WHIMBREL (*Numenius phaeopus*) NESTING HABITAT ASSOCIATIONS, ALTERED DISTRIBUTION, AND HABITAT CHANGE IN CHURCHILL, MANITOBA, CANADA

A Thesis Submitted to the Committee on Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in the Faculty of Arts and Sciences

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ABSTRACT

Whimbrel (*Numenius phaeopus*) nesting habitat associations, altered distribution, and habitat change in Churchill, Manitoba, Canada

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I documented Whimbrel nesting habitat at two spatial scales, hatch success, altered nesting distribution, and habitat change near Churchill, Manitoba, Canada. Whimbrels occupied mesohabitat distinguished either by high percent cover of (1) lichen, or (2) standing water and sedge. Shrubby and treed habitats were avoided. Hatching success using the logistic-exposure method was 26% in 2007, and 14% in 2008. These success rates are lower than previously reported. Current nesting distribution contrasts that reported from the1930s-mid 1970s, but resembles the distribution reported in the 1990s, with much lower use of hummock-bogs adjacent to tree lines. I compared 1973 and 1986 low-altitude aerial photography, and 2006 high-resolution satellite imagery of a 2.55km² hummock-bog, which has experienced a drastic decline in nesting Whimbrels. Shrub and tree cover have increased by 12.6% and 6.9%, and water and other vegetative cover have decreased by 4.4% and 19.1% respectively.

Keywords: Whimbrel, *Numenius phaeopus*, shorebird, nesting habitat, breeding habitat, distribution change, shifted distribution, hatch success, habitat change, shrub encroachment, tree line advancement, tundra reduction, wetland drying, climate change, climate warming, sub-Arctic, Churchill, Manitoba

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Chapter 1: General Introduction

Climate Change Implications for Sub-Arctic and Arctic Breeding Shorebirds

Warming of the Earth's climate system beyond natural variation is unequivocal (IPCC 2007a). Globally averaged air and water temperatures from 1850 to 2001 have increased 0.8°C (Brohan et al. 2006). Warming over the last 50 years has been almost double that of the last 100 years, and the most recent decade has been the warmest in instrumental record dating back to 1850 (IPCC 2007b, WMO 2008). The consequences will be nuanced, complex and extensive, altering air and ocean currents, weather patterns, and hydrological, carbon and nutrient cycles.

The Arctic is especially vulnerable to climate warming, and has warmed at double the global rate (IPCC 2007c). Air temperatures for extensive Arctic areas have risen by up to 5°C (IPCC 2007c). Arctic spring and winter temperatures have risen by approximately 1°C per decade since 1980 (McBean et al. 2005). A number of positive feedback loops such as the albedo effects of snow, ice, and vegetation, increased decomposition and carbon release, and the relationships between permafrost thaw, shrub growth, and snow trapping are exacerbating anthropogenic climate forcing, and its effects (Sturm et al. 2001, Liston et al. 2002, Chapin et al. 2005, Foley 2005, Lawrence and Slater 2005, Sturm et al. 2005a, Sturm et al. 2005b, Aerts et al. 2006). Changes such as loss of sea ice extent, reduction of snow cover, sea level rise, permafrost thawing, drying of wetlands, the northward migration of vegetation and associated communities, increased shrub and tree cover, the reduction in open lichen-heath and sedge-meadow tundra habitats, phenological changes, and altered parasite-host relationships are expected for sub-Arctic and Arctic regions (Michener et al. 1997, Piersma 1997, Holmgren et al. 2001, Kutz et al. 2005, Hudson et al. 2006, Kaplan and New 2006, IPCC 2007b).

Migratory shorebirds (Suborder Charadrii) are a dominant component of high latitude, lowland ecosystems in the spring and summer (Meltofte et al. 2007). Scenarios predicting drying of wetlands and reductions of open tundra will result in decreased nesting habitat for this bird community. Due to the rate of change and the life history attributes of birds, relocation rather than adaptation is likely (Callaghan et al. 2004). Longer northward migrations could cause greater physiological stress and less time to rear young in an already brief breeding season. For those species already migrating to and breeding in high latitude environments adjacent to Artic ocean waters, it will not be possible to shift further north. For shorebirds nesting in the sub-Arctic regions, similar, productive wetlands may not exist further north. Fossil fuel, mineral extraction, and hydrological development in the north will also affect shorebird breeding habitat (Pirie 2008). Furthermore, as sea ice extent decreases, the north may become more developed due to increased accessibility to, and presence of the shipping industry. In addition to breeding habitat reduction, prey and predator communities will be altered (Corcoran et al. 2009), and phenological changes may lead to mistiming between food availability and migration and/or nesting activities (Visser et al. 2004). Climate change will affect shorebirds throughout the annual life cycle. Increased storm frequency, changes in key foraging areas due to altered ocean currents and ocean acidification, and inundation of coastal habitat due to sea level rise will affect shorebirds during migration and nonbreeding stages (Michener et al. 1997, Gough 1998, Holmgren et al. 2001, Galbraith et al. 2002, Durell et al. 2006, IPCC 2007b).

Shorebirds as a group are already a conservation concern due to broad population declines, their reliance on multiple wetland habitats for which there have already been extensive loss and development, highly migratory behaviours, slow reproductive rates, and for some species low nest success (Bildstein et al. 1991, Donaldson et al. 2000, Piersma and Baker 2000, Brown et al. 2001). Seventy-three percent of Atlantic migratory shorebird species (Bart et al. 2007), over sixty percent of North American shorebird species (Morrison et al. 2006), and forty-eight percent of known shorebird populations worldwide are undergoing declines (Stroud et al. 2006).

Waders, especially large waders, have life history traits (e.g. bottlenecked migratory and wintering behaviour, reliance on multiple wetland habitats, slow reproductive rate, low nest success, and larger body size that appeals to harvesters), which make populations vulnerable to declines in adult survival, and in some circumstances to rapid population declines. The International Wader Study Group (2003) advise that "early warning" monitoring, integrated with demographic data are needed for conservation. Unfortunately, local breeding studies are rarely the long-term initiatives needed to capture changes in demographic parameters necessary to determine population trajectories. Thus, this group of birds may be particularly vulnerable to climate change (Meltofte et al. 2007), and is worthy of study.

The Hudson Bay Lowlands and the Churchill, Manitoba Region

The Hudson Bay Lowlands, covering 373 000km², or 3.7% of Canada, comprise the largest wetland in North America, the second largest peatland in the world, and the third largest wetland in the world following the wetlands of West Siberia and the Amazon (Abraham and Keddy 2005). The lowlands play a significant role in water filtration, and water and carbon storage. In addition, the Hudson Bay Lowlands provide critical nesting habitat for shorebirds and waterfowl (Abraham and Keddy 2005). Many birds undertake some of the largest migrations known for any animal group, over several thousands of kilometers, to nesting grounds in this region.

Churchill, Manitoba (58° 44' N, 94° 4' W, 28.7m) is situated on the western coast of Hudson Bay at the mouth of the Churchill River. The Churchill region is a transition zone between boreal forest to the south and tundra along the coast and to the north. The soils experience continuous permafrost resulting in poor drainage and numerous shallow ponds and lakes. Summers are brief, with an average July temperature of 12°C, and winters are cold and long, with an average January temperature of -26.7°C (Environment Canada 2008b, a). Shorebird habitat in the Churchill region includes sedge-meadows, fens, hummock-bogs, and lichen-heaths. Locally breeding shorebirds include the American Golden Plover (*Pluvialis dominica*), Semipalmated Plover (*Charadrius*) semipalmatus), Killdeer (Charadrius vociferus), Lesser Yellowleg (Tringa flavipes), Whimbrel (Numenius phaeopus), Hudsonian Godwit (Limosa haemastica), Least Sandpiper (Calidris minutilla), Dunlin (Calidris alpina), Stilt Sandpiper (Calidris himantopus), Short-billed Dowitcher (Limnodromus griseus), Wilson's Snipe (Gallinago gallinago), Red-necked Phalarope (Phalaropus lobatus), and previously the Semipalmated Sandpiper (Calidris pusilla) (Jehl 2004, Jehl 2007).

Focal Species: Whimbrel (Numenius phaeopus)

The Whimbrel (*Numenius phaeopus*, Linnaeus 1758) is one of eight shorebird species in the genus *Numenius*, collectively referred to as curlews, which are the longest billed and longest legged of the Scolopacidae family (del Hoyo et al. 1996). The

Whimbrel is the widest ranging curlew species, and the only one that nests in both the Nearctic and Palearctic (Figure 1.1 and 1.2) (Skeel and Mallory 1996). Globally, four to six subspecies of Whimbrels have been recognized (del Hoyo et al. 1996, Skeel and Mallory 1996, Endelmoer and Roselaar 1998); however, recent genetic and satellite transmitter research are providing new insights into the composition of populations and subspecies (Watts and Truitt 2008a, Küpper et al. in press). Until recently it was thought that two geographically distinct subspecies existed within North America, although breeding habitat ranges need delineation (Figure 1.2) (Skeel and Mallory 1996). N. p. hudsonicus was thought to breed in the Hudson Bay Lowlands and Southampton Island, NU, and to winter along coasts, coastal islands, and major rivers from the southern Atlantic states to southern South America. N. p. rufiventris was considered a separate, western subspecies breeding in northwest Alaska, the Yukon, and the Mackenzie Delta and Banks Islands, NWT, and wintering irregularly on the coasts of southern Vancouver Island, Oregon, and northern California, and regularly from San Francisco, California to the tip of South America (Skeel and Mallory 1996). In 2008 however, a Whimbrel outfitted with a satellite transmitter in Virginia, U.S.A. crossed the continent and bred in northwest Alaska (Watts and Truitt 2008a). This bird then undertook an elliptical migration and began its fall migration by flying west, and then south along the Pacific coast to Oregon before heading east again and crossing the Rocky Mountains. Future research will help to determine if this was an anomaly, what true migration patterns are, what population structure exists, and how much mixing occurs between populations. As this observation calls into doubt putative sub-species designation, I will omit sub-species designations for the remainder of this thesis.

Whimbrels nest singly or in loose aggregations on the ground in open areas such as wetland and lichen-heath tundra (Skeel and Mallory 1996). Usually a four egg clutch is laid, though smaller clutches occur (Pullianinen and Saari 1993, Skeel and Mallory 1996, Lin 1997), and very rarely, nests with more than four eggs are reported (Witherby et al. 1940, Grant 1991). The laying period averages 4-6 days, and the incubation period 24-26 days (Pullianinen and Saari 1993, Skeel and Mallory 1996, Lin 1997). Parents share incubation duties, but only females incubate at night (Lin 1997). Whimbrels aggressively defend their nests and young, driving off aerial predators such as Common Ravens (Corvus corax) even when several hundred meters away (but see Skeel 1976 for a report of no aggressive defence towards a Short-eared Owl (Asio flammeus)). Ground and aerial distraction and scolding displays are performed for ground predators, including humans when roughly within 150-200m of their nest (Skeel and Mallory 1996). Despite active nest defense, Whimbrels have the lowest hatch success, due to predation, of locally breeding shorebirds in the Churchill region (Jehl 2004), and have even lower fledging success (Lin 1997). Because Whimbrels' territories encompass those of other species, and because other species may benefit from their active nest defence, Whimbrels are considered an 'umbrella' species (Larsen and Moldsvor 1992). In northern Norway, Bartailed Godwits (*Limosa lapponica*), which rely on cryptic strategies rather than active defense, nested closer than expected by chance to Whimbrels (Larsen and Moldsvor 1992). However, in northern Manitoba, Whimbrels were observed depredating Willow Ptarmigan (Lagopus lagopus), Red-necked Phalarope (Phalaropus lobatus), and Savannah Sparrow (Passerculus sandwichensis) eggs (Rockwell et al. 2009).

North American Whimbrel populations appear to be in decline, giving this species a conservation status of high concern (Donaldson et al. 2000, Brown et al. 2001, U.S. Shorebird Conservation Plan 2004). Roughly estimated, the North American Whimbrel population is 66,000 birds; however estimates have low accuracy (Morrison et al. 2006). Migration data from eastern North America from 1974-1998, indicate a Whimbrel population trend of 0.9777, resulting in a 2.3% decline per year (Bart et al. 2007). Spring 2008 aerial counts along the Delmarva Peninsula, VA show a decline of approximately 50% compared to 1994-1996 data (Watts and Truitt 2008). In Wapusk National Park, Manitoba, located about 45km southeast of Churchill, the proportion of days Whimbrels were noted by field biologists from 1980-1996 has significantly decreased by an average of 2.9% per year (Rockwell et al. 2009). In the Churchill, Manitoba region, the exact Whimbrel population trend is unknown (Gratto-Trevor 1994), but Jehl and Lin (2001) suggest a probable decline. Ornithologists who have been visiting the Churchill region since the 1970s or earlier have anecdotally noted a spatial shift in nesting Whimbrel distribution (Gratto-Trevor 1994, Jehl 2004, Alison pers. comm. 2007, Koes pers. comm. 2008).

Whimbrels became protected in Canada and the U.S. by the Migratory Birds Convention Act in 1916, largely abating the early conservation threat of over-harvest, which contributed to the extinction of the Eskimo Curlew (*Numenius borealis*). Destruction, alteration, and degradation of important staging and non-breeding wetland habitats have been identified as leading contemporary threats (Skeel and Mallory 1996). Wetlands along migration routes, particularly along the U.S. coastline, are heavily populated, developed, and exploited by humans (Skeel and Mallory 1996). Delaware

Bay, in New Jersey and Delaware, is a critical shorebird staging site due largely to the large concentration of horsehoe crab (*Limulus polyphemus*) eggs that occur in late May, which shorebirds feed on to fuel their migration (Clark and Niles 1993). Over-harvest of adult horseshoe crabs for the conch and eel fisheries in Delaware Bay has been identified as a major cause contributing to the Red Knot (*Calidris canutus rufa*) population plummet (Sitters 2007). Winter roosting habitat, where Whimbrels congregate in large numbers, is also important. In Sanquianga National Park, Columbia over 900 Whimbrels have been recorded on mangrove islands (Johnston-González et al. 2006), and in the Pacific Ocean, Chiloé Island, Chile supports one of the largest non-breeding populations known of over 15,000 Whimbrels (Andres et al. in press). In addition to wetland development and the degradation of food resources, the accumulation of chemicals in inter-tidal habitats is also a problem in some areas (Senner 2007). More recently, alteration of sub-Arctic and Arctic breeding habitat in northern Canada and United States has become a primary conservation concern due to climate change and natural resource development.

Objectives

The objectives of my thesis are to (1) document current Whimbrel nesting habitat associations in Churchill, MB at two scales (mesohabitat and microhabitat), (2) compare current nesting distribution to historic nesting distribution, (3) determine hatch success and whether any nesting habitat characteristics measured influence daily nest survival rates (Chapter 2), and (4) use remote sensing imagery and techniques to determine whether the habitat in an area which has experienced a drastic reduction in nesting Whimbrels has changed since 1973 (Chapter 3).



Figure 1.1 Whimbrel world range map from the Handbook of the Birds of the World (del Hoyo et al. 1996) (colours modified).



Figure 1.2 Distribution of Whimbrel in North and Middle Americas from the Birds of North America (Skeel and Mallory 1996) (colours modified).

Chapter 2: Whimbrel (*Numenius phaeopus*) nesting habitat associations, and distribution change in Churchill, Manitoba, Canada

Abstract

I documented Whimbrel nesting habitat at two spatial scales, hatch success, and nesting distribution change near Churchill, Manitoba, Canada. Percent cover of dominant vegetation, water, and substrate classes were quantified at mesohabitat (within a 150m radius of nest), and microhabitat (within a 1m radius) scales. Mesohabitat analysis compared nesting areas and randomly-selected, available areas. Whimbrels occupied mesohabitat distinguished either by high percent cover of (1) lichen, or (2) standing water and graminoids (predominantly sedges (*Cyperaceae* spp.)). Shrubby and treed habitats were avoided. Microhabitat analyses compared nest and non-used sites within presumed territories. Nest sites within drier, lichen dominated habitat had higher percent cover of lichen and Dryas heath, and less concealing vegetation than non-nest sites within presumed territories, whereas nest sites within wetter, sedge dominated habitat had greater concealment values. Nests were commonly placed on hummocks and lichen ridges (30/44, 68%). Current geographical and habitat nesting distribution contrasts that reported in the 1930s-mid 1970s (Taverner and Sutton 1934, Grinnell and Palmer 1941, Allen 1945, Breckenridge et al. 1954, Jehl and Smith 1970, Skeel 1976, 1983, Jehl 2004), but resembles the distribution reported in the 1990s (Lin 1997), with much lower use of hummock-bogs adjacent to tree lines, and greater use of sedge-meadows, fen, and lichenheaths. Hatching success calculated with the logistic exposure model was 26% in 2007 and 14% in 2008, corresponding to daily nest survival rates of 0.947 and 0.926, respectively. These success rates are lower than previously reported.

Keywords: Whimbrel, *Numenius phaeopus*, shorebird, nesting habitat, breeding habitat, hatch success, distribution change, shifted distribution, sub-Arctic, Churchill, Manitoba

Introduction

Knowledge of a species' habitat requirements is of fundamental ecological interest. Habitat use can be defined and studied at varying scales. Johnson (1980) described habitat use as hierarchical in nature, ranging from the macro-scale, geographical range of a species (first order) to the micro-scale areas used for specific life history needs, such as nest placement or food acquisition (fourth order). The integration of these habitat scales provide the conditions and resources that support survival and produce occupancy (Block and Brennan 1993). At all hierarchical levels habitat use is typically non-random due largely to the non-random distribution of resources. Generally, it is thought that individuals use habitat and its resources in ways that support and maximize survival and reproduction (Fretwell and Lucas 1970). Disproportionate habitat use however does not necessarily imply habitat quality without supporting demographic data (Van Horne 1983). High densities in particular habitats may reflect a time lag between the past and current habitat quality, between years, or over a breeding season. Territoriality, site fidelity, natal habitat preference induction, individual specialization, conspecific attraction, and/or ecological traps can also lead to scenarios in which there is high use of poor quality habitat or low use of high quality habitat (Van Horne 1983, Block and Brennan 1993, Bates and Zink 1994, Ramsay et al. 1999, Bolnick et al. 2003, Davis and Stamps 2004).

Migratory shorebirds such as Whimbrels (*Numenius phaeopus*, Linnaeus 1758) use multiple breeding, staging, and non-breeding wetland habitats. Predicted climate

warming and development scenarios for the north threaten Whimbrel breeding habitat, which has made documenting and understanding of breeding habitat immediate conservation needs. Whimbrel are considered an 'umbrella' species because their breeding territories encompass or overlap that of other shorebird species (Larsen and Moldsvor 1992). Consequently, preserving Whimbrel nesting habitat would equate to habitat preservation for other species as well.

Declining North American Whimbrel populations have garnered this species a status of high conservation concern (Donaldson et al. 2000, Brown et al. 2001, U.S. Shorebird Conservation Plan 2004). Migration data from eastern North America from 1974-1998 indicate that Whimbrels are declining by 2.3% per year (Bart et al. 2007). Bart et al. (2007) suggest that the most likely hypothesis to account for this trend is a decline in the breeding populations that supply migrants to the North Atlantic region, stressing the urgent need for long-term data from northern breeding grounds. Spring 2008 aerial counts of Whimbrels along the Delmarva Peninsula, VA show a drastic decline of approximately 50% compared to 1994-1996 data (Watts and Truitt 2008). Delmarva Peninsula is a critical staging area where Whimbrels congregate to feed on fiddler crabs (Uca spp.). Whimbrels and other large waders, because of their bottlenecked migratory and non-breeding behaviour, slow reproductive rate, and low nest success, share population dynamics that make them vulnerable to declines in adult survival, which under certain circumstances may cause them to be susceptible to rapid population decline, such as occurred in the extinction of the Eskimo Curlew (Numenius borealis), and the critically endangered Slender-billed Curlew (Numenius tenuitostris) (IUCN 2008).

The objectives of this study were to (1) describe current nesting habitat of Whimbrels (*Numenius phaeopus*) in Churchill, Manitoba at two spatial scales: mesohabitat, defined as the area encompassed by a 150m radius circle around nest sites, and microhabitat, defined as the area within a 1m radius circle around nests, (2) compare the 2007 and 2008 nesting distribution to that of the 1970s and 1990s (Skeel 1976, Lin 1997), (3) determine hatch success, and (4) determine which, if any, habitat measurements resulted in differential hatching success. I hypothesized that Whimbrel would show a strong pattern of habitat associations at the mesohabitat scale, and a weaker one at the microhabitat scale. I predicted a shift in nesting distribution from that reported in the 1970s. I also hypothesized that hatch success would be similar to that reported in other studies, and that some vegetative features would be related to greater nest survival.

Methods

Study Area

Field work was conducted in roughly a 75 km² area in the Churchill, Manitoba, Canada region (58° 44' N, 94° 4' W, 28.7m; Figure 2.1) during the 2007 and 2008 breeding seasons. We searched for Whimbrel nests in the area that lay between the tree line and the coast of Hudson Bay, and was within 2km of road access. The survey area ranged from the town site, east to about 3km past the Churchill Northern Studies Centre (CNSC), and from roughly 200m inland from the coast to 2km south of Launch Road, down Landing Lake Road to Landing Lake, and southward approximately 7.5km along Twin Lakes Road to the large fen (Figure 2.1). We searched lichen-heath, sedge-meadow, mixed lichen-heath and sedge-meadow, hummock-bog, fen, and sparsely treed habitats.

Field Methods

Nest Searching and Monitoring

We located nests through historic knowledge of former territories, local knowledge, systematic walking surveys, and observing behavioural cues of nesting pairs (e.g. flushing, calling, chasing Common Ravens (Corvus corax) or jaegers (Stercorarius spp.)). Walking surveys were typically conducted by two people walking 50-100m apart. After completing a survey we marked the searched area, and located and suspected nests on a map; new areas were then searched. We returned to search areas of suspected nests at least once in attempt to locate the nest sites. When we observed suspected nesting Whimbrels, we hid beneath ground-coloured blankets roughly 15-30m away to observe incubating adults returning to their nests (Skeel 1976); this greatly facilitated the nest finding process. We recorded nest locations with a Global Positioning System (GPS) in NAD83 UTM coordinates, and noted landmarks. We did not mark nests to avoid associative learning of predator species (Reynolds 1985). Our search effort was greatest at the onset of the nesting period in the month of June. In 2007, we monitored 45 nests every 1-5 d, and every 1-3 d once the first stages of hatching (i.e. starring on eggs) had begun to determine nest fate. In 2008, we monitored 38 nests every 1-10 d, and every 1-3 d once starring had begun. In 2007, we could not relocate one nest and it was thought to have failed. In 2008, we did not monitor three nests to completion due to safety concerns caused by the presence of polar bears (Ursus maritimus). We typically visited nests for <5s from 1-4m away. We did not flush adults when it was possible to observe nest incubation at a distance, and we did not approach nests directly during the incubation phase if the adult flushed directly from the nest area. We did not visit nests directly when predators were seen. We did not band or handle adults or nestlings, with the exception of one previously banded adult that we handled to determine origin and age (Appendix 4). A nest was considered successful if ≥ 1 egg hatched and fledged from the nest. We used eggshell evidence (Mabee 1997), parental behaviour (alarm calling and displays), presence of young at or near the nest, and evidence of nest disturbance and mortality such as predator tracks, Short-eared Owl (*Asio flammeus*) pellets, feathers, blood, yolk, and body tissue to determine nest fate. Most often we confirmed success by observing Whimbrel chicks at or near the nest, adult behaviour, and/or eggshell evidence.

Mesohabitat Characteristics

In 2007 we completed mesohabitat measurements at 44 nest and 47 randomlyselected sites (Figure 2.2). To generate random sites, I created a shapefile of the search area with nest sites, the coast, and the tree line buffered by 200m on digital National Topographic System (NTS) 1:50000 maps (Natural Resources Canada) within ArcMap 9.2 (ESRI 2006). I buffered these features to avoid choosing random sites within established territories, on the coast or in continuous forest - two habitats not used by nesting Whimbrels (Skeel and Mallory 1996). I then used the Hawth's Tools extension (Beyer 2008) to generate random points. I excluded points situated in water or over 1.5km from road access. I analyzed these randomly-selected points as available habitat because although I knew the majority of these points were in unoccupied areas, I may have failed to detect some territories.

We completed habitat measurements after nests had failed or fledged. We estimated percent cover classifications [graminoid (sedge/grass/rush), dwarf shrub (≤ 0.5 m), tall shrub (>0.5m), tree (≥ 2 m), Dryas heath (*Dryas integrifolia* and plants in the

Family Ericaceae), moss, lichen, Equisetum spp., herbs (other than above), bare ground, rock, gravel, sand, litter, lake/deep pond, and standing water], and soil moisture (dry - 1, moist - 2, wet - 3, or saturated - 4) within 1m radius circles plots at 50m, 100m, and 150m away from nest and random points in the four cardinal directions, resulting in a total of twelve sample plots per nest or random site (Figure 2.3). I averaged the data from the twelve 1m radius circles plots to represent mesohabitat. I classified the numerous shallow ponds with and without emergent vegetation, and mud resulting from ponds seasonally dried up as standing water. I classified deeper and larger water bodies as lakes/deep ponds. We assessed vegetation density/nest concealment as the averaged amount of a 21.6cm x 27.9cm (8.5" x 11") horizontally placed (e.g. at nest sites placed on the nest cup) cover board obscured at 3m away in the four cardinal directions. We also counted the number of trees ($\geq 2m$ tall) within 30m of nest and random points. I chose an area with a 150m radius to represent the scale of mesohabitat or presumed territory because Whimbrels roughly defended an area this size, and nests in loose aggregations were commonly 200-400m apart (although two were only 96m apart). I did not attempt to quantify home range size. Territories are unlikely perfectly circular, and nests are unlikely placed in the centre of all territories; however, measuring dominant cover classes in plots at 50m, 100m, and 150m away in the cardinal directions provided a representation of proximately available habitat.

Nesting Distribution

I delineated nest sites and the area surveyed in 1973 by Skeel (1976), 1994 by Lin (1997, pers. comm. 2008), 2007, and 2008 on 1:50000 digital NTS maps (Natural

Resources Canada) within ArcMap 9.2 (ESRI 2006) to graphically compare nesting distribution.

Microhabitat Characteristics

I compared nest sites (within a 1m radius) to averaged non-used micro-sites at 50m, 100m, and 150m away in the cardinal directions (excluding plots that were >90% water that would not provide sufficient space for nest placement) within occupied mesohabitat/presumed territories only using a paired design (i.e. used versus unused sites for each breeding pair). I used the same 2007 percent cover data of vegetation, water, and substrate classes collected within 1m radius circle plots, and averaged vegetation density/nest concealment estimates within occupied mesohabitat/presumed territories for microhabitat analyses. We also measured distance to nearest water and tree (\geq 2m) at nest and non-used micro-sites, and recorded whether nests were located on a hummock or lichen ridge, and the presence and direction of protrusions (e.g. moss tussock, clumps of vegetation) rimming the nest cup.

I did not compare nest sites to randomly-selected, available sites at the microhabitat scale; to do so would be redundant since mesohabitat analyses compared Whimbrel occupied areas and randomly-selected, available areas.

Statistical Methods

Mesohabitat Characteristics

I removed mesohabitat cover classes with mean percent occurrences <5% from further analysis [tree (2.5%), *Equisetum* spp. (0%), herbs (1.5%), bare ground (1.5%), gravel (3.5%), rock (0.5%), sand (0.5%) and litter (0.5%)]. Pearson product-moment correlation analysis showed high correlations ($r \ge |0.40|$) among variables. To avoid complications arising from multicollinearity (Graham 2003), I summarized the remaining variables with a principal component analysis (PCA) based on a correlation matrix. I retained principal components (PC) 1, 2, and 3 in accordance with the eigenvalue (≥ 1) criterion, which also agreed with the percent variance ($\geq 10\%$) criterion (Guttman 1954, Jolliffe 1972). I also retained PC4 (eigenvalue=0.84) because although continuous forests were buffered from random site selection, and thus the number of trees did not account for a large amount of the total variation in the dataset, I was interested in the effect of sparse tree cover on habitat occupancy, and exploratory data graphing of PC4 scores showed separation of occupied and available habitat. I plotted PC scores and their representative variables, and 95% confidence ellipses for Whimbrel occupied and randomly-selected, available mesohabitat to provide graphical representation of habitat associations, and the variability of occupied mesohabitat relative to that of available mesohabitat. I also plotted the raw data of the number of trees within 30m (converted to trees/hectare) against tall shrub cover for occupied and randomly-selected, available mesohabitat.

All additive combinations of variables (PC1, PC2, PC3, and PC4) and a constant model resulted in 16 candidate models. Multiple logistic regression tested the models in which the dependent variable distinguished between occupied and available mesohabitat (Hosmer and Lemeshow 2000). I used Akaike's Information Criteria (AIC) corrected for small sample size (AICc), and the differences between the lowest AICc and other models (Δ AICc) to determine the most parsimonious candidate model (Burnham and Anderson 2001). I identified models with Δ AICc values ≤ 2 as the best subset. I used Akaike weights (w_i) to calculate importance values to assess the relative strength of models and variables. Top model parameter estimates and standard errors are reported. I assessed the top model reliability with a receiver operating characteristic (ROC) curve (Hosmer and Lemeshow 2000).

Microhabitat Characteristics

I removed microhabitat cover classes with mean occurrences <5% from further analysis [tall shrub (1.5%), tree (0.5%), *Equisetum* spp. (0%), herbs (1%), bare ground (1.5%), gravel (0.5%), rock (0.5%), sand (0%), and litter (1%)]. I also removed the lake/deep pond classification from further analysis because of low overall occurrence (<5%) once plots >90% water were excluded, following the rationale that these plots did not provide sufficient space for nest placement. Due to high correlations ($r \ge |0.40|$) among cover class variables, I summarized the remaining variables with principal component analysis (Graham 2003). I retained PC1 and PC2 in accordance with the eigenvalue (\ge 1) criterion, which also agreed with the broken stick model criterion (Guttman 1954, Frontier 1976). I plotted PC scores for nest and non-used sites.

The graph of PC1 against PC2 showed nesting habitat in two clusters, described orthogonally by PC1. To avoid having potential differences between nest and non-used sites being masked by the bimodality, I completed further microhabitat analyses separately for two habitat types differentiated by PC1. I performed paired t-tests to determine if any variables differed significantly between nest sites and non-used sites within the same presumed territory. Paired t-tests rather than AIC were performed because the small sample size for the drier, lichen-heath habitat did not allow proper convergence of logistic regression. From the drier, lichen-heath habitat dataset, I

 $log_{10}(x+1)$ transformed the vegetation density/nest concealment variable to achieve normality. For the wetter, sedge and standing water dominated habitat dataset, I $log_{10}(x)$ transformed distance to nearest tree and water, and vegetation density/nest concealment variables. All other data were normal.

I calculated the number of nests placed on hummocks or lichen ridges as a percentage. I performed a G-test to test whether the number of protrusions rimming the nest to the NE, SE, SW, and NW directions deviated from a 1:1:1:1 ratio. I plotted average data from nest sites, 50m, 100m, and 150m away to visually assess habitat homogeneity within presumed territories.

Hatching Success

I built constant logistic-exposure models to determine daily nest survival rate (DSR) and hatch success for 2007 and 2008 separately. The logistic-exposure method accounts for the number of days a nest is exposed to predators, and for time-dependent rates of mortality (Shaffer 2004a, 2004b). I also calculated apparent hatch success as a simple percentage, and Mayfield hatch success (Mayfield 1975) for comparison to previously reported hatch success.

I also built multiple logistic-exposure models to determine which, if any, habitat variables measured helped to predict daily nest survival rate in 2007 (Shaffer 2004a, 2004b). Because mesohabitat and microhabitat percent cover data were correlated, I used PCA to reduce mesohabitat percent cover variables for occupied territories only (Graham 2003). I retained one principal component in accordance with the eigenvalue (\geq 1) criterion, which agreed with the broken stick method criterion (Guttman 1954, Frontier 1976). I used all additive combinations of the following variables to build models: a

principal component describing variation in occupied mesohabitat, nest age and quadratic effect of nest age (assuming a 5 day laying period and a 25 day incubation period), vegetation density/nest concealment, distance of nest to nearest water, tree, road, and known conspecific, and the number of trees within 30m.

I used SAS version 9.0 (SAS Institute Inc. 1999), STATISTICATM version 7 (StatSoft Inc. 2004), and Analyze-it (Analyse-it Software Ltd. 2007) for statistical analyses. Results of inferential statistics were considered significant at an α of 0.05.

Results

Mesohabitat Associations

The four principal components accounted for 71.7% of mesohabitat variation at 44 occupied and 47 randomly-selected, available sites (Table 2.1, 2.2 and 2.3, Figure 2.4a-f). PC1 described a wet to dry gradient of standing water and sedge (negative values) to Dryas heath (positive values). PC2 separated habitat characterized by dwarf shrubs and Dryas heath (negative values) from habitat characterized by lake/deep ponds and tall shrubs (positive values). PC3 differentiated habitat with high lichen cover (negative values) from shrubby habitat with high dwarf and tall shrub cover (positive values). PC4 separated habitat with high numbers of trees within 30m and tall shrub cover (negative values) from habitats without.

The top candidate model to distinguish between Whimbrel occupied and available mesohabitat contained PC1, PC3, and PC4 (Table 2.4). The top model β estimates for

PC1, PC3, and PC4 were -0.43, -0.61 and 0.76 respectively (Table 2.5). The top model equation with an area under the curve of 0.78 (Table 2.5, Figure 2.5) was:

$$y(occupied / available) = \frac{e^{(-0.2071 - 0.4303(PC1) - 0.6145(PC3) + 0.7578(PC4))}}{1 + e^{(-0.2071 - 0.4303(PC1) - 0.6145(PC3) + 0.7578(PC4))}}$$

This was the only model included in the best subset ($\Delta AICc \leq 2$), and thus PC1, PC3, and PC4 all had importance values of 0.75. The global model was the second most parsimonious model ranked 3.70 $\Delta AICc$ units below the top model. The constant model ranked 15.56 $\Delta AICc$ units below the top model (Table 2.4). The top model, and overlaid scatter plots (Table 2.4, Figure 2.4a-f) show that Whimbrels occupied habitat types characterized by standing water and sedge, or lichen; and avoided habitat with high shrub, tree (number of trees within 30m), and lake/deep pond cover. Only one Whimbrel pair nest in are area with >134 trees/hectare (>38 trees within 30m), and no Whimbrels nested in an area with >17.5% tall shrub cover (Figure 2.6). Based on PC1 score comparisons of nesting and available mesohabitat, nests were found in wet sedge-dominated and lichen dominated habitats in greater proportion to what was available (Figure 2.4a-d, f).

Nesting Distribution

Current nesting distribution differs from that reported historically (Figure 2.7a-d). In the 1930s-mid 1970s, nesting Whimbrels were most abundant in hummock-bogs in the Landing Lake area, just north of the tree line and west of the airport (Taverner and Sutton 1934, Grinnell and Palmer 1941, Allen 1945, Breckenridge et al. 1954, Jehl and Smith 1970, Skeel 1976, 1983, Jehl 2004). In 1973 and 1974, Skeel (1976) also found Whimbrels heavily nested in this area (up to 7.6pair/km²) (Figure 2.7a). 2007 and 2008 data shows that Whimbrels are no longer common in these same hummock-bogs, and current distribution is more similar to that found by Lin (1997) in 1994-1996 (Figure 2.7b). A complete loss of breeding Whimbrel has occurred in a 2.6km² hummock-bog adjacent to the tree line, just west of the airport and south of Dump Road, where 17-19 pairs nested in the 1970s (Skeel 1976, 1983) (Figure 2.7(a-d)). In the 1990s, Lin (1997, unpubl. data) reported markedly fewer nests (5-7) in this area. This declining trend continued, and in 2003 Jehl (2004) reported only 2-3 pairs. In 2007 only two nests, one of which was a second nesting attempt, were found in this area (Figure 2.7c). In 2008 no Whimbrel nested in the area (Figure 2.7d). In 2007 and 2008 however, five pairs nested in a 1.6km² area of more open, mixed sedge-meadow and lichen-heath just north of Skeel's main hummock-bog, where Skeel (1976) had not reported any in the 1970s (Figure 2.7a-d).

Microhabitat Associations

Two principal components accounted for 68.4% of the variation in microhabitat at 44 nest and 44 averaged, non-used sites (Table 2.6, 2.7 and 2.8). PC1 described a dry to wet gradient of Dryas heath and lichen (negative values) to standing water and graminoids (positive values). PC2 separated habitat characterized by dwarf shrubs and moss (negative values) from habitat characterized by lichen and Dryas heath (positive values). The graph of PC1 against PC2 showed nesting in two clusters described orthogonally by PC1 (Figure 2.8), reflecting use of both drier, lichen-heath and wet, sedge and standing water dominated habitats.

In drier, lichen-heath habitats, nest sites had significantly lower PC1 values than non-nest sites, meaning nest sites had higher percentage lichen and Dryas heath cover
than non-nest sites (Table 2.9). Nest sites also had significantly lower percent potential nest-concealing vegetative cover. In contrast, in wetter, sedge and standing water dominated habitat, nest sites had higher vegetation density/nest concealment than non-nest sites (Table 2.10). No other significant differences were found. Graphical representation of habitat variables illustrated that habitat 50-150m away from nest sites is largely homogenous (Figure 2.9).

Sixty-eight percent (30/44) of nests were located on a hummock or lichen ridge. Eighty-four percent (37/44) of nests were rimmed by some sort of protrusion, but in no discernable pattern of orientation (G=5.22, df=3, P=0.16). Whimbrels nesting in loose aggregations had nearest conspecifics on average 297 ± 181 m apart; although the closest adjacent nests were only 96m apart. They may nest in closer proximity to other species, as a nesting Long-tailed Duck (*Clangula hyemalis*) was found only 5m away from an active Whimbrel nest.

Hatching Success

Of the 45 nests located in 2007, 18 (40%) resulted in \geq 1 hatched young. Logisticexposure modeling resulted in an overall DSR of 0.947, corresponding to a hatch success of 26% for the 25 day incubation period. Sixty-nine percent (31/45) of nests were known to contain a full, four egg clutch. Of 151 known eggs laid, 58 hatched (38%; 5 eggs infertile or abandoned). In 2008, 11 (31%) of the 35 nests monitored resulted in \geq 1 hatched young. The DSR calculated with the constant logistic-exposure model was 0.926, corresponding to a hatch success of 14% for the 25 day incubation period. 68% (26/38) of nests were known to contain four eggs. Of 122 eggs monitored, 45 hatched (37%; three nests with four egg clutches were not monitored to completion). In both years, the highest hatch success occurred in the fen (Figure 2.1). In 2007, hatching success in the fen calculated with the logistic-exposure method was 74% (apparent success: 8/11=73%). In 2008, hatching success in the fen calculated with the logistic-exposure method was 41% (apparent success: 10/16=63%, three nests were not monitored to completion).

Possible predator species observed included Common Ravens (*Corvus corax*), Long-tailed and Parasitic Jaegers (*Stercorarius longicaudus* and *S. parasiticus*), Shorteared Owls (*Asio flammeus*), Herring and Thayer's Gulls (*Larus argentatus* and *L. thayeri*), American Kestrels (*Falco sparverius*), Bald Eagles (*Haliaeetus leucocephalus*), Sandhill Cranes (*Grus canadensis*), Merlins (*Falco columbarius*), and Red Foxes (*Vulpes vulpes*). Other predator species not observed but within range of the study area may include opportunistic Arctic Foxes (*Vulpes lagopus*), Short-tailed Weasels (*Mustela erminea*), Least Weasels (*Mustela nivalis*), American Mink (*Neovison vison*), American River Otters (*Lutra canadensis*), Gray Wolves (*Canis lupus*), Polar Bears (*Ursus maritimus*), and Lynx (*Lynx lynx*). The only predation events observed were those by Common Ravens, however, a Short-eared Owl regurgitated pellet was found in a depredated nest.

PC1 accounted for 46.8% of the variation in occupied mesohabitat, which distinguished habitats characterized by graminoids, standing water, and high soil moisture (negative values) from habitats dominated by Dryas heath and lichen (positive values). No candidate models were useful in distinguishing DSR, suggesting that other variables not measured, such as predation pressure and/or adult defense behaviour were more important.

Discussion

Mesohabitat Associations and Distribution Change

Whimbrels occupied habitat distinguished by standing water and sedge, or lichen, and avoided habitat with high shrub, tree, and lake/deep pond cover (Table 2.3 and 2.4, Figure 2.4-2.6). Similarly, in the Mackenzie Delta, NWT, Whimbrels nested in both lowcentered polygon sedge habitat and upland tundra habitat, and were absent in areas with dense shrub, no standing water, and/or lacking polygon structure (Gratto-Trevor 1994, Pirie 2008). The avoidance of areas with higher shrub and tree cover supports the hypothesis that most shorebirds are evolutionarily adapted to open landscapes, which may facilitate predator detection (Götmark et al. 1995). Pulliainen and Saari (1993) also used this reasoning to explain why Whimbrels in eastern Finnish Lapland alpine heaths had higher hatch success than Whimbrels nesting in drier heaths with scattered pines. Whimbrels are aggressive nest defenders and were often observed chasing off Common Ravens that were several hundred meters away, suggesting visual detection. The Churchill region has numerous small ponds that provide forage for waders, thus these areas are likely preferred over areas with lakes and deep ponds, which are too deep to wade in to forage. High shrub cover was also often adjacent to lakes and deep ponds (*r*=0.35).

In Churchill, more nests were found in the wet, sedge dominated habitats and lichen dominated habitats than available, with a greater disproportionate use of wet, sedge dominated habitats, perhaps suggesting a stronger preference. Whimbrels commonly nest in open wetland habitats in places where they have been studied (Gratto-Trevor 1996, Gunnarsson et al. 2006, Pirie 2008). In Iceland, Gunnarsson (2006) found Whimbrels most commonly associated with high pond and *Juncus* cover. However, in eastern Finnish Lapland, Whimbrels were observed in a wide range of open habitats including clear-cut, strip-cut forest, bog, flark fen, mire, alpine and dry heaths, seedling stands, and mountain mixed forest showing that although hatch success was highest in open alpine heaths, successful breeding is possible in a wider range of habitats (Pullianinen and Saari 1993). In the Scottish Shetlands, Grant (1989, 1991) reports the greatest number of nests in heathland in proportion to availability, suggesting the lack of a stronger wetland preference in some locations.

My nesting mesohabitat measurements and models focused on dominant vegetation and water cover types are not exhaustive. Other confounding factors such as invertebrate and/or predator abundance, conspecific attraction, site fidelity, previous experience, individual specialization, and natal habitat preference induction may also be important in Whimbrel habitat selection (Van Horne 1983, Block and Brennan 1993, Ramsay et al. 1999, Bolnick et al. 2003, Battin 2004, Davis and Stamps 2004). For example, Skeel (1976, 1983) found that return rates varied among habitat types, with highest return rates in hummock-bogs (63.3% in 1974, and 51.3% in 1975), which also had the highest nesting density, hatch success, and site fidelity at the time. Individuals that returned to the hummock-bogs nested <250m from previous sites (Skeel 1976). Furthermore, in 2007 a banded adult was nested within 400m of its 1994 natal nest (Appendix 4). These findings indicate that previous experience, site fidelity, and philopatry contribute to habitat selection. Still it is believed that birds also use search images based on dominant habitat variables to locate suitable habitat (James 1971).

The low number of nests found in the historically highly-used hummock-bogs in the Landing Lake area contrasts with Skeel's (1976, 1983) nesting distribution in 1973 and 1974 (Figure 2.7a-d). Skeel (1976, 1983) identified hummock-bogs as optimal based on nest density, hatch success, and site fidelity, citing the possibility that Whimbrels were less conspicuous in hummock-bogs due to the heterogeneity of abundant hummocks, bare ground patches, and scattered trees and shrubs compared to the more open and homogeneous sedge-meadows and lichen-heaths. In the main hummock-bog studied by Skeel Whimbrels decreased from 17-19 nesting pairs in 1973 and 1974 (Skeel 1976) to 5-7 pairs in 1994-1996 (Lin 1997), 2-3 pairs in 2003 (Jehl 2004), 1 pair in 2007, and none in 2008 (Figure 2.7(a-d)). These data, along with Whimbrel distribution notes in field books from the 1930s (Taverner and Sutton 1934), 1940s (Grinnell 1941), 1950s (Breckenridge et al. 1954), and 1960s (Jehl and Smith 1970), and anecdotal knowledge of long-term birders (Jehl 2004, Alison pers. comm. 2007, Koes pers. comm. 2008), strongly suggests a shift in nesting distribution. Jehl (in Lin 1997) noted a shift as early as 1977. Given that Whimbrels are long-lived (Appendix 4), territorial, exhibit site fidelity, and have largely abandoned the hummock-bogs that were considered optimal (Skeel 1976, 1983), dispersal and plasticity in territory placement probably exists.

A complementary and/or alternative explanation for the declined use of hummock-bogs in the Landing Lake area is that the local Whimbrel population has declined. Jehl and Lin (2001) report a probable Whimbrel decline in the Churchill region since the 1970s. Because searched areas and effort were not consistent in the years when Whimbrels were most intensely studied, I can not conclusively determine if and to what magnitude a population decline has contributed to lowered use of the hummock-bog areas. Yet, it would be unexpected that a population decline would result in the abandonment of what was the most productive habitat in the 1970s (Skeel 1976, 1983), while nesting in sedge-meadows, fen, and lichen-heath have seemingly increased.

Whimbrel habitat availability and quality in the sub-Arctic and Arctic is threatened under future climate change scenarios that predict the drying of Arctic ponds (Yoshikawa and Hinzman 2003, Smith et al. 2005), a decline in open lichen and graminoid habitats (Chapin et al. 1995, Cornelissen et al. 2001, Kaplan and New 2006), increased shrub cover (Chapin et al. 1995, Sturm et al. 2005a, Sturm et al. 2005b, Tape et al. 2006), and tree line advancement (Caccianiga and Payette 2006, Kaplan and New 2006, Danby and Hik 2007). Furthermore, although Whimbrels do not nest in the lowlying, coastal habitat, sea levels may eventually outpace isostatic rebound in the Hudson Bay Lowlands and elsewhere, resulting in the cessation of new coastal habitat creation that would eventually be terrestrialized (Michener et al. 1997, Gough 1998, Galbraith et al. 2002, Durell et al. 2006). Changes in local habitat and climate may also introduce changes in abundance and diversity of predator and prey species (Walther et al. 2002, Parmesan and Yohe 2003, Pamperin et al. 2006, Corcoran et al. 2009). Mistiming between migration, breeding schedules and prey abundance could also result (Visser et al. 1998, Crick and Sparks 1999, Visser et al. 2004, Pearce-Higgins et al. 2005). The previously and herein noted change in nesting distribution in Churchill may suggest that Whimbrels are already responding to the changing environment (Chapter 3).

Microhabitat Associations

Within drier tundra habitats nest sites were positively associated with higher lichen and Dryas heath cover than non-used sites within presumed territories, possibly to enhance egg crypsis (Table 2.9). Nest sites in drier, lichen dominated habitats also had lower vegetation density/nest concealment, which may be due to the avoidance of vegetation that obscures visibility. In contrast, nest sites in wet sedge and standing water dominated habitat were only differentiated from non-used sites within the presumed territories by higher vegetation density/nest concealment (Table 2.10). In this habitat type, greater vegetation density may aid nest concealment. Anecdotally, Whimbrel eggs were less visible to the human eye within 5m in lichen dominated habitat than in sedge and standing water dominated habitat (personal observation). Apart from these differences between nest and non-used sites, the habitat in the presumed territory was largely homogenous (Figure 2.9). No prey or predator abundance and composition, or daily movement data are available to help determine how habitat use and pressures differ between these different habitats.

Microhabitat selection is likely in part predicted by topographic variables. Upon arrival on breeding grounds, water levels are higher, and hummocks and ridges offer dry ground especially in wet sedge dominated habitats, and also possibly provide disruptive camouflage value and a better view of surroundings. Nests commonly situated on hummocks and/or lichen ridges was also reported by Skeel (1976). Skeel (1976) also reported that protrusions commonly rimmed the nest cup, most often in the NE direction corresponding with the prevailing wind direction. Although I also commonly found protrusions rimming nests, no pattern of orientation was discernable.

Microhabitat nest site selection is also likely influenced by variables not studied such as previous experience, site fidelity, territoriality, and invertebrate abundance (Stamps 1988, Beletsky and Orians 1991, Burke and Nol 1998, Ramsay et al. 1999). According to the previous experience hypothesis individuals who previously nested successfully will nest in a similar or close site the subsequent year (Ramsay et al. 1999). In 2008, Whimbrel territories were found in the general area of 2007 territories, but no Whimbrel nested in the exact same nest cup of the previous year. As the Whimbrels in my study were not individually marked, these hypotheses could not be evaluated.

Hatching Success

Whimbrels have the lowest nest success rates of the locally breeding shorebirds in the Churchill region due to depredation (Jehl 1971, 2004). Whimbrels are also the largest of the locally breeding shorebirds, and are comparatively more visible. Their antipredator strategies include aggressive chasing, dive bombing, and scolding of aerial predators, and a mix of low aerial scolding flights and ground distraction displays for ground predators. Common Ravens, in particular, appear to elicit a strong, ritualized response. These defense behaviours can be successful; however, they can also serve to draw attention to the nest area and indicate to predators the presence of a nest. In eastern Finnish Lapland even adult Whimbrels can fall prey to Gryfalcons (*Falco rusticolus*) (Pullianinen and Saari 1993), so that the conspicuous anti-predator behaviour of nesting adults can sometimes be maladaptive.

Comparatively, hatching success in my study was low (40% and 31% apparent success, 24% and 12% calculated with the Mayfield method, and 26% and 14% calculated with the logistic-exposure method). In Churchill, previously reported Whimbrel hatching success calculated as apparent success or with the Mayfield method has ranged from 27% to 65% averaged annually (Jehl 1971, Skeel 1976, 1983, Lin 1997, Jehl 2004), and was as high as 86% (with the Mayfield method) in hummock-bogs in the

1970s Skeel (1976, 1983). Elsewhere, reported Whimbrel hatch success was 44% (Mayfield method) in the outer Mackenzie Delta (Pirie 2008), 39-78% (apparent success) in the Scottish Shetlands (Grant 1991), 64% (Mayfield method) in eastern Finnish Lapland (Pillianinen and Saari 1993), and 77% (apparent success) in Vorkuta, Russia (Morozov 1993). The reason for the comparatively lower hatch success in my study is unknown. Whimbrel predation rates are even higher during the fledgling stage (Grant 1989, Lin 1997). Lin (1997) found that only 3/30 (10%) chicks of eight broods survived past two weeks.

High predation rates are not uncommon among other similarly sized shorebirds. For example, on the Queen Charlotte Islands, Black Oystercatcher (*Haematopus bachmani*) hatch success was 38%, and fledging rate was 0.49 fledglings per pair (Vermeer et al. 1992). American Oystercatcher (*Haematopus palliatus*) hatch success in Virginia was even lower at 14%, and 0.24% fledged young per year (Nol 1989).

A low reproductive rate (four egg clutch, high nest failure, one brood per year, and delayed age of first breeding) is countered by adult survivorship and longevity (Skeel and Mallory 1996). In the Northern Isles of Shetland, adult Whimbrel annual survival rates were at least 89% (Grant 1991). A band reading made in Churchill in 2007 established a North American longevity record of 13 years (Appendix 4), and the European Whimbrel (*N*.*p. phaeopus*) longevity record from Great Britain is 16 years and one month (Staav and Fransson 2008). Banding data for other curlews include a record of 31 years for the Eurasian Curlew (*N. arquata*) (Rydezewski 1962).

Higher reproductive success does not always result from habitat preference (Pribil 1998). None of the models that I constructed, including the models with a principal

component that separated wet, sedge and standing water dominated habitats from drier, lichen-heath habitats, were successful in predicting daily nest survival. In the Shetlands, Grant (1991) also could not attribute higher nest success to a particular environmental variable, reporting that success was not directly associated with nesting density, and suggested that there was no evidence to attribute inter-site success variation to factors such as laying date, habitat use by brood, or invertebrate abundance.

It was not possible to statistically compare hatch success between geographical areas within the surveyed area due to small sample sizes in some areas. The highest hatch success was observed in the fen located along the Twin Lakes Rd. The high nest survival may be because the fen is large, open, wet, with very few trees, and is further away from the town site. Comparatively fewer Common Ravens, Long-tailed and Parasitic Jaegers, and no Short-eared Owls were observed while in the fen. The wetness of the fen may also deter land predators such as foxes. I saw Common Ravens most frequently during field work in the areas just west of the airport, which is closer to the town site and to treed areas providing nesting and perching habitat for this species. In this area only one of the seven nests located in 2007 was successful. As depredation was rarely observed the main predator species are not certain. As in many studies of nesting birds, more data identifying the types and numbers of ground and aerial predators, both diurnally and nocturnally, are needed.

Hatch success may also be influenced by adult experience, and incubation, and defence behaviour (Smith et al. 2007). Ideally, additional variables to include in future DSR modeling would include an index of predation pressure, the age or breeding experience of adults, adult incubation and defense behaviour as inter-pair differences in

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aggression were noted, distance to a tree line (rather than distance to nearest tree or number of trees within 30m), measures of invertebrate abundance, and year to account for annual variation.



Figure 2.1 Map of the Churchill, Manitoba region courtesy of Pete Kershaw (modified).



Figure 2.2 Map of the Churchill, MB region showing 2007 nests (\blacktriangle ; n=45) and randomly-selected locations (\Box ; n=47). © Department of Natural Resources Canada. All rights reserved.



Figure 2.3 Schematic diagram of sampling design where percent cover classes were quantified at two spatial scales with a series of 1m radius circle plots.

	Occupied	l (<i>n</i> =44)	Random,	available (<i>n</i> =47)	Overall
	Mean	95% CI	Mean	95% CI	Mean
Percent cover					
Graminoid	27	23-32	23	19-28	25.0
Dwarf shrub	6	5-8	7	6-9	6.5
Tall shrub	1	0-1	7	5-10	4.0
Tree	1	0-1	4	2-6	2.5
Dryas heath	12	10-15	15	12-18	13.5
Moss	6	5-7	7	5-8	6.5
Lichen	8	6-11	7	5-9	7.5
Equisetum	0	0-0	0	0-0	0.0
Herbs (other than above)	1	0-1	2	1-3	1.5
Lake/deep pond	12	8-16	14	9-19	13.0
Standing water	23	17-29	12	9-15	17.5
Bare ground	2	1-3	1	1-2	1.5
Gravel	1	0-1	6	3-9	3.5
Rock	0	0-0	1	0-3	0.5
Sand	0	0-0	1	0-2	0.5
Litter	0	0-0	1	0-2	0.5
Number of trees within 30m	6	2-10	19	11-27	12.5
Distance to water (m)	16	7-25	21	10-33	18.5
Distance to nearest shrub $\geq 0.3 \text{ m} \text{ (m)}$	5	3-7	4	3-6	4.5
Distance to nearest tree $\geq 2m$ (m)	34	24-44	32	15-50	33.0

Table 2.1 Mean and 95% confidence intervals (CI) of Whimbrel occupied and randomly-selected, available mesohabitat/territory scale data in the Churchill, MB region, 2007. Percent cover types were estimated within 1m radius circles at 50m, 100m, and 150m away from nest and centre points along transects in cardinal directions.

	Dwarf	Tall	Dryas			Lake/deep	Standing	Soil	# Trees
	shrub	shrub	heath	Moss	Lichen	pond	water	moisture	within 30m
Graminoid	-0.05	-0.28	-0.52	-0.25	-0.41	-0.45	0.43	0.56	-0.31
Dwarf shrub		0.05	0.13	0.22	-0.01	-0.07	-0.26	-0.23	0.20
Tall shrub			0.14	0.25	0.07	0.35	-0.47	-0.33	0.31
Dryas heath				0.32	0.38	-0.05	-0.52	-0.67	0.48
Moss					0.24	0.01	-0.39	-0.41	0.23
Lichen						0.12	-0.32	-0.23	0.24
Lake/deep pond							-0.48	-0.01	0.04
Standing water								0.69	-0.32
Soil moisture									-0.29

Table 2.2 Correlation matrix of mesohabitat variables (n=44 for Whimbrel occupied mesohabitat, n=47 for randomly-selected,available mesohabitat). Bolded correlations are $\geq |0.40|$.

Table 2.3 Eigenvectors, eigenvalues, and variance explained by principal component analysis of mesohabitat percent cover variables averaged from twelve 1m radius circle plots at 50m, 100m, and 150m in the cardinal directions from Whimbrel nests (n=44), and randomly-selected, available (n=47) sites. Bolded loadings are $\geq |0.35|$.

	PC			
	1	2	3	4
Mesohabitat variable				
Graminoid	-0.38	-0.20	0.29	-0.11
Dwarf shrub	0.14	-0.34	0.56	0.18
Tall shrub	0.27	0.34	0.38	-0.38
Dryas heath	0.39	-0.30	-0.28	-0.08
Moss	0.28	-0.21	0.20	0.30
Lichen	0.26	-0.01	-0.54	0.10
Lake/deep pond	0.18	0.71	0.07	0.12
Standing water	-0.43	0.12	-0.20	-0.19
Soil moisture	-0.41	-0.24	-0.03	-0.21
# Trees within 30m	0.29	-0.17	0.01	-0.78
Eigenvalue	3.77	1.43	1.13	.84
Total variance explained (%)	37.68	14.34	11.34	8.37
Cumulative variance explained (%)	37.68	52.01	63.35	71.72



Figure 2.4(a-f) Mesohabitat principal components (PC) 1-4 scores of occupied (\bullet ; n=44), and randomly-selected, available (\Box ; n=47) mesohabitat with 95% confidence ellipses (solid ellipse for occupied, and dashed ellipse for randomly-selected, available).

Table 2.4 Log likelihood (-2ln*L*), number of parameters (k), Akaike's Information Criteria (AIC), AIC adjusted for small sample size (AICc), difference in AICc (Δ AICc), and Akaike weights (w_i) for all models from multiple logistic regression analysis to distinguish between Whimbrel occupied and randomly-selected, available mesohabitat. Models were ranked by suitability, and the highlighted model was the only model in the best subset (Δ AICc2).

Model	k	-2lnL	AIC	AICc	∆AICc	wi
PC1, PC3, PC4	4	104.05	112.05	-104.29	0.00	0.75
PC1, PC2, PC3, PC4	5	105.49	115.49	116.24	3.70	0.12
PC1, PC3	3	111.59	117.50	117.87	5.34	0.05
PC1, PC4	3	112.39	118.39	118.68	6.14	0.04
PC1, PC2, PC3	4	111.53	119.53	120.02	7.48	0.02
PC1, PC2, PC4	4	112.38	120.38	120.87	8.34	0.01
PC1	2	117.73	121.73	121.87	9.33	0.01
PC3, PC4	3	116.12	122.12	122.40	9.87	0.01
PC1, PC2	3	117.65	123.65	123.94	11.40	< 0.01
PC2, PC3, PC4	4	116.05	124.05	124.54	12.00	< 0.01
PC3	2	120.43	124.43	124.57	12.03	< 0.01
PC4	2	122.17	126.17	126.31	13.77	< 0.01
PC2, PC3	3	120.35	126.35	126.64	14.10	< 0.01
PC2, PC4	3	122.10	128.10	128.38	15.85	< 0.01
Constant	1	126.05	128.05	128.10	15.56	< 0.01
PC2	2	125.98	129.98	130.12	17.58	< 0.01
	Param	neter Importance V		ance Value		
	PC1		0.75			
	PC3		().75		
	PC4		().75		

Table 2.5 Top mesohabitat model parameter estimates, standard errors (SE), and 95% confidence intervals (CI).

	Model		95% CI	
Parameter	Estimate	SE	Lower	Upper
Intercept	-0.21	0.25	-0.70	0.29
PC1	-0.43	0.15	-0.72	-0.14
PC3	-0.61	0.25	-1.10	-0.13
PC4	0.76	0.35	0.08	1.44



Figure 2.5 Receiver operating characteristic curve for the top mesohabitat occupancy model (area under the curve is 0.78):

 $y(occupied \, / \, available) = \frac{e^{(-0.2071 - 0.4303(PC1) - 0.6145(PC3) + 0.7578(PC4))}}{1 + e^{(-0.2071 - 0.4303(PC1) - 0.6145(PC3) + 0.7578(PC4))}} \,.$



Figure 2.6 Number of trees within 30m of nest and randomly-selected points converted to trees/hectare against percent cover tall shrub of Whimbrel occupied (\bullet ; n=44), and randomly-selected, available (\Box ; n=47) habitat with 95% confidence ellipses (solid ellipse for occupied, dashed ellipse for randomly-selected, available).



Figure 2.7(a-d) Whimbrel nest (▲) and suspected nest (*) distribution and area searched (shaded) in 1973 (Skeel 1976), 1994 (Lin 1997), 2007, and 2008 in 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 provided. © Department of Natural Resources Canada. All rights reserved.

Table 2.6 Mean and 95% confidence intervals (CI) of microhabitat/nest site scale data from Whimbrel nest and non-used sites within presumed territories in the Churchill, MB region, 2007. Percent cover types were estimated within 1m radius circle plots at nests and at 50m, 100m, and 150m away along transects in cardinal directions. For non-used sites, plots with >90% water or located in water were excluded when calculating the average distance to water.

	Use (<i>n</i> =44)		Non-use v	Overall	
	Mean	95% CI	Mean	95% CI	Mean
Percent cover					
Graminoid	29	22-36	27	25-30	28
Dwarf shrub	6	4-8	6	5-7	6
Tall shrub	1	0-2	3	2-4	2
Tree	0	0-0	1	0-1	1
Dryas heath	16	11-22	12	11-14	14
Moss	7	5-10	6	5-7	7
Lichen	16	11-22	8	7-10	12
Equisetum	0	0-0	0	0-0	0
Herbs (other than above)	1	0-2	1	1-1	1
Lake/deep pond	1	0-6	12	9-15	7
Standing water	22	14-30	23	21-26	23
Bare ground	1	0-2	2	2-3	2
Gravel	0	0-0	1	0-1	1
Rock	1	0-3	0	0-0	1
Sand	0	0-0	0	0-0	0
Litter	2	0-3	0	0-0	1
Distance to water (m)	16	7-25	8	5-12	12
Distance to nearest shrub $\geq 0.3 \text{ m} \text{ (m)}$	5	3-7	13	11-16	9
Distance to nearest tree $\geq 2m$ (m)	34	24-44	40	31-49	37
Vegetation density/nest concealment (% cover 3m away)	4	3-6	4	2-6	4

Table 2.7 Correlation matrix of microhabitat variables measured within 1m radius circle plots at nest, and at non-used sites within presumed territories at 50m, 100m, and 150m in the cardinal direction from nests (n=44; averaged 12 plots/territory except when plots were >90% water). Bolded correlations are $\geq |0.40|$.

	Dwarf	Dryas			Standing
	shrub	heath	Moss	Lichen	water
Graminoid	-0.14	-0.57	-0.22	-0.56	0.15
Dwarf shrub		0.16	0.57	-0.20	-0.29
Dryas heath			0.11	0.36	-0.63
Moss				0.03	-0.31
Lichen					-0.50

PC 1 2 Microhabitat variable Graminoid -0.19 0.45 Dwarf shrub -0.24-0.66 Dryas heath 0.14 -0.50 Moss -0.29 -0.56 Lichen -0.42 0.45 0.48 0.04 Standing water Eigenvalue 2.54 1.57 Percent of Total Variance Explained 42.31 26.11

Cumulative Variance Explained

Table 2.8 Eigenvectors, eigenvalues, and variance explained by principal component analysis of microhabitat percent cover variables from 1 m radius circle plots at Whimbrel nests, and averaged non-used sites at 50m, 100m, and 150m away in the cardinal directions from nests (n=44). Bolded loadings are $\geq |0.35|$.

42.31

68.42



Figure 2.8 Microhabitat principal components (PC) 1 and 2 scores for nest sites, showing that nests were found in two habitats as described orthogonally by PC1. Because data were bimodal further microhabitat analyses were done separately.

	Mean ± SE	Mean ± SE		
Microhabitat Variable	Nest	Non-Nest	t	Р
PC1	-2.34 ± 0.13	$\textbf{-0.97} \pm 0.28$	-4.80	<0.01
PC2	0.59 ± 0.59	-0.17 ± 0.33	1.68	0.11
dist. nearest water (m)	32.04 ± 9.79	20.12 ± 3.97	1.71	0.11
dist. nearest tree (>2m) (m)	28.34 ± 5.92	27.82 ± 4.18	0.09	0.93
%cover 3m away (nest concealment value)	1.63 ± 0.34	4.43 ± 1.09	-2.25	0.05

Table 2.9 Results of paired t-tests comparing nest and non-used sites within the same presumed territory for drier, lichen dominated habitats. Bolded P values are ≤ 0.05 .

Table 2.10 Results of paired t-tests comparing nest and non-used sites within the same presumed territory for wetter, sedge and standing water dominated habitats. Bolded P values are ≤ 0.05 .

	Mean ± SE	Mean ± SE		
Microhabitat Variable	Nest	Non-Nest	t	Р
PC1	1.17 ± 0.15	0.72 ± 0.18	1.73	0.09
PC2	-0.11 ± 0.15	-0.13 ± 0.08	0.15	0.88
dist. nearest water (m)	8.51 ± 3.21	6.58 ± 1.55	-1.53	0.14
dist. nearest tree (>2m) (m)	37.43 ± 7.11	37.80 ± 4.44	-1.84	0.08
%cover 3m away (nest concealment value)	5.68 ± 1.24	2.36 ± 0.71	30.39	<0.01



Figure 2.9 Averaged percent cover classifications estimated within 1m radius circle plots at nests, and at 50m, 100m, and 150m away from nests in the cardinal directions in two main habitat types. Graphed data include plots that were >90% water, which were not included in microhabitat statistical analysis following the rationale that such plots did not provide sufficient space for nest placement. sedge/grass/rush⁻⁻⁻; dwarf shrub -*-; Dryas heath ---; moss ---; lichen ---; standing water -+--; lake/deep pond -*--; tall shrub -*--; tree ----. Lines were added for display purposes only, and do not imply a continuous distribution of habitat features.

Chapter 3: Habitat change in an area historically used as nesting habitat by Whimbrel (*Numenius phaeopus*) in Churchill, Manitoba, Canada

Abstract

Over the past 35 years the nesting distribution of Whimbrels in Churchill, MB has changed. To explore the hypothesis that Whimbrels have abandoned an area of historic nesting importance due to habitat change, I compared low-altitude aerial photography from 1973, 1986, and high-resolution satellite imagery from 2006 of a 2.55km² hummock-bog just north of the tree line. This hummock-bog was occupied by 17-19 nesting Whimbrel pairs in 1973 and 1974 (Skeel 1976, 1983). In 1994-1996 only 5-7 pairs nested in the area (Lin 1997), and only 2-3 pairs in 2003 (Jehl 2004). In 2007 one pair occupied the area, and in 2008 none did. Comparison of the three time period imagery shows that shrubs and trees have increased in cover by 12.6% and 6.9% respectively, whereas water and other vegetation have decreased by 4.4% and 19.1% respectively. This localized evidence of shrub encroachment and tree line advancement adds to the growing documentation of such occurring across the sub-Arctic and Arctic in both North America and Eurasia. The decrease in water cover also supports mounting evidence of wetland drying at northern latitudes, although this result in the area of interest should be viewed with some caution due to the possible bias of precipitation events prior to image capture. The correlation between habitat change and Whimbrel abandonment of this area of interest, coupled with the findings that Whimbrels avoid shrubby and treed habitat (Chapter 2), suggests that the habitat may have become unsuitable to nesting Whimbrels.

Keywords: Whimbrel, *Numenius phaeopus*, shorebird, distribution change, shifted distribution, habitat change, shrub encroachment, tree line advancement, vegetation response, tundra reduction, wetland drying, climate warming, climate change, sub-Arctic,

Churchill, Manitoba

Introduction

It is unequivocal that the Earth has warmed beyond natural variation (IPCC 2007a). The magnitude of climate warming and its effects are greatest at the poles. Arctic sea ice extent has decreased by 15-20% per decade over the past thirty years, with the 2008 September sea ice extent lying 34% below the long-term average from 1979-2000 (NSIDC 2008). On land there is evidence of a pan-Arctic change in vegetation, attended by increased shrub cover, and tree line advancement with concomitant decreases in Arctic ponds, and open tundra habitats (Cornelissen et al. 2001, Yoshikawa and Hinzman 2003, Smith et al. 2005, Tape et al. 2006). Climate change scenarios predict that the area of tundra will shrink by up to 50% by 2100 (White et al. 2000). Such marine and terrestrial changes will contribute to further climate warming through positive feedback processes (Sturm et al. 2001, Chapin et al. 2005, Foley 2005, Sturm et al. 2005a, Sturm et al. 2005b, IPCC 2007a). Predicted changes will alter the very structure and functions of sub-Arctic and Arctic ecosystems with potentially severe consequences for biodiversity.

Nuanced responses and consequences to climate change are already occurring (Walther et al. 2002). Within the 20th century, climate warming has led to earlier arrival dates of birds in Manitoba (Murphy-Klassen et al. 2005). Elsewhere, earlier arrival of birds has resulted in a mistiming between migration, nesting, and invertebrate peak activities with devastating effects on breeding success for some species (Visser et al.

1998, Crick and Sparks 1999). Data on range shifts in shorebirds are mounting (Klima and Jehl 1998, Thomas and Lennon 1999, Rehfisch et al. 2004, Austin and Rehfisch 2005, National Audubon Society 2009). Generally, species ranges are hypothesized to shift northwards with the shifting vegetation; however, the adaptive capabilities of many species are not understood. Species that breed at the highest latitudes may be squeezed between northward advancing vegetation and Arctic waters. In addition, abundance of predators and parasites may increase, and new species originating from the south may be able to out-compete sub-Arctic and Arctic counterparts (Hersteinsson and MacDonald 1992, Kutz et al. 2005, Hudson et al. 2006). Climate change effects vary regionally and by species, and effects may be positive for some species, and proximately positive for others. For example, warmer summer temperatures may promote chick survival and warmer spring and/or fall temperatures may lengthen the breeding season, allowing for second nest attempts (Meltofte et al. 2007).

The sub-Arctic and Arctic lichen-heath and wetland habitats are key breeding areas for shorebirds (Donaldson et al. 2000, Meltofte et al. 2007). Shorebirds, which undertake long distance migrations to breed during the brief sub-Arctic and Arctic summers, are key components of these ecosystems. It is thought that shorebirds rear their young in the north to capitalize on the flush of invertebrates (Boyle and Conway 2007), where they have evolved to nest in open, mostly treeless, landscapes (Götmark et al. 1995). Thus, the consequences of climate change to breeding habitat are leading, contemportary threats to shorebird species. Monitoring vegetation change at multiple spatial and temporal scales is important for understanding localized and broad-scale responses to climate change, including the rate at which change is occurring and the impact on local biodiversity.

Whimbrels (*Numenius phaeopus*, Linnaeus 1758) are long-distance migrants that breed throughout the Holartic. North American Whimbrels breed in both the sub-Arctic Hudson Bay Lowlands and western Arctic (Skeel and Mallory 1996). In Churchill, MB, Whimbrel nesting distribution has changed, with much lower use of hummock-bogs adjacent to the tree line in the Landing Lake area where they were historically most common in the 1930s-mid 1970s (Taverner and Sutton 1934, Grinnell and Palmer 1941, Allen 1945, Breckenridge et al. 1954, Jehl and Smith 1970, Skeel 1976, 1983, Jehl 2004) (Chapter 2).

In 1973 and 1974, Skeel (1976, 1983) found the highest proportion of Whimbrel nests (17-19) in a roughly 2.55km² hummock-bog, resulting in a high, 7.6 pairs/km² nesting density. Skeel (1976, 1983) identified it as the optimal habitat type based on nesting density, success, and site fidelity. In 1994-1996, Lin (1997) reported only 5-7 pairs, and determined that Whimbrel use of this area had drastically decreased by approximately 70% since the 1960s. Jehl (pers. comm. in Lin 1997) reported that the reduced use of this hummock-bog was evident by 1977. Nesting activity in this area of interest continued to decline; in 2003 Jehl (2004) reported only 2-3 pairs, in 2007 only two nests, one of which was a re-nesting attempt, existed, and in 2008 no Whimbrel nested in the area (Chapter 2). In 2007 and 2008, however, five pairs nested just north of the main hummock-bog study site of Skeel (1976), in a 1.6km² more open, mixed sedge-meadow and lichen-heath habitat. I hypothesized that the encroachment of shrubs and trees, drying of the habitat, increase in nesting Canada Geese (*Branta canadensis*) and

predatory Common Ravens (*Corvus corax*) in the area, and/or a local population decline are possible drivers for the abandonment of the area by breeding Whimbrels.

The objective of this study was to complete a habitat change analysis to explore the hypotheses that shrub and tree encroachment, and wetland drying in the main hummock-bog study area of Skeel (1976, 1983) is correlated with the reduction in nesting Whimbrels. This study capitalizes on the existence of previous Whimbrel research completed in Churchill in 1973-1975 by Skeel (1976), and in 1994-1996 by Lin (1997), and the availability of historic, low-altitude aerial photography of the area taken in 1973 and 1986. High-resolution satellite imagery was purchased for 2006. Vegetation, water, and substrate cover classifications of the three time periods were systematically estimated and compared to determine if and how the habitat has changed.

Methods

Study Site

Churchill, MB (58° 44' N, 94° 4' W, 28.7m) is situated 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 high sub-Arctic ecoclimate (Scott 1995). The Churchill region is a transition zone, with boreal forest to the south and tundra along the coast and to the north. The soils experience continuous permafrost, resulting in poor drainage and numerous shallow ponds. The flat lowlands (<50m elevation) are experiencing isostatic rebound at a rate of approximately one meter per century (Webber et al. 1970). The average annual temperature is -6.9°C. Winters are cold and long, and summers are brief with average January and July temperatures of -26.7°C and 12°C respectively (Environment Canada 2008b).

The study area or area of interest (AOI) is a 2.55km² hummock-bog with some higher treed areas, bounded by gravel roads to the north and east, and by tree lines to the south and west. The area is just west of the Churchill airport and south of Dump Rd. (Figure 2.1). The main tree species were Larch (*Larix laricina*), Black Spruce (*Picea mariana*), and White Spruce (*Picea glauca*). The main shrub species were Dwarf Birch (*Betula glandulosa*), and Lapland Rose-bay (*Rhododendron lapponicum*). Northern Bilberry (*Vaccinium uliginosum*), Snow Willow (*Salix reticulata*), and Sweet Gale (*Myrica gale*) were other shrub components of the understory. Sedge (*Cyperaceae* spp., particularly *Carex aquatilis*), lichen, and moss species, Alpine Azalea (*Loiseleuria procumbens*), Alpine Bearberry (*Arctostaphylos alpina*), Bog Rosemary (*Andromeda polifolia*), Black Crowberry (*Empetrum nigrum*), and Common Butterwort (*Pinguicula vulgaris*) were also common.

Imagery Acquisition and Preparation

I acquired imagery from 1973, 1986, and 2006. The 1973 imagery was provided by Skeel, who arranged to have her main study area (the AOI) aerial photographed at the 1:8000 scale (610m in altitude) in July 1973. Neither the original full prints nor negatives were located. Skeel provided contact prints containing 35 photos of the AOI with approximately 40% overlap between photos. One contact sheet containing four photos was missing. The 1986 imagery was 10, 22.9 cm x 22.9 cm (9" x 9") aerial photographs with 60% overlap purchased from the Manitoba Government (Manitoba Conservation, Air Photo Library, Winnipeg, MB). The photos were taken at the 1:10000 scale with a Zeiss Lameogon B lens, focal length 152.176mm, on 10 July 1986. The 1973 and 1986 aerial photographs were scanned on an Epson Expression 10000XL in professional mode at 1200dpi in 8bit grayscale resulting in 17cm and 21cm ground sample distance or resolution respectively. Both the 1973 and 1986 photographs were mosaicked together within PCI Geomatica V9.1 (PCI Geomatics Group 2003) using eight or more welldistributed tie points per photo. I purchased 2006 high-resolution QuickBird satellite imagery from MDA Geospatial Services (Richmond, BC) (DigitalGlobe Inc. 2008). The imagery was natural colour, 3-band pansharpened, 8bit, mosaicked, Standard Ortho-Ready product taken at 17:46 on 10 July 2006, with zero cloud cover and a maximum off-nadir angle of 11.81 degrees. The Ortho-Ready Standard product was chosen due to its low minimum area order size and price, high 61cm resolution, and lack of topographic corrections making it suitable for orthorectification, which can improve the guaranteed 23m absolute geolocation accuracy. This product was mapped to an average base elevation, but because the AOI has extremely low relief this was not a high concern. I georectified the 2006 imagery to NAD83 UTM map projection, using rational polynomial coefficient (RPC) data provided by QuickBird and 40 field acquired Global Positioning System (GPS) ground control points (GCPs). The rectified image was cross-checked against Landsat data to ensure that the roads fell within the roads layer of Landsat data. Based on the RCP and GCP processing, the very low topographic relief of the AOI, the low off-nadir angle, and comparison to ground sampled distances, I estimated that the rectified image had 5-10m accuracy. I preformed a cubic convolution polynomial rectification to register the 1973 and 1986 images to the 2006 image within PCI Geomatica (PCI Geomatics Group 2003), producing three images of the same projection.

Assessing Change

I created a shapefile of the AOI in ArcMAP 9.2 (ESRI 2006), and used it to clip the three time period images (Figures 3.1, 3.2, and 3.3). I overlaid a 50m x 50m grid on the three images within ArcMAP, and produced large printouts (~100cm x 130cm) (Figure 3.4). I estimated percent cover for the following vegetation, water, and substrate classifications: blank, gravel, water, mud, tree, shrub, other vegetation including lichen, and other. I estimated broad cover classifications because habitat structure was my primary interest. I assessed every fourth grid cell, resulting in data from the same 246 grid cells for all three time periods. I made estimates visually from the large-scale printouts, using a stereoscope for aerial photographs, and within PCI Geomatica. My familiarity with the AOI facilitated vegetation identification. Knowledge of species distribution, texture, pattern, shape, and colour also aided the classification process. Field notes on vegetation cover in 2007 and 2008 also helped to verify classification for the 2006 image.

I report percent cover for each class, and following Tape et al. (2006) the change in cover (CC), equal to the percent cover on the more recent image minus the percent cover on the older image, and relative change in cover (RCC), equal to the change in cover divided by the percent cover in the older image (x 100). I also report the change in cover per year between 1973 and 1986, 1986 and 2006, and 1973 and 2006.

In addition, I randomly-selected twenty grid cells and estimated the number of trees, which I converted to trees per hectare and compared to tree densities in Whimbrel occupied mesohabitat data in Churchill, 2007 (Chapter 2, Figure 2.6, and 3.5). The same twenty grid cells were assessed for all three time periods.
Climate Trends

I graphed the Churchill's average annual temperature from 1970-2008 to assess the overall climate trend (Environment Canada 2008a). For the same time period, I graphed total annual degree days, calculated as cumulative mean daily temperature degrees >0°C to investigate the change in growing conditions (Environment Canada 2008a). I also regressed the mean, minimum and maximum temperatures for the months of May, July and October (Environment Canada 2008a) against year to examine the trends for the months that were previously documented to be important for the growth of the tree species in the AOI (Girardin et al. 2005). Although data for recent years were unavailable, I also plotted total annual precipitation (1970-2005), rain and snow fall (1970-1998) (Environment Canada 2008a) to investigate how precipitation events may have influenced the amount of water cover estimated.

Results

Habitat Change

The AOI has experienced a decrease in gravel (-1.1%), water (-4.4%), and 'other vegetation' (-19.1%), and an increase in trees (6.9%), shrubs (12.6%), and mud (5.2%) (Table 3.1, Figure 3.6, 3.7, and 3.8). The change in cover (Table 3.2), the relative change in cover (Table 3.3), and the change per year (Table 3.4) show that drying of the AOI was greatest between 1986 and 2006. Tree cover increase was fairly even, with percent cover increasing by 0.19% per year between 1973 and 1986, and by 0.22% per year between 1986 and 2006. Shrub cover has increased from 5.1% in 1973, to 7.6% in 1986, and 17.7% in 2006 (Table 3.1). The rate of shrub cover change doubled from 1986 to 2006

compared to the increase between 1973 and 1986. Tree densities within the AOI have increased; the averaged density of trees has increased 54% from 1973 to 2006 (78, 106 and 120 trees/hectare for 1973, 1986 and 2006 respectively) (Table 3.5).

Climate Change

From 1970-2007 the average annual temperature in Churchill has significantly risen by 1.78°C (Average Annual Daily Temperature = -102.702 + 0.048(Year), $F_{1,36}$ =5.85, P=0.01, adj R²=0.12; Figure 3.9). Total annual degree days have also significantly increased (Degree Days=-13743.9 + 7.5(Year), $F_{1,36}$ =11.42, P<0.01, adj R²=0.22; Figure 3.10). Over the past 38 years, 285 degree days have been gained, which is the equivalent of an average summer month; greater than the average degree days for June and September (203.9 and 179.5 respectively), but less than that of July or August (382.6 and 370.2 respectively) (Environment Canada 2008b). The total annual number of days with a mean >0 has increased by 7.3 days.

The mean July temperature trend was also positive and significant (July mean temperature (°C)=-118.25+0.02(Year), $F_{1,37}$ =8.99, P<0.01, adj R²=0.17; Figure 3.11b). The mean October temperature trend was positive and close to statistically significant (October mean temperature (°C)=-109.92+0.06(Year), $F_{1,37}$ =3.71, P=0.06, adj R²=0.07; Figure 3.11c), whereas the May temperature trend was not significant (May mean temperature (°C)=19.41-0.01(Year), $F_{1,37}$ =0.06, P=0.80, adj R²=-0.03; Figure 3.11a).

Total annual precipitation has significantly increased from 1970-2005 (total precipitation (mm)= -7215.31+3.85(Year), $F_{1,34}$ =7.51, P=0.01, adj R²=0.16; Figure 3.12). Total rainfall from 1970-1998 (recent data unavailable) also tended to increase, though not significantly (total rain (mm)= -4556.19+2.43(Year), $F_{1,27}$ =2.57, P=0.12, adj R²=0.05;

Figure 3.12). Total snowfall from 1970-1998 (recent data unavailable) has not changed significantly (total snow (cm)= -353.43+0.27(Year), $F_{1,27}=0.06$, P=0.81, adj R²=-0.03; Figure 3.12).

Discussion

Habitat and Climate Change

The warming trend, increase in shrub and tree cover, and decrease in water cover in the AOI adds to growing evidence of climate warming, a longer growing season, shrub and tree encroachment, and wetland drying occurring elsewhere in the sub-Arctic and Arctic (Cooper 1986, Suarez et al. 1999, Rupp et al. 2001, Smith et al. 2004, Caccianiga and Payette 2006, Riordan et al. 2006, Tape et al. 2006, Smith et al. 2007). Warming temperatures and longer growing seasons greatly affect shrub and tree growth. In Churchill, Girardin et al. (2005) found that 60% of Larch growth variation could be accounted for by weather, with May to July of the year temperatures being the most important (May negatively correlated, and June and July positively correlated). White Spruce growth was positively correlated with July and June temperatures, and Black Spruce growth was positively correlated with July temperatures, negatively with May temperatures, and positively with July and August of the previous year temperatures. All were also all significantly positively correlated with mean October temperature of the previous year (Girardin et al. 2005). Historical notes and paleoecological studies also illustrate the relationship between climate and vegetative response. Recent anthropogenic climate warming is part of a longer climate warming trend since the Little Ice Age influenced by natural climate forcing such as increased solar irradiance, decreased

volcanic activity, and ocean thermohaline variability (Overpeck et al. 1997). In the Churchill region, Samuel Hearne (1795), a northern explorer (1745-1792), noted old stumps and blown down trees extended up to 32km (20mi) from living trees as evidence of a southward shift in the tree line due to cooled climate at the end of Little Ice Age (1450-1760). Tree ring chronological studies 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).

Climate also indirectly affects plant growth through its effects on nutrient and carbon dioxide availability. For example, through relationships with water and nutrients, climate drives positive feedback processes that further contribute to shrub growth. Warming air temperatures result in warming soil temperatures, leading to permafrost thaw, and increased active layer depth. Increased soil temperatures and active layer depth in turn increase microbial activity and nitrogen availability that promote shrub growth (Sturm et al. 2005b). Furthermore, shrubs trap drifting snow, which has an insulating effect, leading to increased winter soil temperatures, and in turn nutrient availability (Sturm et al. 2005b). Research also shows that elevated atmospheric carbon dioxide levels spur shrub growth, greatly outgrowing graminoids (Morgan et al. 2007). Additionally, increased shrub and tree growth will decrease the terrestrial albedo effect, which will further force climate warming (ACIA 2005, Chapin et al. 2005, Foley 2005). Climate warming, coupled with these processes could cause the rapid conversion of

tundra to shrub land (Sturm et al. 2005b), and help explain the doubling in shrub cover between 1986 and 2006 compared to the earlier 1973-1986 period.

Warming temperatures and longer growing seasons also contribute to drying of wetlands by causing greater evapotranspiration, and water drainage due to permafrost thaw (Liston et al. 2002, Yoshikawa and Hinzman 2003, Smith et al. 2005). Considering that total precipitation has significantly increased in Churchill (1970-2005), the finding of decreased water cover in the AOI is unlikely to be a detection of annual precipitation variation. Precipitation events or lack thereof prior to image capture in July may have biased results; however, the average July precipitation is low (56mm) (Environment Canada 2008b).

There are sub-Arctic and Arctic climate change effects that may not proximately result in increased shrub and tree cover or wetland drying. For example, in areas where ice-rich permafrost exists in the boreal forest, thawing has resulted in thermokarst collapse in which wet bogs, sedge-meadows, or thermokarst ponds or lakes are created and trees die from flooding as water is trapped by the surrounding maintained permafrost (Hinzman et al. 2005). Eventually, however, as the surrounding permafrost also thaws, these wetlands will likely drain (Yoshikawa and Hinzman 2003). Additionally, Giardin et al. (2005) found that although warm spring temperatures were generally beneficial for tree growth, Larch and Black Spruce growth were significantly negatively correlated with May temperatures. They hypothesized that high May temperatures cause early snow melt while soils are still frozen, causing the water to run-off rather than percolate through the soil (Giardin et al. 2005). Potential increased flooding in areas may also limit shrub and tree establishment (Gratto-Trevor 1996). Furthermore, not all plant species are limited

purely by climatic factors; factors such as photoperiod, ultra-violet radiation, soil type, soil nutrients, shade tolerance, and reproductive and dispersal capabilities play roles in plant growth and distribution (Scott 1995, Gamache and Payette 2004).

In the AOI there are two other important contributing factors to consider: isostatic rebound and destructive geese foraging. Relieved from glacial weight, the Churchill region is rebounding at a rate of approximately one meter per century (Webber et al. 1970). Thus new land has slowly been created, which undergoes natural terrestrialization processes. Isostatic uplift may have also contributed to the drying as land rises above the local water table (Rockwell et al. 2009). A contributing biological factor is the significant increase in Eastern Prairie Canada Geese (*Branta canadensis*) populations since the 1970s (U.S. Fish and Wildlife Service 2007), that now nest abundantly in the AOI. Geese grub and shoot pull graminoids, causing the creation of ponds and peat devoid of vegetation, which in turn increases evapotranspiration (Abraham and Jefferies 1997). Anecdotally, Canada Geese have become more common in the AOI (Taverner and Sutton 1934, Skeel pers. comm. 2007).

Pan-Arctic climate warming, shrub and tree encroachment, and wetland drying in recent history however is clearly driven by anthropogenic climate forcing (IPCC 2007a). Climate warming is increasing the rate at which habitat and ecosystem changes occur, and considering the long-term nature of current anthropogenic forcing, will have an effect for centuries to come (Solomon et al. 2009).

Whimbrel Nesting Distribution Change

In Churchill in 2007 and 2008, I found Whimbrels nesting predominantly in sedge and standing water dominated, and lichen dominated habitats (Chapter 2). I also found they avoided shrubby and treed areas. No Whimbrel nested an area with >269 trees/ha (76 trees within 30m), and only one pair nested in an area with >134 trees/ha (38 trees within 30m). No Whimbrel nested in an area >17.5% tall shrub cover (Figure 3.5). Areas within the AOI with such tree densities have increased since 1973 (Table 3.5), and the 2006 image percent shrub cover (17.7%) exceeds 17.5% (Table 3.1). It is thought that Whimbrels and other shorebirds have evolved to use open habitat types that allow visual predator detection (Götmark et al. 1995). Whimbrels were often observed leaving the vicinity of their nests to chase off predators, even when the predators were several hundred meters away. If Whimbrels require open landscape to effectively detect predators, the AOI may have become too shrubby and treed for breeding Whimbrels.

The correlation between the increase in shrubs and trees, decrease in water and nesting Whimbrel, however, does not necessarily imply causality. A complementary and/or alternative explanation for the declined use of the AOI is that the local Whimbrel population has declined. Skeel's (1976, 1983) conclusion that hummock-bog habitats were optimal habitat based on nest density, success, and site fidelity, and anecdotal observation by ornithologists (Jehl 2004, Alison pers. comm. 2007, Koes pers. comm. 2008) strongly suggests a shift. However, because searched areas and effort were not consistent in the years when Whimbrels were most intensely studied, I can not determine if and to what magnitude a population decline has contributed to lower use of the AOI.

Furthermore, other biological changes have occurred in the AOI over the past 38 years. Nesting Canada Geese have anecdotally become much more common in the area,(Taverner and Sutton 1934, Jehl 2004, Skeel pers. comm. 2007) Unfortunately quantitative data for this species within the AOI does not exist. Besides destructive

foraging, Canada Geese that arrive and nest earlier than Whimbrels could perhaps take suitable nesting sites within the AOI. In the early 1930s, Taverner and Sutton (1934) wrote about the Churchill region, that Canada Geese were common transients that bred sparingly in the area. Canada Geese were not common in the AOI in the early 1970s (Skeel pers. comm. 2007). Sometime between the 1974 and 1980s nesting Canada Geese became abundant in the AOI (Jehl pers. comm.); currently, nesting Canada Geese are very abundant. There is no evident population trend for Common Ravens in Churchill (Jehl 2004), which prey upon both Canada Goose and Whimbrel eggs and young.

In 2007 and 2008, I recorded Whimbrels nesting in a fairly high density (~3 pairs/km²) in a small ~1.62km² area just north of Skeel's main study area. This area is comparatively more open, and is characterized by more graminoid and lichen-heath vegetation, and fewer hummocks, shrubs, trees, and nesting Canada Geese. This localized shift in breeding Whimbrels provides support for the hypotheses that the Whimbrels stopped using the AOI due to vegetation and/or Canada Goose population changes, and/or another unknown, correlated factor. Though I can not disentangle the effects of Canada Geese foraging or nesting, and population decline, the finding of increased tree and shrub density in the AOI coupled with mesohabitat use results (Chapter 2, Figure 3.5) imply that the habitat has become unfavorable. Without knowledge of how Whimbrels select habitats, I can only speculate that either the habitat became unfavorable, and/or nest success was lower in the area causing a decline in adult site fidelity, and the philopatry (Davis and Stamps 2004), thus reducing the overall use of the AOI.



Figure 3.1 1973 image of the area of interest; mosaicked, non-colour-matched aerial photographs (1:8000) provided courtesy of Margaret Skeel (photos missing for the white centre area).



Figure 3.2 1986 image of the area of interest; mosaicked, non-colour-matched aerial photographs (1:10000). © Province of Manitoba.



Figure 3.3 2006 high-resolution QuickBird satellite imagery of the area of interest. © DigitalGlobe, Inc. All Rights Reserved.



Figure 3.4 Example of the 50m x 50m grid overlain on imagery. Percent cover classifications were estimated for every fourth grid cell, except in the area of missing 1976 images (the same 246 grid cells were assessed for all three time periods).

						Other Veg (including
Year	Gravel	Water	Mud	Tree	Shrub	Lichen)
1973	3.4	30.9	1.2	3.4	5.1	50.2
1986	3.1	33.6	1.4	5.9	7.6	42.9
2006	2.3	26.5	6.5	10.3	17.7	31.1

Table 3.1 Summary of percent cover classification averages for the three time periods.

Table 3.2 Change in cover defined as the percent cover on the more recent image minus the percent cover of the older image, for the three time periods.

	1973→1986	1986→2006	1973→2006
Gravel	-0.3	-0.8	-1.1
Water	2.7	-7.1	-4.4
Mud	0.1	5.1	5.2
Tree	2.5	4.4	6.9
Shrub	2.5	10.1	12.6
Other Veg (including Lichen)	-7.3	-11.8	-19.1

Table 3.3 Relative change in cover defined as the change in cover divided by the percent cover in the older image (x100), for the three time periods.

	1973→1986	1986→2006	1973→2006
Gravel	-9.4	-24.7	-31.8
Water	8.8	-21.2	-14.2
Mud	9.7	376.1	422.1
Tree	72.6	73.8	200.1
Shrub	49.6	133.1	248.7
Other Veg (including Lichen)	-14.5	-27.6	-38.1

 Table 3.4 Change in percent cover per year between time periods.

	1973→1986	1986→2006
Gravel	-0.02	-0.04
Water	0.21	-0.36
Mud	0.01	0.26
Tree	0.19	0.22
Shrub	0.19	0.50
Other Veg (including lichen)	-0.56	-0.59



Figure 3.5 (Figure 2.6 modified) Number of trees within 30m of nest and centre points converted to trees/hectare against percent cover tall shrub of Whimbrel occupied (\bullet ; n=44), and randomly-selected, available (\Box ; n=47) habitat with 95% confidence ellipses (solid ellipse for occupied, and dashed ellipse for randomly-selected, available), and the 134 trees/hectare and 17.5% cover tall shrub value lines. In 2007, only one Whimbrel nested in an area >134trees/hectare, and none did in an area >17.5% cover tall shrub.

	trees/50mx50m grid cell			trees/ha		
cell	1973	1986	2006	1973	1986	2006
X09	13	17	27	52	68	108
R39	43	40	44	172	160	176
α18	23	19	20	92	76	80
γ48	48	64	72	192	256	288
V19	4	4	14	16	16	56
N11	12	36	34	48	144	136
a38	48	45	46	192	180	184
Y28	29	45	50	116	180	200
α26	26	16	25	104	64	100
X49	12	17	18	48	68	72
α42	6	19	19	24	76	76
K14	16	19	16	64	76	64
C10	27	37	34	108	148	136
J15	14	14	14	56	56	56
I16	0	8	9	0	32	36
δ27	4	34	48	16	136	192
T45	6	23	16	24	92	64
δ39	7	10	17	28	40	68
Z15	15	25	23	60	100	92
I20	38	38	53	152	152	212
average	20	27	30	78	106	120

Table 3.5 Estimated numbers of trees within twenty randomly-selected grid cells converted to trees per hectare. Bolded densities are >134 trees/ha (38 trees within 30m).



Figure 3.6 1973, 1986, and 2006 imagery samples showing increased shrub and tree cover in the AOI. Includes copyrighted material of the Province of Manitoba and DigitalGlobe, Inc., All Rights Reserved.



Figure 3.7 1973, 1986, and 2006 imagery samples showing increased shrub and tree cover in the AOI. Includes copyrighted material of the Province of Manitoba and DigitalGlobe, Inc., All Rights Reserved.



Figure 3.8 1973, 1986, and 2006 imagery samples showing decreased water cover in the AOI. In the 1973 and 1986 images, water is for the most part reflecting as darker grey, except the larger water body on the left which is reflecting as lighter grey. In the 2006 image, water is reflecting as white for the most part, but also as black in the far right of the image. Includes copyrighted material of the Province of Manitoba and DigitalGlobe, Inc., All Rights Reserved.



Figure 3.9 Average annual daily temperature (°C) in Churchill, MB from 1970-2007 . Average Annual Temperature= -102.702 + 0.048(Year), $F_{1,36}=5.85$, P=0.01, adj R²=0.12.



Figure 3.10 Total annual degree days in Churchill, MB from 1970-2008 . Degree Days=-13743.9 + 7.5(Year), $F_{1,36}$ =11.42, P<0.01, adj R²=0.22.



Figure 3.11(a-c) Mean, and mean maximum and minimum monthly temperatures in Churchill, MB from 1970-2008 . a) Non-significant mean May temperature trend ($F_{1,37}$ =0.06, P=0.80). b) Significant mean July temperature trend ($F_{1,37}$ =8.99, P<0.01). c) Closely significant October mean temperature trend ($F_{1,37}$ =3.71, P=0.06).



Figure 3.12 Total precipitation (mm; — and —), total rain (mm; — and — - –), and total snow (cm; — and - - –) in Churchill, MB since 1970 (total rain and snow fall data are missing since 1999, and total precipitation data are missing since 2006). Total precipitation (mm)= -7215.31+3.85(Year), $F_{1,34}=7.51$, P=0.01, adj R²=0.16; total rain (mm)= -4556.19+2.43(Year), $F_{1,27}=2.57$, P=0.12, adj R²=0.05; total snow (cm)= -353.43+0.27(Year), $F_{1,27}=0.06$, P=0.81, adj R²=-0.03.

Chapter 4: General Discussion

Findings, Limitations, Future Research, and Conservation

The Hudson Bay Lowlands and other sub-Arctic and Arctic regions provide critical nesting habitat for Whimbrels and other shorebirds, many of which are undergoing population declines (Morrison et al. 2006, Stroud et al. 2006, Bart et al. 2007). With great uncertainty surrounding the impacts of climate change and human development on Whimbrels and other shorebirds, research on habitat use requirements and thresholds, and habitat change are needed.

This study found that in the Churchill region, Whimbrels nested in habitats dominated by (1) lichen, and (2) standing water and sedge. It is not understood what is driving this dual habitat use. This study and others suggest that graminoid and standing water dominated habitats are disproportionately used (Göransson et al. 1975, Gratto-Trevor 1994, Pirie 2008); however, elsewhere preference for heath is reported (Grant 1991). Further studies documenting nesting habitat in relation to available habitat, prey availability, predator pressure, and determining habitat use with either VHF or satellite tracking devices during incubation and post hatching could help elucidate differences between the two habitat types and how Whimbrels use them.

In Churchill in 2007 and 2008, Whimbrels had lower hatching success than previously reported. Predation was rarely observed. Research on nest predation aided by nest cameras could help determine predator types, frequencies, and timing of depredation events. Knowing the cause of predation may also help predict how climate and habitat changes will affect productivity. It is unknown whether this finding of low hatching success represents annual variation or a trend that could be caused by changes in vegetation, climate, and/or predator and prey communities. As some of my study areas have continued to experience high hatch success the loss of previously suitable and productive habitat, causing a redistribution of nesting Whimbrels to overall lower productivity sites is another hypothesis. Long-term monitoring and research studies collecting both predation pressure and demographic data that have the power to detect trends, and can be used in population analyses are needed. I therefore recommend a longterm study of Whimbrel breeding productivity in the Churchill region be conducted. Information on adult mortality is also needed throughout the annual life cycle, and among years.

As this study was based on data from a single region, the findings of nesting habitat, changed distribution, and hatching success can not be extrapolated to other regions with high confidence. One area of future research would be to test the resulting mesohabitat model, on data collected from another region. With this in mind I collected data in a fairly similar manner, with the same cover classifications as Pirie (2008), who studied nesting Whimbrel habitat in the outer MacKenzie Delta. It may also be possible to build habitat occupancy models based on remote sensing imagery if it were available for the entire study area. The resulting model could then be validated with past nesting and imagery data provided both were available for the whole study area in the same year. Investigation and documentation of other potential shorebird distribution shifts, habitat changes, habitat use thresholds, and a comprehensive literature review to determine main drivers behind habitat abandonment by birds, distribution shifts, and other responses to changing environments are needed topics of study. In the absence of long-term studies, revisiting areas where previous research was conducted, as was done in this study, can help determine how species respond to changing environments.

In Churchill, Whimbrels have changed their nesting distribution, abandoning areas of historical importance. I found a correlation between Whimbrel habitat abandonment and increased shrub and tree cover, and decreased water and other vegetative cover. These correlations, however, do not equate to causality and other confounding factors such as increased Canada Goose abundance may exist. A study of the sequence of events of Canada Goose colonization concomitant with documented potential abandonment by large waders, or a study of sympatric nesting or lack thereof could help determine if Whimbrel habitat abandonment is influenced by high Canada Goose abundance.

Research verifying the theory that shorebirds have evolved to nest in open landscapes to aid predator detection would help make clear the effects of increased shrub and tree in the sub-Arctic and Arctic tundra. A simple experiment to determine if predator detection is predominantly auditory or visual could be conducted by employing a stuffed raven and/or raven call recordings at varying distances from incubated nests and observing adult responses. Whimbrels seemingly have a ritualized, aggressive response to Common Ravens, and anecdotally, it appeared they were visually detected.

Land cover maps with biological significance (e.g. tree line and densities, shrub cover, dates of 50% snow cover etc.) to biota such as shorebirds should be developed, and change should be assessed historically and monitored into the future. Habitat change analysis methodologies and tools are expanding. I visually estimated percent land cover from images. Human interpretation can be advantageous in terms of accuracy if the researcher is familiar with the study area and/or is skilled in image interpretation (Zsilinsky 1966). Unlike traditional computer classification that use spectral band information, the human eve can process many attributes at once, such as colour, shape, size, height, location, associations, tone, texture, and pattern . Furthermore, with sufficient aerial photo overlap, it is possible to view images in stereo so that depth can be perceived and photogrammetric measurements can be taken. In addition, when classification needs to be done at a very fine scale such as at the scale needed to count individual trees, and/or when the landscape is extremely heterogeneous (e.g. when water reflects many different colours due to varying depths, or when more than one land cover classification reflects at a similar colour), computer classification is often inaccurate and/or training of the software is difficult. Computer classification, such as "supervised" and "unsupervised" classification also has advantages. It is much quicker, more spectral data are utilized as much data are undistinguishable to the human eye (e.g. data collected using 256 shades of gray, but analysts may only be able to distinguish 8 shades), and it has high repeatability (Zsilinsky 1966). High repeatability, even if erroneous, allows the results to be compared and contrasted, whereas, with human interpretation, results may vary due to subjectivity, analyst skill, and familiarity with the area. The future of land cover classification likely lies in software such as eCognition® (Definiens Inc. 2008), which is unique in that it completes automated classification based on objects rather than pixels. eCognition® classification allows the user to train the software to recognize cover types similar to traditional "supervised" classification. It is also able to take into account attributes such as texture and shape in discerning cover types and objects, thus emulating human cognitive processes.

Habitat change analyses will also benefit from new high-resolution satellite imagery. Satellite imagery is available in a range of resolutions, with the WorldView-1 and QuickBird satellites currently providing the highest resolution available of 50cm and 61cm respectively (DigitalGlobe Inc. 2008). Satellite imagery acquisition can greatly cut down on the time requirements, as the scanning, mosaicking, and rectification or orthorectification of aerial photography is time intensive. Mosaicking and rectification can be done digitally with the digital data collected with satellite imagery. Currently, however, low-altitude aerial photography can still provide higher resolution and a three dimensional image, and will still be required depending on the time periods to be studied.

Key for conservation efforts is maintaining the integrity of Whimbrel habitat throughout its annual cycle, including non-breeding, staging, and breeding habitats. The full identification of breeding habitat, migration patterns, and population structure is needed. In the far north where comparatively sparse human populations and development pressures exist, there is the opportunity and necessity to complete conservation planning and implementation in the most comprehensive, effective, and timely manner. Ecologists and climatologists need to collaborate to help predict how, and to what magnitude and time frame climate change will affect biodiversity. Long-term monitoring at both broad and local scales is vitally important for population assessment and conservation. Most fundamentally for reversing declines in Whimbrels and biodiversity in general is the control of anthropogenic climate forcing, habitat loss, fragmentation and degradation, pollution, and invasive species introductions.

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Appendix 1a. NAD83 UTM (Zone 15) coordinates of Whimbrel nest sites (n=45) and randomly-selected, available sites (n=47) in the Churchill, MB region during the 2007 breeding season.

Nest			Random		
Site ID	Easting	Northing	Site ID	Easting	Northing
01WHIM07	449116	6511224	01RAND07	451630	6512082
02WHIM07	437657	6509943	02RAND07	450693	6514181
03WHIM07	443550	6512919	03RAND07	450880	6512332
04WHIM07	452297	6511345	04RAND07	449156	6510982
05WHIM07	453201	6510782	05RAND07	452340	6502636
06WHIM07	454647	6510457	06RAND07	451528	6502786
07WHIM07	452549	6512396	07RAND07	451777	6509670
08WHIM07	452447	6511983	08RAND07	447806	6512482
09WHIM07	452078	6503449	09RAND07	443994	6513044
10WHIM07	452781	6503894	10RAND07	452832	6510164
11WHIM07	452443	6504074	11RAND07	438958	6509208
12WHIM07	450521	6503490	12RAND07	436406	6511482
13WHIM07	449034	6511833	13RAND07	436469	6511270
14WHIM07	446014	6513143	14RAND07	437309	6512369
15WHIM07	448673	6511579	15RAND07	441795	6513919
16WHIM07	453235	6502890	16RAND07	441995	6513594
17WHIM07	453153	6510388	17RAND07	443582	6513569
18WHIM07	453153	6510388	18RAND07	451018	6512994
19WHIM07	453298	6511629	19RAND07	444788	6513601
20WHIM07	451464	6511907	20RAND07	447619	6511607
21WHIM07	452257	6503891	21RAND07	451633	6509989
22WHIM07	436997	6511698	22RAND07	439294	6508141
23WHIM07	437088	6512075	23RAND07	438041	6509062
24WHIM07	437193	6511933	24RAND07	438001	6510409
25WHIM07	446475	6512919	25RAND07	436056	6512944
26WHIM07	452488	6509810	26RAND07	434619	6511757
27WHIM07	451946	6503308	27RAND07	433832	6513869
28WHIM07	437394	6511573	28RAND07	432295	6514581
29WHIM07	436936	6512041	29RAND07	452392	6513544
30WHIM07	437623	6509796	30RAND07	449918	6511307
31WHIM07	452614	6512467	31RAND07	451651	6509285
32WHIM07	453886	6511660	32RAND07	455037	6510023
33WHIM07	453245	6510500	33RAND07	443595	6512657
34WHIM07	451627	6504408	34RAND07	442382	6512969
35WHIM07	451824	6504346	35RAND07	448522	6512031
36WHIM07	452388	6503810	36RAND07	440708	6513678
37WHIM07	449129	6511605	37RAND07	448444	6510439
38WHIM07	453681	6509278	38RAND07	436487	6513219
39WHIM07	452273	6509823	39RAND07	448093	6510220
40WHIM07	451628	6509461	40RAND07	451105	6503579
41WHIM07	453974	6510022	41RAND07	445884	6513609
42WHIM07	452102	6504180	42RAND07	450078	6512463
43WHIM07	453402	6509404	43RAND07	452800	6501998
44WHIM07	447153	6512936	44RAND07	452306	6501846
45WHIM07	452495	6511497	45RAND07	452252	6502250
			46RAND07	452546	6502036
			47RAND07	452496	6512691

Nest		
Site ID	Easting	Northing
01WHIM08	452782	6503746
02WHIM08	451831	6504345
03WHIM08	453263	6511722
04WHIM08	447602	6511746
05WHIM08	452696	6503565
06WHIM08	451960	6503501
07WHIM08	449069	6511057
08WHIM08	451981	6503922
09WHIM08	453309	6503927
10WHIM08	454822	6511639
11WHIM08	454408	6511088
12WHIM08	454512	6511657
13WHIM08	454218	6511029
14WHIM08	453333	6510787
15WHIM08	443950	6512057
16WHIM08	451859	6509532
17WHIM08	451952	6509464
18WHIM08	453640	6509441
19WHIM08	453647	6508831
20WHIM08	453268	6510466
21WHIM08	452266	6511071
22WHIM08	451278	6503238
23WHIM08	453988	6510717
25WHIM08	439130	6512283
27WHIM08	451228	6504986
28WHIM08	451597	6503652
29WHIM08	452082	6504511
30WHIM08	449181	6511735
31WHIM08	437294	6511429
32WHIM08	451701	6504304
33WHIM08	451924	6504483
34WHIM08	451787	6504910
35WHIM08	451612	6504983
36WHIM08	451541	6504800
37WHIM08	454214	6511683
38WHIM08	451579	6504596
39WHIM08	453204	6510204
41WHIM08	451318	6504696

Appendix 1b. NAD83 UTM (Zone 15) coordinates of Whimbrel nest sites (n=38) located in the Churchill, MB region during the 2008 breeding season.



Appendix 2a. Whimbrel 2007 breeding season schedule.



Appendix 2b. Whimbrel 2008 breeding season schedule.

Appendix 3. Daily survival of Whimbrel nests monitored in 2007 (n=43), and 2008 (n=32) in Churchill, MB. Some nests were excluded from the analysis due to insufficient data needed to age the nest.





Appendix 4. Whimbrel *Numenius phaeopus* North American banding longevity record from Churchill, Manitoba, Canada

Since 1962, 322 Whimbrels (*Numenius phaeopus*) have been banded in the Churchill, Manitoba (58° 43' N, 94° 7' W) region. Twenty-one Whimbrels have been banded in Churchill since the 1990s, and none more recently than 1999 (Bird Banding Laboratory database, USGS, Biological Resources Division, Laurel, MD). During the 2007 breeding season three banded Whimbrels were observed near Churchill. Band readings were made on two of these Whimbrels, one of which establishes a North American longevity record of 13 years (see Klimkiewicz 2008).

A Whimbrel with band number 0634-89020 was banded as a chick by Jehl and Lin on 6 July 1994. Thirteen years later, on 25 June 2007 it was recaptured and released at its nest (NAD83 UTM: 452273, 6509823), which we estimate was within 400m of its 1994 natal nest. A complete, 4-egg clutch hatched on 2 July 2007. This age establishes a new, known longevity record for a North American Whimbrel, surpassing the previously published record of 11 years also from Churchill (Skeel 1976a, Klimkiewicz 2008). However, another sighting of a banded bird in Churchill suggested a Whimbrel of at least 19 years (Skeel and Mallory 1996).

A male Whimbrel with band number 1714-00044 was banded by Jehl on 15 June 1999 as an adult. Both members of the pair were banded. On 16 July 2007 the band was read through multiple photographs of the Whimbrel taken near its nest (NAD83 UTM: 452495, 6511497). This Whimbrel nest was first located on 10 July 2007, and three of their four eggs hatched on 18 July 2007. It is suspected that this nest was a re-nesting attempt, and this late hatching date is two days later than the latest reported hatch date in the Birds of North America Whimbrel account (Skeel and Mallory 1996). One of the eggs that successfully hatched was light blue, the only egg observed of this colour, perhaps indicating a problem with the egg pigmentation process (Kilner 2006), although the rare possibility of intraspecific dumping cannot be ruled out (Witherby et al. 1940, Harris et al. 1981, Grant 1991) (Fig. 1). The 2007 nest of this bird was approximately 100m from its 1999 nest site. Its 2007 mate was not banded. This Whimbrel was banded as an after hatch year and thus was at least 9 years in age. As it is believed that Whimbrels first breed at age 3, this bird is probably at least 11 years in age.

The above longevity record, the Whimbrels' active breeding statuses, the proximity of the nest to the natal nest, and the late hatching date are of ecological interest. The longevity record, however, is not surprising based on longevity records for the European Whimbrel subspecies and other curlews. The European Whimbrel *N*.*p*. *phaeopus* longevity record from Great Britain is 16 years and one month (Staav & Fransson 2008). Records for other curlews include a record of 31 years for the Eurasian Curlew *N. arquata* also from Great Britain (Rydzewski 1975), 23 years for the Bristle-thighed Curlew *N. tahitiensis* from the Northwestern Hawaiian Islands (Marks 1992, Klimkiewicz 2008), and 19 years and one month for the Eastern Curlew *N. madagascariensis* from Australia (Australian Bird and Bat Banding Scheme database, Department of the Environment, Water, Heritage and the Arts, Canberra, ACT).

New longevity records can be expected for North American species should banding and research continue. Long-term studies of sub-Arctic and Arctic North American breeding shorebirds are important in garnering basic ecological knowledge necessary for population analyses. Whimbrel longevity records from the Churchill region were only possible because of the concentrated ornithological research over a long period at Churchill (Jehl 2004, Lin 1997, Skeel 1976b).

Dr. J.R. Jehl, Winli Lin and Margaret Skeel are acknowledged for their Whimbrel research and banding efforts in Churchill, Manitoba.



Fig. 1. The nest of a Whimbrel (band number: 1714-00044) in Churchill, Manitoba, showing the light blue colour of one of the eggs, the only egg observed of this colour. It is believed that this nest was a re-nesting attempt.

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format that allows printing and viewing at no better than ten meter resolution and (b) the proper copyright is conspicuously marked. The Product and any Derivative Works may be posted to secure Intranet websites and may be used only for the purposes of a Joint Project and subject to Section 3;

- c. If you are a State and Local Government Agency, you may post the Product and Derivative Works on your website at full resolution for non-Commercial Purpose in a non-downloadable, non-distributable fashion and in a manner that does not allow a third party to extract or access the Product as a standalone file;
- d. Make unlimited copies of the Product for internal use only;
- e. Create Derivative Works for internal use, including reformatting the Product into different formats or media from which it is delivered, modifying the Product through manipulation techniques and/or the addition of other data, and making copies of the resulting bundled image product;
- f. Publish the Product, in a non-digital format and for a non-Commercial Purpose, in research reports or similar publications after obtaining the express written consent of DigitalGlobe; and
- g. All Products or Derivative Works must contain the following copyright notice conspicuously displayed: "(c) DigitalGlobe, Inc. All Rights Reserved" for the Product, and "Includes copyrighted material of DigitalGlobe, Inc., All Rights Reserved" for Derivative Works.

3. Sublicense.

a. Subject to Section 3(d), you may sublicense the rights granted under Section 2 to Customer Groups identified by you at the time you acquire this license who are engaged in a Joint Project with you. The number of permitted Customer Groups sublicensed hereunder depends on the type of license purchased by you as follows:

Type of License Purchased	Number of Permitted Customer Groups
Base	Up to five
Group	From six to ten
Enterprise	From 11 to 25
Enterprise Premium	More than 25
Educational	One
Demonstration	One

b. If the number of individuals of a sublicensed Customer Group using the Product exceeds the number of users permitted under this Section 3, the Customer Group will be counted as multiple sublicensees based on the number of individuals using the Product, for purposes of determining compliance with the table above. If a Customer Group is involved in multiple Joint Projects, the Customer Group will be counted as

multiple sublicensees, based on the number of Joint Projects involved, for purposes of determining compliance with the table above.

- c. Subject to Section 3(d), you may also sublicense the rights granted under Section 2 to any independent contractor hired by you to perform customization services for the Product.
- d. You may grant a sublicense to a sublicensee under Section 3(a) or 3(c) provided that (i) such sublicensee agrees to be bound by this Agreement, (ii) the sublicense is limited to using the Product solely for the purposes of the Joint Project or for purposes of performing the customization services, and (iii) you are responsible for any noncompliance by such sublicensee and such sublicensee's breach of this Agreement shall be deemed to be your breach of this Agreement.
- 4. **Prohibited Use**. You recognize and agree that the Product is the property of DigitalGlobe and contains valuable assets and proprietary information of DigitalGlobe. Accordingly, you will not:
- a. Use the Product or Derivative Works for any purpose not expressly permitted under this Agreement, including without limitation for Commercial Exploitation;
- b. Sell, license, rent, transfer, give away, disclose, copy or reproduce (even if merged with other materials), create Derivative Works of, display, or distribute the Product, except as expressly permitted under this Agreement; or
- c. Alter or remove any copyright notice or proprietary legend contained in or on the Product. You acknowledge that you need to obtain a separate distribution license from DigitalGlobe in order to distribute or publish the Product or any Derivative Work in any form not expressly permitted under Section 2.
- 5. **Ownership**. The Product, and all intellectual property rights therein, are the exclusive property of DigitalGlobe and its suppliers. All rights in and to the Product not expressly granted to you are reserved by DigitalGlobe and its suppliers. This Agreement does not grant you title to the Product or any copies of the Product.
- 6. **Confidentiality**. The Product includes metadata and other confidential and proprietary information of DigitalGlobe ("Confidential Information"). You will not use any Confidential Information for any purpose not expressly permitted hereunder and will disclose Confidential Information only to your employees and permitted sublicensees who have a need to know for purposes of this Agreement and who are under a duty of confidential Information from unauthorized use, access, or disclosure in the same manner as you protect your own confidential or proprietary information of similar nature and with no less than reasonable care.

- 7. Audit. At DigitalGlobe's request, you will provide assurances that you are using the Product consistent with the terms of this Agreement. Upon notice, DigitalGlobe may inspect your records, accounts and books relating to the use of the Product to ensure that the Product is being used in accordance with this Agreement.
- 8. Term and Termination. This Agreement remains in full force until terminated as provided below. DigitalGlobe has the right to terminate this Agreement, effective immediately upon notice to you, if you breach any provision of this Agreement. Upon termination of this Agreement, all rights granted to you hereunder shall immediately cease. You and your sublicensees will (i) discontinue all use of the Product; (ii) if the product was delivered on a tangible medium, return to DigitalGlobe the Product and all copies thereof; (iii) purge all copies of the Product or any portion thereof from all computer storage device or medium on which you have placed or permitted others to place the Product; and (iv) give DigitalGlobe a written certification that you have complied with all of your obligations hereunder.
- 9. Limited Warranty. DigitalGlobe warrants that for a period of thirty (30) days after delivery, the Product will perform substantially in accordance with its applicable specification. DigitalGlobe's sole obligation and your entire remedy for breach of the above warranty is for DigitalGlobe, at its option and expense, to (i) repair or replace the non-conforming Product returned during the warranty period; or (ii) refund all fees paid by for the non-conforming Product returned during the warranty period.

EXCEPT AS PROVIDED ABOVE, THE PRODUCT IS PROVIDED "AS IS" WITHOUT ANY WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, AND ALL WARRANTIES OF MERCHANTABILITY, NON-INFRINGEMENT, AND FITNESS FOR A PARTICULAR PURPOSE ARE EXPRESSLY DISCLAIMED. DIGITALGLOBE DOES NOT WARRANT THAT THE PRODUCT WILL MEET YOUR NEEDS OR EXPECTATIONS, OR THAT OPERATIONS OF THE PRODUCT WILL BE ERROR FREE OR UNINTERRUPTED.

The limited warranty is void if any non-conformity has resulted from accident, abuse, misuse, misapplication, or modification by any person other than DigitalGlobe.

10. Limitation of Liability. IN NO EVENT WILL DIGITALGLOBE OR ITS SUPPLIERS BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL, SPECIAL, EXEMPLARY, OR INDIRECT DAMAGES (INCLUDING LOST PROFITS AND LOST DATA) ARISING FROM OR RELATING TO THIS AGREEMENT AND THE PRODUCT, EVEN IF DIGITALGLOBE OR ITS SUPPLIERS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. DIGITALGLOBE AND ITS SUPPLIERS' TOTAL CUMULATIVE LIABILITY IN CONNECTION WITH THIS AGREEMENT AND THE PRODUCT, WHETHER IN CONTRACT OR TORT OR OTHERWISE, WILL NOT EXCEED THE AMOUNT OF LICENSE FEES PAID TO DIGITALGLOBE FOR THE PRODUCT. THIS SECTION SHALL BE GIVEN FULL EFFECT EVEN IF THE WARRANTIES PROVIDED IN SECTION 9 IS DEEMED TO HAVE FAILED OF ITS ESSENTIAL PURPOSE.

11. **Export Control**. You will not export or re-export the Software in violation of the U.S. Export Administration regulations or other applicable laws and regulations. You will defend, indemnify, and hold harmless DigitalGlobe from and against all fines, penalties, liabilities, damages, costs, and expenses incurred by DigitalGlobe as a result of any violation of such laws and regulations by you or any of your agents or employees.

12. Miscellaneous Terms.

- a. You acknowledge that any actual or threatened breach of Section 2, 4, or 6 will constitute immediate, irreparable harm to DigitalGlobe for which monetary damages would be an inadequate remedy, and that injunctive relief is an appropriate remedy for such breach. If any action is brought to enforce this Agreement, the prevailing party will be entitled to receive its reasonable attorney's fees, court costs, and other collection expenses, in addition to any other relief it may receive.
- b. Failure to require performance of any provision of this Agreement does not waive DigitalGlobe's right to subsequently require full and proper performance of such provision. If any provision of this Agreement is determined to be invalid or unenforceable, the remaining provisions of this Agreement shall continue to be valid and enforceable.
- c. Neither this Agreement nor any of the rights or obligations hereunder may be assigned or transferred by you without the prior written consent of DigitalGlobe. This restriction on assignment or transfer shall apply to assignments or transfers by operation of law, as well as by contract, merger or consolidation. Any attempted assignment or transfer in violation of the foregoing will be null and void.
- d. This Agreement shall be governed by the laws of the State of Colorado, U.S.A., without regard to conflicts of law principles that would require the application of the laws of any other state or jurisdiction. The United Nations Convention on Contracts for the International Sale of Goods does not apply to this Agreement. Any action or proceeding arising from or relating to this Agreement must be brought in a federal court or a state court in Boulder County, Colorado, and each party irrevocably submits to the jurisdiction and venue of any such court in any such action or proceeding.
- e. The software portion of the Product is "commercial item" as that term is defined in 48 C.F.R. 2.101, consisting of "commercial computer software" and "commercial computer software documentation" as such terms are used in 48 C.F.R. 12.212. Any technical data provided with or included in the Product is "commercial technical data" as defined in 48 C.F.R. 12.211. Consistent with 48 C.F.R. 12.211 through 12.212, 48

C.F.R. 227.7202-1 through 227.7202-4, and 48 C.F.R. 252.227-7015, all U.S. Government end users acquire the Product with only those rights set forth therein.

- f. This Agreement represents the entire agreement between you and DigitalGlobe as to the matters set forth herein and integrates all prior discussions and understanding between us. Your acceptance of this Agreement is expressly limited to the terms and conditions set forth herein; any additional or inconsistent terms provided by you in any other documents such as a purchase order will not have any legally binding effect. This Agreement may be modified only by a binding written instrument entered into by you and DigitalGlobe.
- 13. **Notices**. Any notices relating to this Agreement should be sent by personal delivery or U.S. certified mail (return receipt requested) to the address provided below and will be effective upon receipt:

DIGITALGLOBE, INC. ATTN: LEGAL DEPT. 1601 Dry Creek Dr., Suite 260 Longmont, CO 80503, USA