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| 16 | Rock (2) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ns |
| | All habitats (236) | 1.7(9.0) | 0.3(4.6) | 3.5(22.6) | 1.2(13.2) | 15.7(73.5) | 16.6(84.2) | | *** |
| | ANOVA[1] (within species) | ** | ns | *** | ns | *** | *** | *** | |

[1] Statistical significance: ns = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$; ANOVA significance indicated at bottom of column for analysis of differences in densities within a species across habitats, and at end of row for differences between species in the same habitat. Lines (double, single, no line) indicate groups of densities that were significantly different from one another (no differences within the group). Vertical lines indicate differences within a species across habitats ($p < 0.05$, multiple t-test, Fisher's Least Significant Difference (LSD)). Horizontal lines indicate differences between species across the same habitats ($p < 0.05$, multiple t-test with GT2 or Tukey options to control maximum experimentwise error rate, applies to all habitat categories except Other Water and Grassland 2, where differences were significant only with LSD procedure).

TABLE 4. Population estimates (breeding pairs) for shorebirds nesting on Prince Charles Island, Foxe Basin, Northwest Territories.

| Species | Population estimate (breeding pairs) for Prince Charles Island: (1) No modelling, direct extrapolation Estimate ± SE | (2) Modelled for distance from coast Estimate ± SE | (3) Further modelled for inter-habitat proximity Estimate ± SE |
|---|---|---|---|
| Black-bellied plover | 6205 ± 6234 | (not modelled)[1] | 3531 ± 5824 |
| Lesser golden-plover | 1726 ± 2414 | (not modelled)[1] | (not modelled)[1] |
| Ruddy turnstone | 25066 ± 11198 | 19372 ± 9864 | 11721 ± 8989 |
| Semipalmated sandpiper | 12022 ± 9953 | 13559 ± 9203 | 9506 ± 8611 |
| White-rumped sandpiper | 129846 ± 35344 | 129350 ± 35682 | 126162 ± 34725 |
| Red phalarope | 188684 ± 25144 | 177708 ± 24561 | 141599 ± 21882 |
| All species[1] | 363549 ± 66434 | 347920 ± 60961 | 294245 ± 58501 |

[1] Totals for "All species" in the modelled estimates (2 and 3) include the unmodelled individual species estimate from column (1) where "not modelled" is indicated.

were modelled. For proximity to sea habitats, the distance used was the greater value resulting from either (1) the proximity analysis itself or (2) the calculated distance at which the nesting density became zero as determined from the regression analysis. Relationships with saltmarsh and upper and lower flats were not further modelled because they are adjacent to the sea. Proximities to other types of barren ground habitats (ridge, gravel, rock) were also not modelled, as there was not a statistically significant relationship in some cases. Also, the biological significance of such relationships was not always clear, in that nesting pixels were usually farther from these habitats than nearer to them, indicating

TABLE 5. Statistically significant weighted regression relationships between nesting densities of shorebirds at survey sites and distance of nesting habitats from coast.

| Species habitat/sites | regression | $R^2$ | $p$[1] | n |
|---|---|---|---|---|
| **Black-bellied plover** | | | | |
| [all habitats/sites | bbpld = 2.272-0.083*dist | 0.18 | 0.011* | 35] |
| **Ruddy turnstone** | | | | |
| [all habitats/sites | rutud = 6.845-0.251*dist | 0.26 | 0.002** | 35] |
| (9)ridge | rutud = 34.866-1.920*dist | 0.71 | 0.001** | 11 |
| [(13)tundra: veg | rutud = 37.317-1.894*dist | 0.20 | 0.06(*) | 18] |
| [(14)tundra: unveg | rutud = 2.077-0.112*dist | 0.14 | 0.10(*) | 20] |
| **Semipalmated sandpiper** | | | | |
| [all habitats/sites | sesad = 2.696-0.115*dist | 0.16 | 0.02* | 35] |
| (8)wet marsh | sesad = 16.646-0.684*dist | 0.18 | 0.04* | 25 |
| **White-rumped sandpiper** | | | | |
| (3) saturated marsh | wrsad = 10.971-0.422*dist | 0.26 | 0.02* | 20 |
| [(13)tundra: veg | wrsad = 14.608-0.852*dist | 0.17 | 0.09(*) | 18] |
| **Red phalarope** | | | | |
| (3) saturated marsh | rephd = 78.491-1.958*dist | 0.28 | 0.02* | 20 |
| (4) grassland 1 | rephd = 5.315+0.989*dist | 0.27 | 0.006** | 27 |
| [(6)other water | rephd = 4.873-0.168*dist | 0.12 | 0.096(*) | 24] |
| **All shorebirds** | | | | |
| [(6) other water | alld = 4.873-0.168*dist | 0.12 | 0.096(*) | 24] |
| (3) saturated marsh | alld = 89.462-2.380*dist | 0.31 | 0.01* | 20 |
| [(5)tundra: poor | alld = 29.792-1.162*dist | 0.15 | 0.08(*) | 22] |
| (13)tundra: unveg | alld = 60.084-3.174*dist | 0.36 | 0.009** | 18 |
| (9) ridge | alld = 34.866-1.920*dist | 0.71 | 0.001** | 11 |

[1] Statistical significance: (*) = 0.1 > $p$ > 0.05, * = $p$ < 0.05, ** = $p$ < 0.01. No significant relationships were found for lesser golden-plover. Only statistically significant relationships involving specific habitats were used in the modelling procedure: relationships in square brackets [where $p$ = (*) or for "all" habitats] were not used in the modelling procedure.

avoidance rather than association. Finally, it was considered unduly restrictive to model relationships using proximities of all members of a group of similar habitats (e.g., marsh types, grassland types, tundra types): in such cases, a very close proximity value for one habitat within the group might eliminate many pixels of other similar habitats with only slightly greater proximity values. The proximity value that was used for modelling the individual habitats within an entire group of similar habitats was therefore set to the maximum found for any member within that group.

The resulting criteria used during the modelling procedure are shown in Table 8. For ruddy turnstones, for instance, suitable habitats were defined as those occurring within 9 pixels (225 m) of water, within 11 pixels (275 m) of tundra and marsh habitats, and within 13 pixels (325 m) of grassland habitats.

Proximity modelling of habitats resulted in an approximately 20% reduction (compared to the unmodelled figure) in the estimated overall shorebird population, with decreases ranging from about 3% for white-rumped sandpipers to about 53% for ruddy turnstones (Table 4). The major effect was to eliminate small patches of breeding habitats located in the middle of larger patches of unsuitable habitats, especially isolated patches of marsh or tundra found on the very barren gravel uplands in the interior of the island. This effect was pronounced, for example, for ruddy turnstones. They breed on ridge habitats, which were found throughout the interior, but rarely in close proximity to marsh habitats used by the species for feeding; in contrast, ridge habitats along the coast were usually found in close proximity to marsh habitats.

### *Accuracy of Classification Procedures*

Accuracy of the classification procedure was tested by comparing areas of known habitat not used during the

TABLE 6. Mean proximities (in pixel units (= 25 m), mean (SD)) of pixels used by shorebirds for breeding and of the general pixel population ("All pixels") to different habitat categories[1].

| No. | Habitat category | All pixels n = 15916250 | Red phalarope n = 99 | White-rumped sandpiper n = 94 | Semipalmated sandpiper n = 7 | Ruddy turnstone n = 21 | Black-bellied plover n = 7 | Lesser golden-plover n = 2 |
|---|---|---|---|---|---|---|---|---|
| 1 | Sea | 669.8 (467.7) | 697.1 (499.0) | 631.3 (487.4) | 95.7 (30.4)* | 215.5 (239.7)* | 225.9 (156.8)* | 386.5 (494.3) |
| 2 | Lakes | 13.0 (17.1) | 6.1 (7.2)* | 6.6 (6.6)* | 4.3 (3.0)* | 3.9 (2.0)* | 6.3 (2.1)* | 8.0 (8.5) |
| 6 | Other water | 6.1 (7.1) | 2.6 (1.9)* | 3.6 (3.7)* | 1.4 (0.5)* | 3.1 (1.9)* | 4.9 (3.8) | 7.5 (6.4) |
| 10 | Saltmarsh | 92.0 (71.7) | 108.4 (84.6) | 106.7 (88.5) | 43.3 (16.3)* | 60.2 (55.2)* | 68.9 (40.2) | 16.5 (2.1)* |
| 4 | Grassland 1 | 15.7 (25.0) | 2.3 (2.7)* | 4.1 (5.2)* | 2.4 (1.6)* | 3.8 (1.9)* | 4.6 (1.8)* | 8.0 (7.1) |
| 7 | Grassland 2 | 10.0 (13.4) | 3.9 (3.6)* | 2.9 (2.5)* | 4.4 (3.2)* | 3.8 (4.0)* | 3.6 (1.6)* | 1.5 (0.7)* |
| 8 | Wet marsh | 5.0 (8.5) | 0.9 (1.6)* | 1.7 (2.0)* | 0.3 (0.8)* | 2.7 (1.8)* | 3.6 (1.8) | 3.0 (2.8) |
| 3 | Saturated marsh | 9.0 (11.5) | 3.6 (4.0)* | 6.8 (6.1)* | 4.3 (4.9)* | 4.8 (2.6)* | 5.1 (1.8)* | 8.5 (9.2) |
| 5 | Tundra: poor | 7.8 (11.9) | 5.3 (6.5)* | 4.2 (4.6)* | 2.0 (1.3)* | 1.6 (1.1)* | 2.1 (1.7)* | 0.5 (0.7)* |
| 14 | Tundra: unveg | 16.9 (28.9) | 25.8 (39.1)* | 23.4 (39.8) | 2.4 (1.3)* | 3.0 (3.3)* | 1.0 (1.2)* | 4.5 (6.4) |
| 13 | Tundra: veg | 20.5 (36.9) | 70.4 (82.7)* | 58.4 (79.3)* | 1.4 (0.8)* | 4.1 (16.1)* | 0.7 (0.8)* | 3.0 (1.4)* |
| 11 | Flats: lower | 175.2 (131.8) | 280.6 (159.5)* | 257.4 (152.3)* | 64.7 (23.5)* | 132.4 (120.9) | 131.4 (123.2) | 142.5 (171.8) |
| 12 | Flats: upper | 97.9 (82.0) | 201.0 (129.6)* | 174.5 (118.6)* | 24.1 (14.5)* | 71.0 (52.1)* | 63.6 (69.8) | 22.5 (10.6)* |
| 9 | Ridge | 39.6 (56.9) | 145.7 (109.9)* | 113.3 (105.0)* | 4.4 (4.0)* | 27.1 (33.0) | 11.0 (19.4)* | 7.0 (7.1)* |
| 15 | Gravel: barren | 59.3 (80.3) | 147.9 (97.2)* | 130.3 (96.5)* | 40.3 (96.0) | 63.9 (84.5) | 12.1 (19.5)* | 133.0 (183.8) |
| 17 | Gravel: interior | 168.0 (186.3) | 359.4 (237.9)* | 316.6 (248.8)* | 141.1 (297.6) | 247.4 (275.1) | 51.4 (45.1)* | 404.5 (565.0) |
| 16 | Rock | 141.5 (148.4) | 191.1 (156.2)* | 163.5 (146.2) | 71.3 (37.0)* | 95.7 (83.0)* | 43.0 (18.4)* | 126.0 (28.3) |

[1] Statistically significant differences between pixels used for breeding and the general pixel population are indicated by an asterisk ($p$ < 0.05, t-test, assuming unequal variances).

TABLE 7. Distances[1] (in pixel units = 25 m) from each habitat within which 98% of breeding pixels of various species of shorebirds should be found based on proximity analysis of known nesting pixels.

| No. | Habitat[2] | Red phalarope n = 99 | White-rumped sandpiper n = 94 | Semipalmated sandpiper n = 7 | Ruddy turnstone n = 21 | Black-bellied plover n = 7 | Lesser golden-plover n = 2 |
|---|---|---|---|---|---|---|---|
| 1 | Sea | 1840 | 1765 | **166** | **773** | **591** | 1536 |
| 2 | Lakes | **23** | **22** | **11** | **9** | **11** | 28 |
| 6 | Other water | **7** | **12** | **3** | **7** | 14 | 22 |
| 10 | Saltmarsh | 305 | 312 | **81** | **189** | 162 | **21** |
| 4 | Grassland 1 | **9** | **16** | **6** | **8** | **9** | 24 |
| 7 | Grassland 2 | **12** | **9** | **12** | **13** | **7** | **3** |
| 8 | Wet marsh | **5** | **6** | **2** | **7** | 8 | 10 |
| 3 | Saturated marsh | **13** | **21** | **16** | **11** | **9** | 30 |
| 5 | Tundra: poor | **21** | **15** | **5** | **4** | **6** | **2** |
| 14 | Tundra: unveg | **117** | 116 | **5** | **11** | **4** | 19 |
| 13 | Tundra: veg | **263** | **242** | **3** | **41** | **2** | **6** |
| 11 | Flats: lower | **652** | **612** | **119** | 414 | 418 | 542 |
| 12 | Flats: upper | **502** | **450** | **58** | **192** | 226 | **47** |
| 9 | Ridge | **401** | **358** | **14** | 104 | 56 | **23** |
| 15 | Gravel: barren | **374** | **355** | 264 | 261 | **58** | 561 |
| 17 | Gravel: interior | **912** | **895** | 833 | 887 | **156** | 1719 |
| 16 | Rock | **554** | 504 | **157** | **289** | **86** | 192 |

[1] mean proximity plus 2.326 standard deviations rounded to the nearest unit.

[2] Habitats for which the mean species proximity was significantly different from the mean proximity of the general pixel population are indicated in bold.

TABLE 8. Distances, in pixel units (= 25 m), used in proximity modelling of shorebird distribution/populations on Prince Charles Island.

| No. | Habitat classes | General habitat category | Red phalarope | White-rumped sandpiper | Semipalmated sandpiper | Ruddy turnstone | Black-bellied plover |
|---|---|---|---|---|---|---|---|
| 1 | Sea | Sea | 1840 | 1765 | 938* | 1091* | 1095* |
| 2 | Lakes | Water | 23 | 22 | 11 | 9 | 11 |
| 6 | Other water | | | | | | |
| 3 | Wet marsh | Marsh | 13 | 21 | 16 | 11 | 9 |
| 8 | Saturated marsh | | | | | | |
| 4 | Grassland 1 | Grassland | 12 | 16 | 12 | 13 | 9 |
| 7 | Grassland 2 | | | | | | |
| 5 | Tundra: poor | Tundra | - | - | 5 | 11 | 6 |
| 13 | Tundra: veg | | | | | | |
| 14 | Tundra: unveg | | | | | | |

* determined from distance modelling, see Methods.

classification procedure itself with those appearing on the classified image, to produce an error matrix (Janssen and van der Wel, 1994). Similar habitats within the 16 land categories were combined to give a total of 10 habitats for the comparisons, involving a total of 15 501 pixels (Table 9). The results indicated that the proportion correctly classified (PCC) was 98.3%; the mean percentage correct was 92.6%. The latter figure has also been termed the "reliability" of the classification, or the "user's accuracy," and represents the percent of the pixels classified as in a given habitat that are that habitat in reality: the percentage incorrectly classified is the "error of commission" (7.4%) (Janssen and van der Wel, 1994). "Errors of omission" represent the percentage of the reference classes that were incorrectly classified (9.9%), corresponding to a "producer's accuracy" of 90.1%.

Most of the classification errors occurred within the major habitat types. There were no errors between barren ground habitats and either marsh or water habitats, but small numbers of misclassifications between marsh and tundra habitats and vice versa. The least accurately classified habitat category was "wet marsh," which was sometimes confused with grassland or saturated marsh, and occasionally with tundra and water habitats. This may reflect the relatively large variety of habitats that are likely to occur in the wet marsh category (see habitat descriptions), as opposed to the relatively well-defined and homogeneous habitats occurring in the grassland and saturated marsh categories. In general, however, the classification errors between the major groups were very small (PCC = 99.0%, mean % correct = 97.5%, mean error of commission = 2.5%, mean error of omission = 3.9%).

## DISCUSSION

### *Classification Accuracy*

The overall classification accuracy of greater than 90% achieved by the present methods was highly satisfactory and

TABLE 9. Error matrix for habitat classification on Prince Charles Island, Foxe Basin.

| | Water | | Marsh | | | | Tundra | | Barren | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Habitat (No.) | 1 | 2,6 | 10 | 4,7 | 8 | 3 | 5,14 | 13 | 11,12 | 9,15,17 | 16 | Total | % correct pixels | Error of commission % |
| Sea[1] (1) | 266985 | | | | | | | | | | | 266985 | 100 | 0 |
| Lakes, water (2,6) | | 6914 | | | 23 | 5 | | | | | | 6942 | 99.6 | 0.4 |
| Saltmarsh (10) | | | 492 | 2 | 19 | | 11 | | | | | 524 | 93.9 | 6.1 |
| Grassland (4,7) | | | | 626 | 22 | | 18 | | | | | 666 | 94.0 | 6.0 |
| Wet marsh (8) | | 8 | | 23 | 161 | 14 | 22 | 4 | | | | 232 | 69.4 | 30.6 |
| Saturated marsh (3) | | 1 | | | | 1110 | | | | | | 1111 | 99.9 | 0.1 |
| Tundra: unveg (5,14) | | | | 20 | 14 | | 453 | 22 | | 2 | | 511 | 88.6 | 13.4 |
| Tundra: veg (13) | | | | 2 | | | 5 | 40 | | | | 47 | 85.1 | 14.9 |
| Flats (11,12) | | | | | | | | | 2836 | | | 2836 | 100 | 0 |
| Gravel (9,15,17) | | | | | | | 7 | 5 | | 2347 | | 2359 | 99.5 | 0.5 |
| Rock (16) | | | | | | | 9 | | | | 264 | 273 | 96.7 | 3.3 |
| Total pixels | 266985 | 6923 | 492 | 673 | 239 | 1129 | 525 | 71 | 2836 | 2349 | 264 | 15501 | | |
| Error of omission % | 0 | 0.1 | 0 | 6.6 | 32.6 | 1.7 | 13.7 | 43.7 | 0 | 0.1 | 0 | | | |

[1] The category 'Sea' was excluded from the calculations since it was a defined category, so that calculations refer to figures within the box; Proportion correctly classified (sum of diagonal/total pixels) = 98.3%; Mean % correct = 92.6%; Mean Error of Commission = 7.4%; Mean Error of Omission = 9.9%.

appeared to hold up over wide areas on Prince Charles Island. This contrasts with the findings of some previous studies in which accuracy decreased over wide areas (George et al., 1977; Wickware et al., 1980; Gratto-Trevor, 1996). Similar inaccuracies were found during production of a preliminary supervised classification for the island based on training areas located on Rowley Island, some 120 km to the northwest (Morrison, unpubl. results). Some of these problems may be related to the habitat classification procedures employed, which typically involved one of two methods. In the "supervised" approach, areas of known habitat are identified on the image and their spectral characteristics used as a reference against which to identify pixels in the rest of the image. In the "unsupervised" approach, a computer is used to cluster pixels into a number of groups based on their spectral similarity, and the identity of the groups is later determined by ground truthing; the number of groups may be chosen by the investigator. Both methods have their drawbacks. Whereas the supervised approach does involve working with known habitats, if these have been identified within too small a portion of the image being considered, or if they do not include all habitat types present, then the analytical routines will not be able to identify new and spectrally different habitats that may be encountered elsewhere within the region. Where there is some heterogeneity within the training areas themselves, the possibility of different but spectrally similar habitats being drawn into the same cluster will increase. With the unsupervised approach, choosing too few categories may lead to overlap of the groups that are produced, though greater accuracy is generally obtained with fewer categories (Rees, 1990), while increasing the number of categories too far may lead to inappropriate splitting of groups. Moreover, the groups are chosen on the basis of their spectral similarity rather than on ecological grounds, which may lead to difficulties in relating the classes to habitat types observed in the field (Rees, 1990).

The approach in the present work was to combine the potential advantages of both methods, while avoiding their pitfalls. The initial procedure was unsupervised, in the sense that the clustering routine was requested to produce the maximum number of groups possible (255), thus extracting the maximum possible amount of spectral information in the image. The K-Means clustering procedure was the most successful, producing more groups (242) than the Isoclus procedure (203) or NGCLUS nonparametric routine (51). These groups were then aggregated one by one, on the basis of locations of known habitat types on the ground. Initial aggregation into categories proceeded quickly, since many of the groups could be easily identified in this manner. Where there was some uncertainty about the habitat category to which a new group should be assigned, the decision could often be based on its proximity to a known habitat type and its spectral characteristics when compared with those of the groups being aggregated. Aggregation was continued in this manner until a realistic number of categories had been recognized in relation to the habitat types found in the field. This method potentially enables more successful separation of groups that are fairly spectrally similar, since it may be possible to distinguish between such groups on the basis of their locations.

Habitat classification was very accurate in terms of the major types that were defined, complete separation being achieved between water or marsh habitat types on the one hand and barren ground types on the other. Most of the misclassifications were recorded within the major types themselves; marsh habitats were the most commonly misclassified within their type, while the most common interhabitat misclassification involved confusion between poorly vegetated tundra and various marsh categories, particularly grassland and wet marsh. Many factors can cause confusion between habitat classes. In the present work, the set of reference sites against which the classification was tested consisted of areas of apparently homogeneous habitat, chosen to maximize the sample size of pixels being tested; this was judged to be a more practicable approach than attempting an error assessment on the basis of a pixel-by-pixel comparison between ground and image. Although superficially homogeneous, such habitats may have contained small areas of variable reflectance not characteristic of that reference habitat, thus introducing an unknown—and in the present case unassessable—source of error within the reference habitat itself.

Many other factors can lead to classification errors. For example, habitat patches that are smaller than the pixel size of the image result in mixed reflectance characteristics and difficulties in distinguishing habitats in transition zones. This problem was noted, for instance, by Gratto-Trevor (1996) in habitat classifications of the Mackenzie Delta and by Tomlins and Boyd (1988) in wetland mapping in British Columbia. Its significance is again difficult to assess in the present work, but it is likely to be a factor affecting the classification of "water" habitats that were known to follow river and stream courses and would certainly have covered adjacent marshy banks as well as the water itself. This likelihood is indicated by the occurrence of errors between water and marsh categories: all errors in the overall water categorization, 23 to marsh and 5 to saturated marsh (Table 9), involved the water category, none being from the lake category (Morrison, unpubl. data) and vice versa. Errors between the habitats that involved relatively large expanses of apparently homogeneous habitat, such as grasslands, intertidal flats and gravelly barren ground were generally low, while errors were most common in the wet marsh category, probably because this category included a number of related but similar habitats, with more variability in ground and vegetation cover than the "homogeneous" habitats: similar results were found by Tomlins and Boyd (1988) in their study of wetland habitats in British Columbia. The poorly vegetated tundra habitats also had relatively high error rates, probably for the same reasons, as they included a number of different substrate types with varying kinds of vegetation present in low amounts. Another factor that would affect both poorly vegetated tundra and marsh habitats was moisture, and variations from this source could also produce errors in classification. This situation was described by Johnston and Barson (1993), who noted that habitat clusters produced using an unsupervised approach represented differences in vegetation density, productivity, and moisture rather than differences in plant composition.

### *Densities of Shorebirds on Prince Charles Island and at Other Arctic Locations*

Highest densities of nesting shorebirds occurred in marshy (graminoid) habitats, with red phalaropes and white-rumped sandpipers having the highest nesting densities found in the study in these habitat types. Species nesting primarily in tundra types of habitat, principally ruddy turnstones, black-bellied plovers, and lesser golden-plovers, did so in generally lower densities (Table 3).

Densities of shorebirds recorded at other Arctic locations are shown in Table 10. Densities of shorebirds nesting both in wetter marshy habitats and on drier cushion plant/shrub habitats on Prince Charles Island are comparable to those in similar situations in the western Arctic, often higher than those in such areas in the eastern Arctic, and higher than those at High Arctic locations. For sites in the Foxe Basin region, overall densities on Prince Charles Island appeared to be somewhat higher than those observed on grassy tundra by Soper (1940) in 1929 at Bowman Bay on the west coast of Baffin Island, and were higher than those observed by Forbes et al. (1992) at Igloolik on the west side of Foxe Basin, or by Montgomerie et al. (1983) on plateau areas at Sarcpa Lake to the southwest of Igloolik (Table 10). In terms of breeding densities, Prince Charles Island would therefore appear to be of considerable importance to shorebirds breeding in the eastern Arctic, especially white-rumped sandpipers and red phalaropes, a suggestion supported by observations of these species reported by Soper (1940).

Comparison of nesting densities of shorebirds on Prince Charles Island with those at other localities is not entirely straightforward. It is difficult to compare densities reported either as "birds/km$^2$" or as "pairs (or territories)/km$^2$," since identification of a territory or breeding pair during census operations may have involved observation of either one or two birds linked to a single territory. Whether one or both birds of a pair are present during a census may depend on many factors, such as whether the nesting territory includes feeding habitats, as well as on the breeding biology of the species concerned (Pitelka et al., 1974). In addition, nesting densities in a given locality may vary enormously from year to year, sometimes by a factor of 10–25 (Pattie, 1990; TERA, 1993; Troy, 1996). Moreover, few studies have reported habitat-specific densities, and where overall densities are reported, the habitat composition of the area may be only approximately known.

Nevertheless, broad comparisons at different localities do appear feasible, especially if the general habitat composition of the area is known. Many studies have suggested that only a limited number of types of habitat occur across the Arctic: these are characterized by whether they are dominated by graminoid (grasses and/or sedges) vegetation in wetter situations or by cushion plants and or (dwarf) shrubs (e.g., *Dryas* species, purple saxifrage) in drier locations (Sheard and Geale, 1983; Muc et al., 1989; Batten and Svoboda, 1994). These categories correspond to *Marsh* and *Tundra* habitat types, respectively, in the present work, and suggest a broad equivalence, for instance, between habitats variously described as marsh, sedge meadows, wet coastal plain tundra, grassy tundra, and sedge tundra at various localities across the Arctic (Table 10). While climate and regional geology influence the diversity of plants and categories of habitat

TABLE 10. Breeding densities of shorebirds and other birds at various arctic locations.

| No. | Location | Lat. | Long. | Year | ha | Habitat | Shorebirds | | All birds | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | birds/km² | pairs/km² | birds/km² | pairs/km² | |
| 1 | North Twin Island, NWT | 53.18 | 80 | 1973 | | all habitats | 33.6 | | | | Manning, 1981 |
| 2 | Belcher Islands, NWT | 56.12 | 80 | 1971 | | all habitats | 28.2 | | | | Manning, 1976 |
| 3 | Chesterfield Inlet, NWT | 63.21 | 90.42 | 1950 | 1036 | rock, sedge, lichen, heath | | 3.09 | | 59.4 | Savile, 1951 |
| 4 | Frobisher Bay, NWT | 63.44 | 68.31 | 1964 | | sedge meadow, heath | | | | 20 | McLaren, 1965 |
| 5 | Foxe Peninsula, NWT | 64.12 | 76.32 | 1955 | 5265 | coastal, rocky | | 0.7 | | 9.8 | Macpherson and McLaren, 1959 |
| 6 | Bowman Bay, NWT | 65.3 | 73.4 | 1929 | 405 | grass tundra, rocks | 24.2 | | 167.1 | | Soper, 1940 |
| 7 | Bowman Bay, NWT | 65.3 | 73.4 | 1929 | 259 | grass tundra, rocks | 25.5 | | 108.1 | | Soper, 1940 |
| 8 | Bowman Bay, NWT | 65.31 | 73.4 | 1929 | 259 | grass tundra, rocks | 30.9 | | 151.4 | | Soper, 1940 |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | tundra: poor vegetation | | 16.2 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | wet marsh | | 109.6 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | tundra: vegetated | | 36.9 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | tundra: unvegetated | | 11.1 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | all habitats (censused) | | 38.5 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | gravel ridge | | 15.9 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | entire island (all habitats) | | 29.6 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | grassland 2 | | 40.3 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | other water | | 2.47 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | saturated marsh | | 48.7 | | | Present study |
| 9 | Prince Charles Island, NWT | 67.47 | 76.12 | 1989 | | grassland 1 | | 65.2 | | | Present study |
| 10 | Rasmussen Lowlands, NWT | 68 | 94 | 1975 | | well-vegetated lowland basin | 51.8 | | | | McLaren et al., 1977 |
| 10 | Rasmussen Lowlands, NWT | 68 | 94 | 1976 | | | 50.4 | | 152.4 | | McLaren et al., 1977 |
| 10 | Rasmussen Lowlands, NWT | 68 | 94 | 1976 | | | 49 | | | | McLaren et al., 1977 |
| 11 | Adelaide Peninsula, NWT | 68.15 | 97.3 | 1957 | | all habitats | 8.11 | | | | Macpherson and Manning, 1959 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | sedge meadow | 50 | | 260 | | Williamson et al., 1966; Hoffmann, 1974 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | riparian willows | 83 | | 897 | | Williamson et al., 1966; Hoffmann, 1974 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | sedge meadows (ridged) | 5 | | 210 | | Williamson et al., 1966; Hoffmann, 1974 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | cotton grass tussocks | 7 | | 321 | | Williamson et al., 1966; Hoffmann, 1974 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | low centre polygon | 40 | | 484 | | Williamson et al., 1966; Hoffmann, 1974 |
| 12 | Cape Thompson, AK | 68.2 | 166.5 | | | sedge marsh | 40 | | 124 | | Williamson et al., 1966; Hoffmann, 1974 |
| 13 | Sarcpa Lake, NWT | 68.33 | 83.19 | 1981 | 1300 | plateau, tundra and marsh | | 11.1 | | 35.5 | Montgomerie et al., 1983 |
| 13 | Sarcpa Lake, NWT | 68.33 | 83.19 | 1982 | 1300 | plateau, tundra and marsh | | 8.8 | | 34.3 | Montgomerie et al., 1983 |
| 14 | Blow River, YT | 68.46 | 137.1 | 1971 | 51 | coastal plain | 49 | | | | Schweinsburg, 1974; Hawkings, 1987 |
| 15 | Blow River, YT | 68.46 | 137.1 | 1974 | 26 | coastal plain | 311 | | | | Koski, 1975; Hawkings, 1987 |
| 16 | Babbage River, YT | 68.55 | 138.3 | 1972 | 40.1 | sedge tundra | | 14.1 | | 198.1 | Richardson and Gollop, 1974 |
| 17 | Mackenzie Delta, NWT | 69 | 136.2 | 1992 | | wet sedge/emergents | | 9.8 | | | Gratto-Trevor, 1994, 1996 |
| 17 | Mackenzie Delta, NWT | 69 | 136.2 | 1992 | | uplands | | 8.4 | | | Gratto-Trevor, 1994, 1996 |
| 17 | Mackenzie Delta, NWT | 69 | 136.2 | 1992 | | willow | | 10 | | | Gratto-Trevor, 1994, 1996 |
| 17 | Mackenzie Delta, NWT | 69 | 136.2 | 1992 | 352 | all habitats | | 15.2 | | | Gratto-Trevor, 1994, 1996 |
| 17 | Mackenzie Delta, NWT | 69 | 136.2 | 1992 | | polygons or sedge | | 64.9 | | | Gratto-Trevor, 1994, 1996 |
| 18 | Mackenzie Delta, NWT | 69 | 134 | 1973 | 25 | upland, alder, cottongrass | | | | 168 | Owens, 1974 in Erskine, 1976 |
| 19 | Mackenzie Delta, NWT | 69 | 134 | 1973 | 25 | river escarpment/upland | | (16+) | | 207 | Owens, 1974 in Erskine, 1976 |
| 20 | Mackenzie Delta, NWT | 69 | 134 | 1973 | 25 | floodplain, sedge, willows | | (24+) | | 119 | Owens, 1974 in Erskine, 1976 |
| 21 | Clarence Lagoon, YT | 69.02 | 140.47 | 1971 | 73 | coastal plain | 7 | | | | Schweinsburg, 1974; Hawkings, 1987 |
| 22 | Clarence Lagoon, YT | 69.02 | 140.47 | 1974 | 17 | coastal plain | 295 | | | | Koski, 1975; Hawkings, 1987 |
| 23 | Babbage River, YT | 69.04 | 138.22 | 1972 | 31.4 | sedge tundra | 37.8 | | 253.7 | | Gunn et al., 1974 |
| 23 | Babbage River, YT | 69.04 | 138.22 | 1973 | 31.4 | sedge tundra | 159.5 | | 698.1 | | Gunn et al., 1974 |
| 24 | Phillips Bay, YT | 69.05 | 138.25 | 1971 | 38 | coastal plain | 80 | | | | Schweinsburg, 1974; Hawkings, 1987 |
| 25 | Babbage River, YT | 69.05 | 138.25 | 1974 | 40 | coastal plain | 156 | | | | Koski, 1975; Hawkings, 1987 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | tussocky tundra (t.t.) | 19.8 | | 149.3 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | dry sedge | 45.1 | | 195.1 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | site 1 all habitats coastal | 54.2 | | 236 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | wet sedge | 45.1 | | 270.7 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | wet sedge/patterned | 108.4 | | 252.5 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | site 2 all habitats coastal | 50 | | 258.7 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | t.t. patterned | 84 | | 238.9 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | shrub | 13.4 | | 262.4 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | site 3 all habitats coastal | 65 | | 237.2 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | site 4 all habitats inland | 10.6 | | 211.8 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | graminoid/d.s. | 17.6 | | 222.2 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | d.s. (patterned) | | | 276 | | Dickson, 1985 |
| 26 | King Point, YT | 69.06 | 137.58 | 1981 | | dwarf shrub (d.s.) | 10.4 | | 226.4 | | Dickson, 1985 |
| 27 | King Pt, Stokes Pt, Phillips Bay | 69.06 | 137.58 | 1981 | 367 | coastal plain | 40.9 | | | | Dickson, 1985; Hawkings, 1987 |
| 27 | King Pt, Stokes Pt, Phillips Bay | 69.06 | 137.58 | 1983 | 878 | | 91.7 | | | | Dickson, 1985; Hawkings, 1987 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 195 | low-centred polygons (veg) | | 139 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 402 | low-centred polygons (unveg) | | 91 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 123 | levees | | 80 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 85 | uplands | | 21 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 30 | other | | 27 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1985 | 835 | total | | 91 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 134 | low-centred polygons (veg) | | 110 | | | Dickson et al., 1989 |

TABLE 10. Breeding densities of shorebirds and other birds at various arctic locations – *continued*:

| No. | Location | Lat. | Long. | Year | ha | Habitat | Shorebirds | | All birds | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | birds/km² | pairs/km² | birds/km² | pairs/km² | |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 804 | total | | 43 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 29 | other | | 10 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 92 | uplands | | 11 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 445 | low-centred polygons (unveg) | | 33 | | | Dickson et al., 1989 |
| 28 | Mackenzie Delta, NWT | 69.22 | 134.55 | 1986 | 104 | levees | | 34 | | | Dickson et al., 1989 |
| 29 | Firth River, YT | 69.23 | 139.23 | 1971 | 38 | coastal plain | 71 | | | | Schweinsburg, 1974; Hawkings, 1987 |
| 30 | Firth River, YT | 69.23 | 139.23 | 1974 | 32 | coastal plain | 86 | | | | Koski, 1975; Hawkings, 1987 |
| 31 | Igloolik, NWT | 69.24 | 81.49 | 1985 | 1000 | wet meadow 65%, Dryas 35% | | 10.2 | | 28.5 | Forbes et al., 1992 |
| 32 | Nunaluk Spit, YT | 69.36 | 139.45 | 1971 | 58 | coastal plain | 16 | | | | Schweinsburg, 1974; Hawkings, 1987 |
| 33 | Firth River, YT | 69.37 | 139.22 | 1972 | 31.4 | sedge meadow | 19.3 | | 255.2 | | Gunn et al., 1974 |
| 33 | Firth River, YT | 69.37 | 139.22 | 1973 | 31.4 | sedge meadow | 202.3 | | 699.2 | | Gunn et al., 1974 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1981 | 100 | coastal tundra | 156.1 | | 276 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1982 | 100 | coastal tundra | 142.4 | | 241.8 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1984 | 100 | coastal tundra | 106.3 | | 216.5 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1986 | 100 | coastal tundra | 86.9 | | 161.5 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1987 | 100 | coastal tundra | 110 | | 165.8 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1988 | 100 | coastal tundra | 122.6 | | 216.5 | | TERA ,1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1989 | 100 | coastal tundra | 91.8 | | 144.5 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1990 | 100 | coastal tundra | 192.9 | | 275 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1991 | 100 | coastal tundra | 100.1 | | 174.5 | | TERA, 1993; Troy, 1996 |
| 34 | Prudhoe Bay, AK | 69.41 | 148.42 | 1992 | 100 | coastal tundra | 120.7 | | 186.5 | | TERA, 1993; Troy, 1996 |
| 35 | Prudhoe Bay, AK | 69.41 | 148.42 | 1979 | 100 | inland coastal tundra | | 28 | | 72 | Jones et al., 1980 |
| 36 | Deadhorse, AK | 70.05 | 148.3 | 1979 | 100 | wet coastal plain tundra | | 74 | | 126 | Hohenberger et al,. 1980 |
| 37 | Atkasook, AK | 70.27 | 157.19 | 1979 | 25 | arctic low foothills tundra | | 92 | | 158 | Myers et al., 1980c |
| 38 | Barrow, AK | 71.18 | 156.42 | 1979 | 33 | wet coastal plain tundra | | 113 | | 164 | Myers et al., 1980d |
| 39 | Barrow, AK | 71.18 | 156.43 | 1979 | 36 | wet coastal plain tundra | | 88 | | 171 | Myers et al., 1980b |
| 40 | Barrow, AK | 71.18 | 156.38 | 1979 | 25 | wet coastal plain tundra | | 74 | | 162 | Myers et al., 1980a |
| 41 | Prince of Wales Island, NWT | 72.4 | 99 | 1959 | | all habitats | 7.72 | | | | Manning and Macpherson, 1961 |
| 42 | Cresswell Bay, NWT | 72.4 | 93.3 | 1975 | | well-vegetated coastal tundra | 37.1 | | | | Alliston et al., 1976 |
| 42 | Cresswell Bay, NWT | 72.4 | 93.3 | 1975 | | thermokarst | 63.36 | | | | Alliston et al., 1976 |
| 42 | Cresswell Bay, NWT | 72.4 | 93.3 | 1975 | | thermokarst | 34.5 | | | | Alliston et al., 1976 |
| 43 | Banks Island, NWT | 72.45 | 121.3 | 1953 | | all habitats | 5.29 | | | | Manning et al., 1956 |
| 44 | Truelove Lowland, NWT | 75.33 | 84.4 | 1971 | | | 5.53 | | 31.12 | | Pattie, 1990 (postbreeding densities) |
| 44 | Truelove Lowland, NWT | 75.33 | 84.4 | 1971 | | coastal lowland oasis | 2.3 | | 24.4 | | Pattie, 1977 |
| 44 | Truelove Lowland, NWT | 75.33 | 84.4 | 1972 | | | 0.19 | | 6.6 | | Pattie, 1977 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1970 | 100 | sedge-moss meadow | | 8 | | 12 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1971 | 100 | sedge-moss meadow | | 15 | | 18 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1972 | 100 | sedge-moss meadow | | 3 | | 3 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1973 | 100 | sedge-moss meadow | | 14 | | 14 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1971 | 100 | sedge-moss meadow | | 8.25 | | 11.75 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1970 | 200 | dry upland | | 2 | | 5 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1971 | 200 | dry upland | | 2.5 | | 5 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1972 | 200 | dry upland | | 0 | | 2.5 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1973 | 200 | dry upland | | 2 | | 4.5 | Mayfield, 1983 |
| 45 | Polar Bear Pass, NWT | 75.44 | 98.25 | 1971 | 200 | dry upland | | 1.625 | | 4.25 | Mayfield, 1983 |
| 46 | Isachsen, NWT | 78.47 | 103.31 | 1960 | 3885 | mostly unvegetated | | 0.08 | | 1.9 | Savile, 1961 |
| 47 | Alexandra Fjord, NWT | 78.53 | 75.55 | 1980 | 1200 | arctic oasis lowland | 1 | | 12.8 | | Freedman and Svoboda, 1982; Freedman, 1994 |
| 47 | Alexandra Fjord, NWT | 78.53 | 75.55 | 1981 | 1200 | arctic oasis lowland | 0.9 | | 13.2 | | Freedman, 1994 |
| 47 | Alexandra Fjord, NWT | 78.53 | 75.55 | 1981 | 1200 | arctic oasis lowland | 0.8 | | 13.7 | | Freedman, 1994 |
| 47 | Alexandra Fjord, NWT | 78.53 | 75.55 | 1982 | 1200 | arctic oasis lowland | 0.8 | | 13.2 | | Freedman, 1994 |
| 48 | Lake Hazen, NWT | 81.49 | 71.18 | 1962 | 2227 | sparsely vegetated tundra | | 2.4 | | 4.8 | Savile and Oliver, 1964 |

present (e.g., Rannie, 1986; Edlund and Alt, 1989), the broad similarity or equivalence in habitat types across the Arctic may result from the widespread distribution and wide ecological tolerance of many vascular plant species.

### *Accuracy of Population Estimates of Shorebirds on Prince Charles Island*

The population estimates for Prince Charles Island should be regarded as approximate, since a number of sources of error and uncertainty are involved in their calculation. Standard errors in the individual estimates of habitat-specific densities (Table 4) are fairly high, especially for species breeding at low densities, but appear similar to those indicated by Gratto-Trevor (1996) for shorebirds in the Mackenzie Delta, and are likely to be typical for this type of survey. Gratto-Trevor (1994) and Pattie (1990) noted moderate reproducibility of results during repeated surveys within the same season, with identical numbers of birds being observed in about half the plots surveyed in the Mackenzie Delta (though overall density estimates remained similar for different habitats) (Gratto-Trevor, 1994), and rather wider variation occurring in plots on Devon Island (Pattie, 1990). Many factors can influence numbers of birds found during repeated surveys within the same season, including nest loss, presence of wandering birds, and differences in behaviour of birds under different weather conditions, between sexes, and at different stages of incubation. Detectability may vary between different species depending on breeding system and behaviour: Pattie (1990) reported high coefficients of detectability (CD) for ruddy turnstones and the two species of plovers observed on Prince Charles Island (0.9), while the CD for white-rumped sandpipers was lower (0.5).

Variability in population levels of different shorebird species can also be high between years, varying from a factor of 2–3 times to one as high as 25–30 times at sites in the western and eastern Arctic (Pitelka, 1959; Norton,1973; Dickson et al., 1989; Pattie, 1990; TERA, 1993; Gratto-Trevor, 1994; Troy, 1996). Most species with a "conservative" breeding system (Pitelka et al., 1974), in which the two members of the pair tend to form monogamous relationships and share nesting duties, return to the same area to breed from year to year, and population densities can be fairly stable between years: in species with more opportunistic or promiscuous systems, birds often do not return to the same area from year to year, and population levels may vary widely between years. The ruddy turnstone exhibits a high degree of site faithfulness in Foxe Basin and on Ellesmere Island (Morrison, unpubl. results), whereas species such as red phalaropes, white-rumped sandpipers, and pectoral sandpipers can show very large local variations in population in different parts of the Arctic (Pitelka, 1959; Pattie, 1990).

All the above factors make it difficult to obtain reliable population estimates over wide areas. On Prince Charles Island, the standard error varied between about 15% and 30% of the population estimate for the more common or numerous species, rising to well over 100% of the estimate for the less abundant species (Table 4). While these error terms may seem high, they are realistic given the accuracy of measurement that can be achieved.

### *Effects of Modelling Densities*

The modelling procedures employed appeared to improve the realism of the distribution of the various species, and hence their population estimates. Particularly noticeable was the reduction observed in habitats designated as potential breeding areas in the interior of the island on the very barren gravel and rock uplands. Proximity analyses appeared successful in delineating combinations of habitats needed by shorebirds for breeding and, with distance modelling, resulted in reductions of 20–53% in estimates of populations of black-bellied plovers, ruddy turnstones, semipalmated sandpipers, and red phalaropes, compared to simple extrapolations based on mean densities. Proximity analyses were considered useful for black-bellied plovers and semipalmated sandpipers, despite small sample sizes ($n = 7$ for both), since they were based on statistically significant results and led to conservative population estimates. Modelling altered the population estimate for white-rumped sandpipers least amongst the shorebirds, perhaps reflecting their wide use of graminoid and other habitats throughout the island.

### *Population Sizes of Shorebirds on Prince Charles Island*

The population estimates for the six species of shorebirds breeding on Prince Charles Island varied from less than 1800 pairs (approximately 3500 birds) for the lesser golden-plover to over 140 000 pairs (approximately 283 000 birds) for the red phalarope (Tables 4 and 10). The importance of the island as a breeding area may be assessed both regionally in comparison with other parts of the Arctic and generally in comparison with current estimates of overall population sizes for the various species. Such assessments can only be crude, as little well-documented information is available for either comparison (Morrison et al., 1994; Rose and Scott, 1994).

Shorebird population estimates that have been attempted for other parts of the Canadian Arctic, ranging in area from 288 $km^2$ to 63 714 $km^2$, are shown in Table 11. They indicate that Prince Charles Island is of considerable importance for breeding shorebirds. The overall density of shorebirds on Prince Charles Island was the highest recorded at the nine locations, and the island supported larger estimated populations of red phalaropes and especially white-rumped sandpipers than any of the other areas considered. Prince Charles Island supported a higher overall population of shorebirds than the similarly-sized Rasmussen Lowlands, though the latter supported a much wider range of species.

Few reliable estimates of overall population size exist for the 40 species of shorebirds found breeding in Canada (Morrison et al., 1994) against which to compare estimated populations breeding on Prince Charles Island. For semipalmated sandpipers, the estimate of 20 000 breeding birds would approach about 1% of the 2–5 million estimated total population (Morrison et al., 1994), enough to qualify the area as being of international importance according to the criteria of the Ramsar Convention (Rose and Scott, 1994). Estimated breeding populations of black-bellied plovers and lesser golden-plovers would reach about 10% of their total estimated populations, while estimates for ruddy turnstones (about 23 500) and red phalaropes (over 280 000) form even higher percentages of the total estimated populations (25 000 to 100 000 and 100 000 to 1 000 000, respectively; Morrison et al., 1994; Rose and Scott, 1994). For white-rumped sandpipers, breeding population estimates on Prince Charles Island (280 000) far exceed the numbers that have been counted on wintering areas (73 000; Morrison and Ross, 1989). Breeding densities of some species of shorebirds, such as the white-rumped sandpiper, can vary widely from year to year, and reassessment of breeding densities of this species on Prince Charles Island (and elsewhere in the Arctic) over a number of years, as well as determining the extent to which densities vary in broad areas of homogeneous habitat (e.g., grasslands) within a single year, would be useful in refining population estimates. In general, the present results indicate that Prince Charles Island holds internationally significant numbers of breeding shorebirds.

TABLE 11. Estimates of shorebird populations at various locations in the Canadian Arctic. For species abbreviations and names, see Appendix 1.

| | N. Twin Island | Belcher Islands | Prince Charles Island | Rasmussen Lowlands | Adelaide Peninsula | Mackenzie Delta (outer) | Prince of Wales Island | Cresswell Bay, Stanwell Fletcher Lake | Banks Island |
|---|---|---|---|---|---|---|---|---|---|
| Latitude | 53.18 | 56.12 | 67.47 | 68 | 68.15 | 69 | 72.4 | 72.4 | 72.45 |
| Longitude | 80 | 80 | 76.12 | 94 | 97.3 | 136.2 | 99 | 93.3 | 121.3 |
| Area (km$^2$) | 150 | 330 | 9948 | 9842 | 7770 | 4493 | 32375 | 288 | 63714 |
| BBPL | | | 7062 | 45600 | 5000 | | 35000 | 1893 | 45000 |
| LGPL | | + | 3452 | 37620 | 6000 | 1598 | + | 1059 | 15000 |
| SEPL | 1200 | 3000 | | | + | + | | | 6000 |
| KILL | 25 | | | | | | | | |
| WHIM | | | | | | 2578 | | | + |
| HUGO | | | | | | 5068 | | | |
| RUTU | | | 23442 | 7600 | + | | 20000 | 868 | 35000 |
| REKN | | | | | | | + | | |
| SAND | | | | | + | | 70000 | 1821 | 65000 |
| SESA | 2000 | 2000 | 19012 | 23560 | + | 6146 | | | 70000 |
| LESA | 500 | | | | | | | | |
| WRSA | | | 252324 | 67600 | + | | 15000 | 5738 | 25000 |
| BASA | | | | 9120 | 15000 | | 40000 | 243 | 25000 |
| PESA | | | | 44080 | 17000 | 1328 | + | | 14000 |
| PUSA | 100 | 4000 | | | | | | | + |
| DUNL | 150 | | | 12920 | | | | | + |
| STSA | | | | 1900 | | 6832 | | | |
| BBSA | | | | 4560 | | | | | 2000 |
| SBDO | 30 | | | | | | | | |
| LBDO | | | | | | 624 | | | |
| COSN | 30 | | | | | 35170 | | | |
| RNPH | 1000 | 300 | | 760 | | 61682 | | | + |
| REPH | | | 283198 | 212040 | 20000 | | 70000 | 3554 | 35000 |
| U-PLOV | | | | 1520 | | | | | |
| U-PHAL | | | | 1900 | | | | | |
| U? | | | | 24320 | | | | 251 | |
| TOTAL | 5035 | 9300 | 588490 | 495100 | 63000 | 121026 | 250000 | 15427 | 337000 |
| BIRDS per km$^2$ | 33.6 | 28.2 | 59.12 | 50.30 | 8.11 | 26.94 | 7.72 | 53.65 | 5.29 |
| Reference | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

References: 1. Manning, 1981; 2. Manning, 1976; 3. Present work; 4. McLaren et al., 1977; 5. Macpherson and Manning, 1959; 6. Gratto-Trevor, 1994; 7. Manning and Macpherson, 1961; 8. Alliston et al., 1976; 9. Manning et al., 1956.

*The Use of Remote Sensing in Evaluating Shorebird Breeding Habitats*

Remote sensing appears to be capable of producing useful results in assessing habitat and shorebird numbers in at least some areas if applied in a carefully controlled manner. For shorebird applications in non-Arctic areas, it has been used successfully for assessing numbers of breeding dunlins (*Calidris alpina*) in northern Scotland (Avery and Haines-Young, 1990), for assessing probability of nesting by curlews (*Numenius arquata*) in Scotland (Aspinall and Veitch, 1993), and for predicting bird numbers on coastal intertidal areas in the United Kingdom (Goss-Custard and Yates, 1992; Yates, 1995). In the Canadian Arctic, problems have been noted with accuracy of habitat identifications during classification of large areas (e.g., Dickson et al., 1989; Gratto-Trevor, 1996). Such problems can arise from various sources. The present approach of extracting maximum spectral information from the scene before aggregating into the final number of habitat classes, rather than allowing the computer to choose an intermediate number of groups during an unsupervised classification, may help in separating spectrally similar habitats. Choice of an appropriate date after the main melt and runoff have occurred may help minimize annual differences in wetness and maximize habitat differences resulting from growth of vegetation during the summer. Obtaining TM imagery on specific dates can be problematical, however, since acquisition is dependent on cloud-free conditions, which may occur infrequently in some parts of the Arctic. Development of methods based on or including radar imagery, which can be obtained through cloud cover, may be helpful. Finally, the most northerly parts of the Arctic cannot presently be mapped using TM methods, since coverage is not available beyond approximately 80˚N.

Mapping wildlife habitats over large areas of the Arctic would require constant ground truthing and recalibration of habitat classes in different regions. Differences in vegetation amount and type and in substrates would all lead to changes in spectral characteristics, as would variations in wetness, extent of vegetation growth, atmospheric conditions, and date of imagery acquisition. Thus, while the present results indicate that habitat classification can be successful on a regional basis, extension of the results over broader areas would require painstaking analysis to produce the reliability and accuracy required.

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## APPENDIX 1. SHOREBIRD SPECIES ABBREVIATIONS AND NAMES (SEE TABLE 11).

| | | |
|---|---|---|
| BBPL | Black-bellied plover | *Pluvialis squatarola* |
| LGPL | Lesser golden-plover | *Pluvialis dominica* |
| SEPL | Semipalmated plover | *Charadrius semipalmatus* |
| KILL | Killdeer | *Charadrius vociferus* |
| WHIM | Whimbrel | *Numenius phaeopus* |
| HUGO | Hudsonian godwit | *Limosa haemastica* |
| RUTU | Ruddy turnstone | *Arenaria interpres* |
| REKN | Red knot | *Calidris canutus* |
| SAND | Sanderling | *Calidris alba* |
| SESA | Semipalmated sandpiper | *Calidris pusilla* |
| LESA | Least sandpiper | *Calidris minutilla* |
| WRSA | White-rumped sandpiper | *Calidris fuscicollis* |
| BASA | Baird's sandpiper | *Calidris bairdii* |
| PESA | Pectoral sandpiper | *Calidris melanotos* |
| PUSA | Purple sandpiper | *Calidris maritima* |
| DUNL | Dunlin | *Calidris alpina* |
| STSA | Stilt sandpiper | *Calidris himantopus* |
| BBSA | Buff-breasted sandpiper | *Tryngites subruficollis* |
| SBDO | Short-billed dowitcher | *Limnodromus griseus* |
| LBDO | Long-billed dowitcher | *Limnodromus scolopaceus* |
| COSN | Common snipe | *Gallinago gallinago* |
| RNPH | Red-necked phalarope | *Phalaropus lobatus* |
| REPH | Red phalarope | *Phalaropus fulicaria* |
| U-PLOV | Unidentified plover species | |
| U-PHAL | Unidentified phalarope species | |
| U? | Unidentified shorebird species | |

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