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Polar Biology

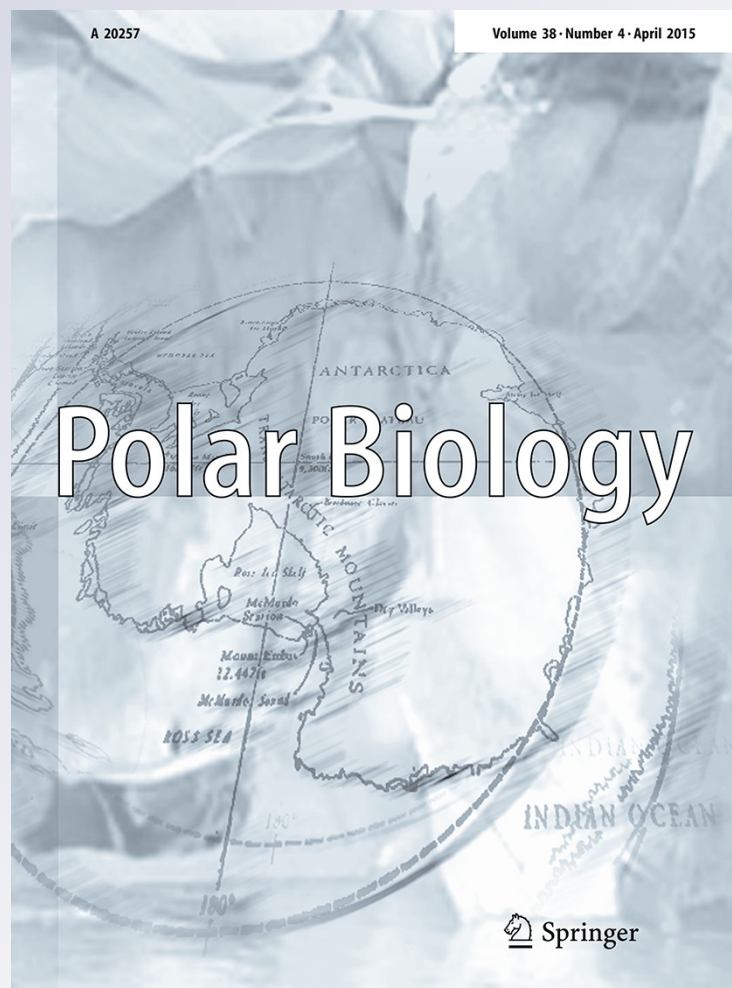
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Localized habitat change near Churchill, Manitoba and the decline of nesting Whimbrels (*Numenius phaeopus*)

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Abstract Whimbrels (*Numenius phaeopus*) are large shorebirds that breed in two geographically disjunct regions in the North American Subarctic and Arctic. Since the early 1970s, the nesting distribution of Whimbrels in the Subarctic near Churchill, Manitoba, Canada has changed, and an area of historic breeding importance was no longer used as nesting habitat in 2008. We compared aerial photography of the 2.55 km² area from 1973 to 1986, to high-resolution satellite imagery from 2006 to assess structural habitat change. Comparison of the three time-period imagery showed that over the 33-year span shrubs and trees increased in cover by 12.6 and 6.9 %, respectively, whereas other vegetation, including lichen, decreased by 19.1 %. This localized evidence of shrub and tree encroachment is accompanied by a decline in Whimbrel nesting densities from 17–19 pairs (max. 7.45 pairs/km²) in 1973 and 1974, to 1–2 pairs (max. 0.78 pairs/km²) in 2007, and 0 pairs in 2008. Change in vegetation structure has important implications for the long-term viability of Subarctic and Arctic breeding shorebird populations.

Keywords Whimbrel (*Numenius phaeopus*) · Shorebird · Subarctic · Shrub encroachment · Tundra reduction · Climate change

Introduction

Since the 1950s, the earth has warmed at a rate beyond documented natural variation (Le Treut et al. 2007). On land, there is evidence of a pan-Arctic change in vegetation, including increased shrub cover, tree line advancement, and decreased open tundra, wetland habitats and arctic ponds (Cornelissen et al. 2001; Smith et al. 2005; Riordan et al. 2006; Tape et al. 2006). Climate change scenarios predict that the amount of tundra habitat will shrink by 33–44 % by 2099 (Feng et al. 2012). Terrestrial changes such as shrub encroachment and tree line advancement could contribute to further climate warming through positive feedback processes (Chapin III et al. 2005; Sturm et al. 2005). These changes alter the structure and function of Subarctic and Arctic ecosystems with potentially severe consequences for biodiversity.

Lichen-heaths and wetlands of the Subarctic and Arctic are key breeding habitats for shorebirds (Donaldson et al. 2000; Meltotte et al. 2007), which have evolved to nest in open, mostly treeless landscapes (Henningsson and Alerstam 2005). Shorebirds undertake long-distance migrations to breed in the Subarctic and Arctic during the summers to capitalize on food availability, lowered competition, and predator and disease avoidance (McKinnon et al. 2012). Whimbrel (*Numenius phaeopus*) winter in scattered numbers from South Carolina on the Atlantic coast and southern Vancouver Island on the Pacific Coast, to as far south as the tip of South America, including Caribbean and other offshore islands, while breeding in southern and western Hudson Bay regions, and in Alaska, Yukon and the northwestern region of the Northwest Territories (Skeel and Mallory 1996). Data on bird species shifting their range to cooler isotherms are accumulating (Thomas and Lennon 1999; Austin and Rehfish 2005; Zuckerberg

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et al. 2009). In the Subarctic and Arctic, shorebird species ranges are generally hypothesized to shift northward with shifting vegetation. Therefore, species that breed at the highest latitudes will be squeezed between the advancing tree line and the Arctic Ocean, although the adaptive capabilities of species are not fully understood (Callaghan et al. 2005). In addition, the abundance and diversity of predators and parasites may increase, and Subarctic and Arctic species may be out-competed by southern counterparts (Hersteinsson and MacDonald 1992; Kutz et al. 2005; Hudson et al. 2006). Both the magnitude and rate of climate warming in northern breeding grounds are currently greater than that occurring in habitats occupied during other life stages of migrant shorebirds (Meehl et al. 2007), and the consequences of climate change constitute leading contemporary threats to shorebird populations (North American Bird Conservation Initiative Canada 2012).

Monitoring changing vegetation and shorebird habitat use is important for understanding localized and broad-scale responses to climate change, including the rate at which change is occurring and how populations are potentially responding. Limited, plot-based monitoring exists in the north, and remote sensing imagery is often too coarse to measure change at fine-scale, local levels. Near Churchill, MB, field observations showed that Whimbrels, although still common in the region, were no longer nesting in some areas where they were documented to be most common in the 1960s and 1970s (Skeel 1976; Jehl 2004).

During the 1970s and 1990s, Skeel (1976, 1983) and Lin (1997), respectively, published Whimbrel nesting distribution data in a hummock-bog study area, adjacent to the tree line, where they were historically most common, and nested in densities three to four times greater than in other habitats (Skeel 1983). The objective of our study was to investigate changes in habitat within a 2.55 km² area, which encompasses Skeel's (1976, 1983) hummock-bog study area, over three time periods using aerial photography and satellite imagery. We also discuss alternative hypotheses to explain the habitat change and decline of nesting Whimbrels in the same area from 1973 to 2008, including the effects of isostatic rebound, increased numbers of Canada Geese (*Branta canadensis*) and Common Ravens (*Corvus corax*), and the effect of the adjacent roads.

Materials and methods

Study site

Churchill, Manitoba, Canada (58°44'N, 94°4'W; Fig. 1) is located on the west coast of Hudson Bay at the mouth of the Churchill River and is considered part of the Hudson Plains ecozone, characterized by a Subarctic ecoclimate (Kottek et al. 2006). The Churchill region is a transition zone, with boreal forest to the south and tundra along the

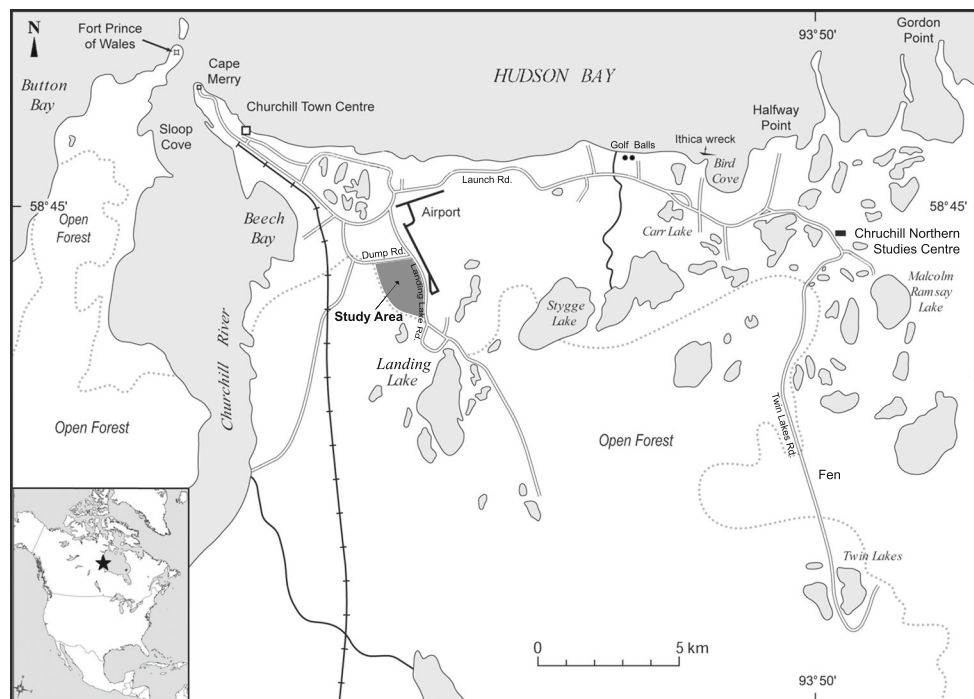


Fig. 1 Map of the Churchill, MB, Canada region courtesy of Pete Kershaw (modified) showing the location of the study area

coast and to the north. The soils currently experience continuous permafrost, resulting in poor drainage and numerous shallow ponds and lakes (Brown et al. 2014). The lands are flat lowlands (<50 m elevation) that are experiencing isostatic rebound at a rate of 0.90 m/century (Sella et al. 2007). The average annual, January and July temperatures are -6.5 , -26.7 and 12 °C, respectively (Environment Canada 2014). Winters are cold and long, and summers are brief, with June to September as the only months with average daily temperatures above 0 °C and with 0 cm average snow depth (Environment Canada 2014).

The 2.55 km^2 study area is characterized by hummock-bog habitat with some higher treed areas, bounded by gravel roads to the north and east and by forest to the south and west. This study area encompasses the historically important hummock-bog habitat described by Skeel (1983). The area is just west of the Churchill airport, which was built in 1942. The northern edge of the study area is approximately 3 km inland from the coast, and the western edge is approximately 5.5 km inland from the Churchill River. The main tree species are larch (*Larix laricina*), black spruce (*Picea mariana*) and white spruce (*Picea glauca*). The main shrub species are dwarf birch (*Betula glandulosa*) and Lapland rosebay (*Rhododendron lapponicum*). Northern bilberry (*Vaccinium uliginosum*), snow willow (*Salix reticulata*) and sweet gale (*Myrica gale*) and form a minor component of the understory.

Imagery acquisition and preparation

In July 1973, Skeel had the hummock-bog study area aerial photographed at 610 m in altitude at a scale of 1:8,000. Although the original prints were not located, Skeel provided contact prints containing 35 photos of the area with approximately 40 % overlap between photos. One contact sheet containing four photos was missing. The 1986 imagery consisted of 10, $9'' \times 9''$ aerial photographs with 60 % overlap purchased from the Manitoba Government. The photos were taken at a scale of 1:10,000 with a Zeiss Lameogon B lens, focal length 152.176 mm, on July 10, 1986. The 1973 and 1986 aerial photograph imagery were scanned on an Epson Expression 10000XL in professional mode at 1200 dpi in 8-bit grayscale resulting in 17 and 21 cm ground sample distance or resolution, respectively. Both the 1973 and 1986 photographs were mosaicked within PCI Geomatica V9.1 (PCI Geomatics Group 2003) using a minimum of eight or more well-distributed tie points per photo. High 60-cm resolution QuickBird satellite imagery (DigitalGlobe Inc. 2006) of the study area in 2006 was purchased from MDA Geospatial Services. The imagery was natural color, 3-band pansharpened, 8-bit, mosaicked, Standard Ortho-Ready product, taken at 17:46 on July 10,

2006, with zero cloud cover and a maximum off-nadir angle of 11.81° . This product is mapped to an average base elevation, but because the study area has extremely low relief this was not a concern. The 2006 imagery was georectified using rational polynomial coefficient (RPC) data provided by QuickBird and 40 field-acquired global positioning system (GPS) ground control points (GCPs). Based on the RPC and GCP processing, the very low topographic relief of the study area, the low off-nadir angle, and comparison with ground sampled distances, it is estimated that the rectified image had 5–10 m accuracy. A cubic convolution polynomial rectification was performed to rectify the 1973 and 1986 images to the 2006 image within PCI Geomatica producing three images of the same scale and projection. Although our positional accuracy is estimated at 5–10 m, the 1973 and 1986 images are rectified to the 2006 image. Having the 1973 and 1986 images rectified to the 2006 image limits potential sampling error associated with the estimated 5–10 m positional accuracy of the resulting 2006 image.

Habitat change

A shapefile of the area was created in ArcMap 9.2 (Environmental Systems Research Institute 2006) and used to clip the imagery from the three time periods. A 50×50 m grid was overlaid across the three images within ArcMap, and large ($\sim 100 \times 130$ cm) printouts were produced. Within every fourth grid cell ($n = 246$), percent cover of the following vegetation, water and substrate classifications were estimated to the nearest 0.5 % for all three time periods: Other Vegetation Including Lichen, Shrub, Tree, Mud, Water, Gravel, and No Data (outside of shapefile or part of missing imagery for 1973). Broad cover classifications were estimated, because vegetation structure was the primary interest and species level identifications were not possible. Although water and mud cover were estimated, their interpretation is unreliable as annual variation in precipitation may have been detected rather than a historical trend, and precipitation events prior to image capture can bias results. Furthermore, the two parameters are related to some unknown degree (i.e. if water in ponds is high, mud would correspondingly be lower). Estimates were made visually from the large-scale prints, using a stereoscope for the aerial photograph imagery, and on the computer within PCI Geomatica using the zoom function. In 2007 and 2008, we recorded GPS location and habitat class in areas of each of our classifications (Other Vegetation Including Lichen, Shrub, Tree, Mud, Water, and Gravel) to aid in the training of imagery interpretation to ensure classification accuracy. All classification was completed by one person.

We report percent cover for each class at each time period, the mean change in cover (calculated as the percent

cover of each cell on the more recent image minus the percent cover of each corresponding cell on the older image) and the 95 % confidence intervals of this change. The rates of averaged annual change between the time periods were also calculated as the difference between the newer and older image divided by the number of years between them.

Climate trends

Using climate data from Churchill A station (Environment Canada 2008) and General Linear Model analysis, we examined temporal trends of annual average temperature (°C) from 1970 to 2007 (complete 2008 data were unavailable), and growing degree days calculated as the cumulative mean daily temperature degrees above 0 °C from 1970 to 2008.

Nesting distribution and density

Fieldwork was conducted throughout a 75 km² area in the Churchill, MB region during the 2007 and 2008 breeding seasons (Ballantyne and Nol 2011), but for this paper, we concentrated search efforts for Whimbrel nests within the 2.55 km² study area described above. Nest site coordinates from 1973 were obtained from Skeel (1976), and from 1994 from Lin's (1997) field data (W. Lin, pers. comm. 2009). Nest sites and the areas surveyed were delineated on 1:50,000 digital National Topographic System maps (Natural Resources Canada 2007) within ArcMap 9.2 (Environmental Systems Research Institute 2006).

Results

Habitat change

Over the 33-year span of the three images, we documented significant increases in Shrub and Tree classifications, and a significant decrease in Other Vegetation Including Lichen (Table 1). The annual rate of change, adjusted for the length of the time period, of Tree cover increase was relatively even between the two time periods, while the rate of annual increase in Shrub cover more than doubled in the latter time period (Table 2; Fig. 2). Other Vegetation Including Lichen and Gravel decreases were relatively even between time periods. Changes in Mud and Water cover could not be reliably interpreted due to possible precipitation bias and the unknown degree to which the two are related.

Climate trends

From 1970 to 2007, the average annual temperature in Churchill significantly increased by 1.78 °C (average

Table 1 Percent cover classification averages and standard deviation (in parentheses) of six cover classes for 1973, 1986 and 2006 images ($n = 246$ grid cells)

Habitat cover class	1973	1986	2006
Other Vegetation Including Lichen	50.2 (23.3)	42.9 (23.8)	31.1 (22.5)
Shrub	5.1 (6.8)	7.6 (10.6)	17.7 (16.1)
Tree	3.4 (8.9)	5.9 (11.6)	10.3 (12.5)
Mud	1.2 (2.9)	1.4 (3.8)	6.5 (9.4)
Water	30.9 (24.2)	33.6 (27.1)	26.5 (25.4)
Gravel	3.4 (10.2)	3.1 (10.3)	2.3 (8.1)

temperature = $-102.702 + 0.048$ (year), $F_{1,36} = 5.85$, $P = 0.01$, $R^2 = 0.14$; Fig. 3a). Annual growing degree days (>0 °C) also increased significantly ($GDD = -13743.9 + 7.5$ (year), $F_{1,36} = 11.42$, $P < 0.01$, $R^2 = 0.24$; Fig. 3b). From 1970–2008, 285 growing degree days (>0 °C) were gained, which is the equivalent to that of an average summer month (June = 203.9, July = 382.6, August = 370.2).

Nesting distribution and density

Whimbrel nesting density in the study area during 2007 and 2008 was low in comparison with that reported by Skeel (1983) in 1973 and 1974, and by Lin (1997) in 1994–96 (Fig. 4). In the 1970s, Skeel (1983) reported 17–19 nesting pairs within our 2.55 km² study area (max. 7.45 pairs/km²), and in the 1990s, Lin (1997) reported markedly fewer, 5–7 nests (max. 2.75 pairs/km²). In 2007, only two nests, one of which was likely a re-nest, were found. In 2008 no Whimbrel nested in the area. In 2007 and 2008, five pairs nested in a 1.6 km² area of mixed sedge-meadow and lichen-heath tundra habitat just north of the study area, where Skeel (1976) had not reported any; however, Skeel did not search the area extensively (Fig. 4).

Discussion

Habitat and climate change

The increase in Shrub and Tree cover in our study area provides quantitative evidence of recent, localized changing Subarctic terrestrial environment near Churchill, MB. These habitat changes coincide with a warming trend and declining Whimbrel nesting densities in the area of historical nesting importance. The observed habitat change and warming trend add to growing evidence from Alaska (Suarez et al. 1999; Rupp et al. 2001; Tape et al. 2006), eastern Hudson Bay (Caccianiga and Payette 2006) and the

Table 2 Mean percent change in cover classes between newer and older images for each grid cell with 95 % CIs, and average annual change calculated as the mean percent cover change over period divided by the number of years within the period

Cover class	Mean cover change (%) over period			Annual change (%)		
	1973–1986	1986–2006	1973–2006	1973–1986	1986–2006	1973–2006
Other Vegetation Including Lichen	−7.26 (−9.81, −4.72)	−11.83 (−15.05, −8.62)	−19.10 (−22.49, −15.71)	−0.56	−0.59	−0.58
Shrub	2.52 (1.27, 3.77)	10.08 (8.02, 12.14)	12.60 (10.70, 14.51)	0.19	0.50	0.38
Tree	2.50 (1.60, 3.39)	4.38 (3.37, 5.39)	6.88 (5.66, 8.10)	0.19	0.22	0.21
Mud	0.12 (−0.44, 0.69)	5.11 (3.88, 6.34)	5.23 (4.03, 6.44)	0.01	0.26	0.16
Water	2.73 (0.28, 5.12)	−7.13 (−9.76, −4.49)	−4.40 (−7.03, −1.77)	0.21	−0.36	−0.13
Gravel	−0.32 (−0.99, 0.35)	−0.77 (−1.63, 0.09)	−1.09 (−1.96, −0.22)	−0.02	−0.04	−0.03

Bolded values indicate changes where the 95 % CIs do not overlap 0

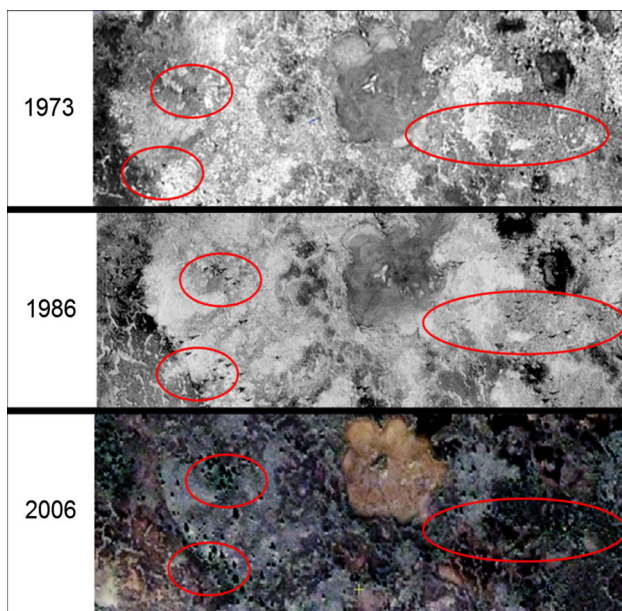


Fig. 2 1973, 1986 and 2006 imagery samples showing increased shrub and tree cover in the study area. Includes copyrighted material of the province of Manitoba and DigitalGlobe, Inc., all rights reserved

Holarctic (Epstein et al. 2013) documenting climate warming, shrub encroachment and tree line advancement.

In the Churchill region, Girardin et al. (2005) found that tree growth was strongly positively correlated with temperatures throughout June, July and August, the period when most annual growing degree days are accumulated. Historical notes and paleoecological studies also support the projections of vegetative response to climate. In Churchill, Samuel Hearne, a northern explorer (1745–1792), noted a major southward shift in the tree line due to cooled climate at the end of Little Ice Age (1450–1760; Hearne 1795). Tree ring chronological studies also show that tree growth covaries with temperature proximately and that the tree line covaries with climate over larger time scales, showing that tundra habitats were invaded by boreal trees in the period of climate warming following the

Little Ice Age (MacDonald et al. 2000; Pellatt et al. 2000; Kullman 2002). In tundra of Northeastern Siberia, the growth of two species of shrubs studied were both found to be most influenced by early-summer temperatures, with wider growth rings correlated to higher early summer temperatures (Blok et al. 2011). Shrub and tree growth are also associated with positive feedback processes. Warming air temperatures result in warming soil temperatures and increased active layer depth, while shrubs and trees trap snow, insulating and increasing winter soil temperatures (Sturm et al. 2005). Furthermore, increased shrub and tree growth decreases the terrestrial albedo effect, which will further force climate warming (Chapin III et al. 2005).

The relationship between habitat and climate change is confounded by isostatic rebound in the Hudson Bay Lowlands (Sella et al. 2007). Part of the observed vegetation change is due to natural terrestrialization, as the land isostatically rebounds post-glacial retreat. The region experiences high rates of rebound, 0.90 m/century near Churchill (Sella et al. 2007). This rate is not projected to be overcome by sea level rise in the near future (Riley 2011). Between 1973 and 1986, the earlier time period of our study, the calculated annual increase for Shrub and Tree cover was 0.18 % each, with Other Vegetation Including Lichen decreasing by 0.52 %. Neither the average annual temperature nor growing degree days during the same time span showed a significant warming trend; these climate trends become significant when data span the longer time series (1970–2007/2008). The observed habitat change during the earlier period may be explained largely by isostatic rebound and associated terrestrialization processes. However, considering the recent rate of uplift is steady during our study period (Sella et al. 2007), and that the rate of increase in Shrub cover that we document in the latter period (1986–2006) was more than twice that of the earlier period (1973–1986), it is likely that climate warming is a primary contributor during the latter period. At a pan-Arctic scale, correlations between warming caused by

Fig. 3 Climate trends for Churchill A station (Environment Canada 2008).

a Average annual daily temperature ($^{\circ}\text{C}$) from 1970–2007 ($P = 0.01$).
b Cumulative annual growing degree days $>0^{\circ}\text{C}$ from 1970–2008 ($P < 0.01$)

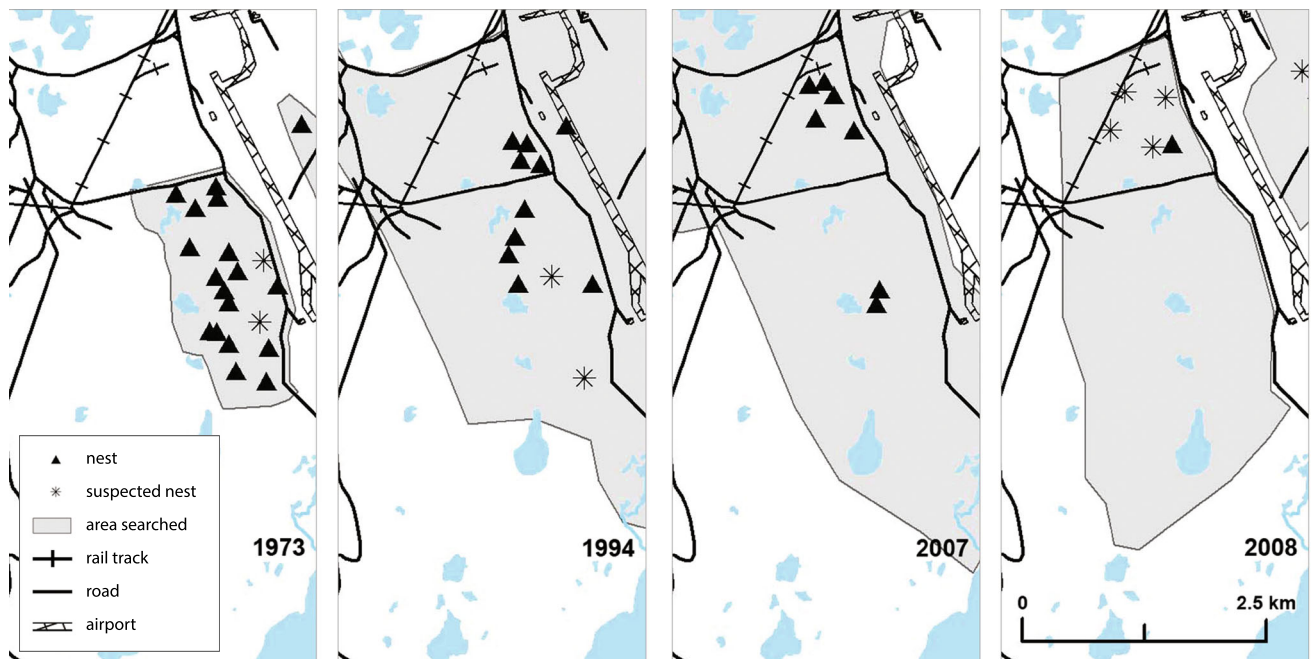
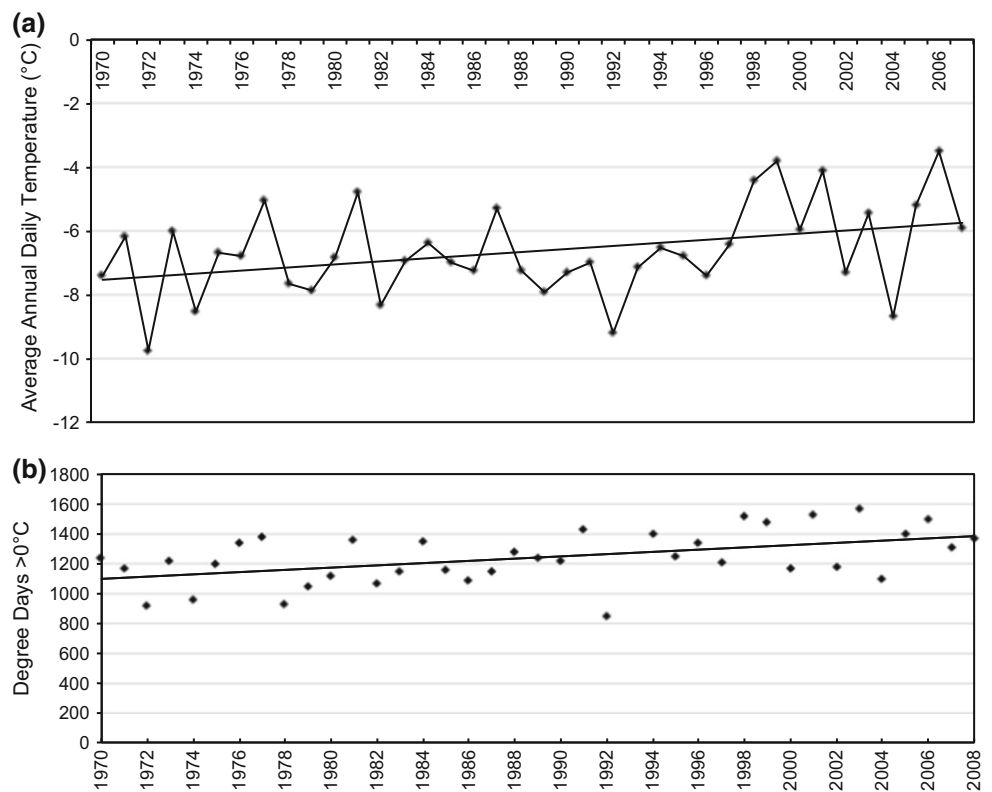


Fig. 4 Whimbrel (*Numenius phaeopus*) nest and suspected nest distribution and area searched in and near the study area in 1973 (Skeel 1976), 1994 (Lin 1997), 2007 and 2008 near Churchill, MB. Nesting distribution in 1974 (Skeel 1976) strongly resembles the 1973 distribution map provided. Likewise, nesting distribution in 1995 and

1996 (Lin unpubl. data) strongly resembles the 1994 distribution map. The area north of the east-west road bordering the study area was searched, but not intensively for nests by Skeel in 1973 and few Whimbrel were noted there (Skeel 2009, pers. comm.). Includes copyrighted material of Natural Resources Canada, all rights reserved

anthropogenic climate forcing and shrub and tree encroachment are reported (Kaplan and New 2006; Tape et al. 2006; Bogaert et al. 2007). Despite the unknown degree to which isostatic rebound and climate change are each contributing to habitat change, anthropogenic climate warming will increase the rate at which ecosystem changes occur, and considering the long-term nature of climate change, will affect these process for centuries to come (Solomon et al. 2009).

Roads can also alter habitat in Subarctic and Arctic environments. In a study in the Northwest Territories near a mine site (Male and Nol 2005), there was significantly higher soil moisture at sampling sites adjacent to roads than at reference sites but impacts of roads on snow–water equivalents were restricted to the first 20 m from the road. Additionally, there was no significant impact of roads on the composition of shrubs, forbs or lichens (Male and Nol 2005). The roads bounding our study area were built prior to the 1970s and the habitat changes documented occur throughout the 2.55 km² study area, with the exception of Gravel that decreased slightly adjacent to the roads.

Nesting habitat and biological factors

In the mid-1970s, Whimbrels nested within our study area at some of the highest densities ever reported for this species in North America (Skeel 1983). In 2007, only one pair, and in 2008, no pairs nested in the area; however, Whimbrels are still present outside of this study area and nest commonly on hummocks and ridges, and in habitat dominated by sedge and standing water, or lichen and *Dryas* heath, while avoiding shrubby and treed areas (Skeel 1983; Ballantyne and Nol 2011). In our previous study, no Whimbrel nested in areas with >76 trees within 30 m of a nest site, and only one pair (out of 44 sampled) nested in an area with >38 trees within 30 m of a nest site. Similarly, no Whimbrel nested in areas with >17.5 % tall shrub cover (within a 150 m radius circle centered on the nest) while most (41/44 = 93.2 %) nested in areas with <10 % tall shrub cover (Ballantyne and Nol 2011). The overall percent cover of shrubs in the 2006 image of the study area (17.7 %) just exceeds this apparent threshold. Whimbrels and other shorebirds are believed to have evolved to use open habitat types that allow visual predator detection (Götmark et al. 1995). Trees also provide more perches and nesting habitat for potential avian predators such as Common Ravens (*C. corax*) that commonly prey on Whimbrel eggs and young in the Churchill region (Ballantyne and Nol 2011).

Nesting habitat use data, coupled with the correlation between shrub and tree encroachment and decreased Whimbrel nesting densities in the study area, are suggestive, but does not necessarily imply causality. Other biological changes have also occurred in the study area during the 33-year span: both numbers of grazing and nesting Canada Geese (*B. canadensis*)

and Common Ravens (*C. corax*), a main egg predator, have increased. In the early 1930s, Taverner and Sutton (1934) wrote that Canada Geese were common transients that bred sparingly in the Churchill region. Of Common Ravens, they wrote that they were not a common permanent resident, but that they likely nested in the vicinity. Neither Canada Geese nor Common Ravens were common in the study area in the 1970s (Skeel 2009, pers. comm.). Currently, nesting Canada Geese are abundant in the study area, and migrating geese also use the area for grazing. Canada Geese uproot roots and rhizomes and pull shoots of graminoids, resulting in lower graminoid cover and areas denuded of vegetation, which in turn, may increase pond temperature and evapotranspiration (Abraham and Jefferies 1997). These habitat changes as a result of arctic geese foraging have primarily been documented for supratidal marshes, not hummock-bog habitat, and are associated with a decrease, rather than an increase in shrub cover (Peterson et al. 2013). In addition to the habitat change that they can cause, Canada Geese that arrive and nest earlier than Whimbrels may also take the suitable nesting sites on top of hummocks and ridges. Data on the foraging effects of geese and reliably interpreted Mud cover data within the study area, along with a possible mud cover threshold for nesting Whimbrel would have helped to determine what effect geese had and a possible other dimension of habitat suitability for nesting Whimbrel. Data on hummock and ridge availability on Whimbrel arrival would aid in determining whether Canada Goose nesting abundance also explains the decline in nesting Whimbrel.

In 2007 and 2008, we recorded Whimbrels nesting in a fairly high density (~3 pairs/km²) in a small area (~1.62 km²) just north of Skeel's main study area (Fig. 4). This area of mixed sedge-meadow and lichen-heath tundra habitat is comparatively more open with less shrub, tree and mud cover. In 2007 and 2008, the area also had fewer nesting Canada Geese; however, a pair of Common Ravens frequented both areas. The current use of the area just north of the study area, and presence of Common Ravens in both areas provides support for the hypothesis that Whimbrels moved out of the area of interest because of vegetation changes, increasing numbers of Canada Geese, or a combination of these factors.

Scenarios predicting the reduction of tundra ecosystems, the encroachment of shrubs, the advancement of tree lines, as well as the drying of Arctic and Subarctic ponds will result in decreased nesting habitat for Whimbrels and many other shorebird species across the Hudson Bay Lowlands, an important shorebird nursery area (Abraham and Keddy 2005). Given the encroachment of shrubs and trees documented here, data on Whimbrel nesting habitat (Ballantyne and Nol 2011), and the decline in nesting density of Whimbrels in the area of interest, habitat change and drivers such as climate change, should be considered as hypotheses when investigating distribution changes and shorebird declines.

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