

**SHOREBIRD STAGING AND MIGRATORY MOVEMENTS AT CHAPLIN AND REED
LAKES, SASKATCHEWAN, WITH IMPLICATIONS FOR WIND ENERGY
DEVELOPMENT**

A Thesis Submitted to the College of
Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements
For the Degree of Master of Science
In the Department of Biology
University of Saskatchewan
Saskatoon

By

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ABSTRACT

Increasing knowledge of long distance shorebird (order Charadriiformes) migrations may elucidate causes of shorebird declines and direct management within migratory routes. Migrating birds rely on staging sites, areas with reliably high food abundance, for rest and refueling. Stressors at these sites could have population level impacts and post-migration carry-over effects. My thesis research examined staging bird abundance and migratory movements to and from Chaplin and Reed Lakes, Saskatchewan, a major staging site of hemispheric importance in the Central Flyway used by over 100,000 shorebirds each year. My objectives were to 1) examine time of peak abundance by multiple migratory shorebird species using Chaplin and Reed Lakes during spring and fall migration, as well as estimate spring stopover duration and population size of Sanderling (*Calidris alba*) and 2) investigate movement patterns of migratory shorebirds as they arrive at and depart from Chaplin and Reed Lakes, and determine the extrinsic factors influencing observed flight patterns to inform risk from current and future wind energy developments.

I used a combination of point count surveys and radio telemetry data to meet my objectives. Staging, arctic-breeding species at Chaplin and Reed Lakes were counted weekly during spring northward (2014 – 2017) and fall southward (2016 – 2017) migration by conducting point count surveys to examine temporal patterns and estimate population size. Detailed assessments of my focal species, Sanderling included capture, banding and radio-tagging in the Gulf of Mexico and at Chaplin Lake (2015-2017) to track their migratory movements and stopover duration in relation to weather and time of day variables using automated radio telemetry.

Spring migration involved larger numbers of species (including species at risk), larger numbers of individuals, and more concentrated timing among years than fall migration. Sanderlings staged for a mean of 11.1 (95% CI = 8.59 – 13.6) days and population size averaged ~75,000 birds, with estimates ranging from ~56,000 to ~91,000 among years. Population estimates were seven to 17 times larger than raw peak abundance counts, demonstrating the need to account for stopover duration in population estimates. Chaplin and Reed Lakes departures, but not arrivals, were significantly influenced by time and weather. Sanderlings were more likely to depart at sunset or sunrise when winds were blowing towards the northwest at intermediate speeds and less likely to depart when winds were blowing towards the southeast at high speeds.

Knowledge of when large numbers of birds are using the area and what environmental conditions are associated with migratory movements can be used to identify where and when birds are at the greatest risks of collision with wind energy turbines. My results have implications for shorebird conservation at Chaplin and Reed Lakes and other staging sites in the Central flyway, and my thesis provides recommendations for management and mitigation of threats from current and future wind energy developments.

ACKNOWLEDGEMENTS

Thank you to my supervisors, Drs. Christy Morrissey and Ann McKellar, for allowing me the opportunity to pursue my M.Sc. at the University of Saskatchewan, and for their mentorship, support, patience, and encouragement throughout the project. Thank you also to my committee members Drs. Rick Espie and Kirsty Gurney, for their help and guidance with all aspects of the project, including all-night shorebird trapping efforts in the field! Thank you also to Dr. Bob Clark, Dr. Mark Drever, and Matt Frey for sharing your statistical knowledge and improving my confidence in the field.

Thank you to the many who faired the cold and wind at Chaplin Lake to provide field assistance: Kristin Bianchini, Chris Chutter, Leanne Flahr, Matt Frey, Carla Labarère, Katelyn Luff, Jamille McLeod, Laura Messett, Steve Pemble, Nicholas Shephard, Steve Simpson, Merci Rapolti, Alex Vien, Steve Wilkie, Lori Wilson, and others that offered their time. Thank you to our collaborators and landowners for all of their support: the Chaplin Nature Centre, David Newstead (Coastal Bend Bays & Estuaries Program, CBBEP, U.S.A.), John Brzustowski, Zoe Crysler, and Stuart Mackenzie (Motus Wildlife Tracking System/Bird Studies Canada), Dave Halstead, Shannon Munroe, and Leila Benmerrouche (Saskatchewan Polytech Applied Research), Ron and Glenda Gleim (Chaplin Grain Corporation), Grant Lea (Compass Minerals), Joel Perry (Danielson Provincial Park), Ducks Unlimited, Kerry Hecker (Last Mountain Lake National Wildlife Area), Jim Mackie, Robert and Maria McKay, Nature Conservancy Canada, Saskatchewan Mining and Minerals, Bob and Marjore Walde, and Lori and Mark Wilson. It has been an honour and a privilege to work with you all, and the project would not have been possible without you.

Thank you to my funding sources, including Saskatchewan Ministry of Environment, Environment and Climate Change Canada, NSERC, and University of Saskatchewan Department of Biology.

Thank you to all of the Sanderlings that carried radio transmitters on their epic migratory journeys. In addition to providing me with data, they have left me awestruck by their ability to find their way thousands of kilometers across continents and oceans each year.

Thank you to all of my wonderful family and friends near and far, whose love, support, and encouragement mean the world to me. I am so grateful to my parents, Dana and April

Howell, for fostering my loves of nature and adventure from the beginning and for always emphasizing their faith in me when I needed to hear it most. Thank you to my husband, Steve Pemble, for being my rock throughout this journey; my thoughtful and patient life partner. Finally, a special thank you to my dogs Timber and Kietha, for keeping me calm through puppy kisses, cuddles, and walks.

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CHAPTER 1:

UNDERSTANDING SHOREBIRD MIGRATION IN A CHANGING WORLD

1.1 A “Golden Age” of Migration Research

1.1.1 General Knowledge

Migrations, defined here as regular seasonal movements between wintering and breeding grounds, are journeys undertaken by hundreds of bird species in the Americas (Berthold 2001). Birds migrate to take advantage of seasonal food and nesting conditions, and can migrate short to extremely long distances across continents and oceans (Berthold 2001). Migration is composed of two alternating phases: flight and fuel (fat) deposition (Alerstam 2011). How these two phases interact through migratory decisions to contribute to overall migration success remains a significant area of research as species-specific patterns and environmental influences are not fully understood.

Four main flyways (Atlantic, Mississippi, Central, and Pacific), generalized paths running north to south between the Americas, are used by millions of waterbirds (Boere and Stroud 2006). There are different costs and benefits associated with each flyway; birds using the Atlantic or Pacific Flyways may navigate by following the coastline and save energy under stronger assisting spring winds (Atlantic Flyway only) (Åkesson 1993; La Sorte et al. 2014). Birds using the interior Mississippi and Central Flyways typically experience milder weather and are not at risk of being blown out over the ocean (Richardson 1990; Werner et al. 2013). Regardless of the flyway used, migrating birds stop to rest and refuel at multiple stopover or staging sites along the journey. Both stopover and staging sites are defined by abundant food, shelter, low competition, and low predation, but staging sites often have more stable food abundance, are larger than stopover sites, and may be located in otherwise inhospitable landscapes such as deserts. Birds using stopover sites typically use different migratory strategies than those at staging sites. Stopover sites are used by “hopping” migrants, flying short distances to then rest and refuel for short intervals of time (hours to days). Many passerines employ the stopover strategy. Staging sites are used by “jumping” migrants, flying longer distances to then rest and refuel for longer intervals of time (weeks). Many waterbirds utilize the staging strategy (Warnock 2010).

Successful migration in both the flight and fuel phases requires migrants to opportunistically respond to a dynamic suite of extrinsic (e.g. weather) and intrinsic variables (e.g. body condition). Weather conditions such as low cloud cover, low precipitation, and light to intermediate winds blowing in the direction of travel (creating tailwinds) are conducive to flight (Richardson 1990). Wind appears to show the strongest effect on departure decisions across taxa; birds depart in energy-saving tailwinds significantly more often and in larger numbers than in headwinds (Schmaljohann and Naef-Daenzer 2011; Grönroos et al. 2012; Sjöberg et al. 2015). Migrating birds can synchronize fueling phases with seasonal peaks in resources, such as the use of spring emergence of spawning horseshoe crabs, which lay high calorie eggs, by shorebirds at Delaware Bay (Castro and Myers 1993).

Optimal migration theory predicts that migrating birds will respond as part of an overall strategy to minimize travel time, energy expenditure, and/or predation risk and maximize their chances of survival and reproduction on the breeding grounds (Alerstam and Lindström 1990). For example, raptors fly during the day, minimizing energy expenditure through thermal lift. Conversely, shorebirds and passerines minimize predation risk and maximize energy intake by flying at night when predators and foraging opportunities are few. While staging, shorebirds often have higher fuel deposition rates than passerines, reflecting a time minimization strategy which is expected given longer flights (“jumps”) and longer overall migration distance of many shorebirds (Warnock 2010; Alerstam 2011). However, multiple variables influence migratory behaviour; in reality strategies are more complicated and not mutually exclusive to species (Alerstam 2011).

1.1.2 Importance of Migratory Phases in the Annual Cycle

A migratory bird’s annual cycle in the Western Hemisphere includes multiple phases: wintering at lower latitudes, spring northward migration, breeding at higher latitudes, and fall southward migration. The migration phases may involve higher mortality rates than stationary periods (wintering and breeding) because of the high energetic requirements and risks associated with crossing broad, unfamiliar landscapes. Individually, high energetic requirements may compromise immune system function, predisposing migrating birds to disease (Altizer et al. 2011). Mass-mortalities of flocking migrants are often due to problems from storms encountered during flights, leading to hypothermia, drowning (if forced down in altitude over water), or

collision with structures due to low visibility, hail, or electrocution by lightning strikes (Newton 2007). When compared to the wintering and breeding (stationary) phases of the annual cycle, mortality rates during migration were 15 times higher in color-banded Black-throated Blue Warblers (*Setophaga caerulescens*) in North America (Sillett and Holmes 2002) and six times higher in raptors tracked using satellite transmitters in Europe and Africa (Klaassen et al. 2014).

In addition to direct mortality in a single phase of the annual cycle, risks and success in one phase can affect the next through carry-over effects- events or conditions in one season that affect success and fitness in the next season (Newton 2006; Harrison et al. 2011). During migration, changes in food supply, food access, weather, predation, and disease at a staging site can have carry-over effects into the breeding season. For example, if food supplies at a staging site decline, birds might depart from the site later and with lower fuel stores, resulting in later arrival to the breeding grounds, lower clutch sizes, lower nest success, and lower survival (Newton 2006). This occurred in Red Knots (*Calidris canutus rufa*) staging at Delaware Bay in the springs of 1997 - 2002; knots arrived later and departed in poorer body condition, likely due to prey shortages from human overharvesting of horseshoe crab eggs and shoreline habitat destruction. This was followed by lower recruitment of young and lower adult survival on the wintering grounds (Baker et al. 2004). Because of these carry-over effects, habitat degradation or damage at stopover and staging sites (e.g. oil spills or wetland drainage) could have repercussions across seasons, locations, populations, and species (Henkel et al. 2012).

1.1.3 Small Bird Tracking Techniques

Studies of migratory birds have long been limited by the difficulty of following small, highly mobile animals, but rapidly evolving technologies have initiated what has been called a “Golden Age” of migration science (Wilcove and Wikelski 2008). New technologies allow for more detailed tracking (more detections, finer spatial resolution, and inclusion of various sensors such as temperature, altitude, and light) over entire migratory routes and across seasons (Shamoun-Baranes et al. 2017). Tracking technologies include data loggers (e.g. solar geolocation, GPS loggers) that store information until retrieved from the animal carrying the device and data transmitters (e.g. radio telemetry, satellite or cellular transmitting devices) that transmit information to receivers (meaning that the animal does not have to be recaptured to access the data). A key challenge is in reducing the weight of transmitters while increasing

battery life for longer tracking. Bigger batteries add weight, but transmitters should weigh no more than 3 – 5% of a bird's body weight (Barron et al. 2010).

Radio telemetry is a well-established, broadly applicable technology that has recently advanced with the availability of smaller transmitters and increased tracking range. Radio transmitters (tags) can be applied to birds weighing as little as 5 g; a 0.25 g radio transmitter called a nanotag is the smallest tracking technology currently available (Lotek Wireless Inc. 2017). Establishment of automated receivers that continuously scan for nanotags rather than labor intensive manual tracking allows for the collection of datasets that are less limited by staff hours and availability. The Motus Wildlife Tracking System, established by researchers and Bird Studies Canada in 2012, is an expanding network of automated receivers (telemetry towers) across the Americas. Tags can be detected by any of the over 500 active automated receivers, enabling users to collaborate by monitoring a much larger area than would be possible with a single receiver or a local array of receivers. This has provided new insights into migratory connectivity, stopover behaviour, and departure decisions (Taylor et al. 2017). Continued development in low weight tracking technologies will allow even better understanding of the intricacies of migration by the smallest species over the longest distances.

1.2 Shorebird Ecology

1.2.1 Taxonomy and Ecology of Shorebirds

Most species of shorebirds (also known as waders in Europe), of the order Charadriiformes, are migratory, some of which travel tens of thousands of kilometers such as between the southern tip of Argentina and the Arctic (Colwell 2010). Diverse in species, body sizes, bill sizes and shapes, and life histories, this group includes the sandpipers, plovers, oystercatchers, avocets, and stilts. Fifty shorebird species regularly migrate through North America (Sibley 2000). Shorebirds are typically associated with aquatic habitats, capitalizing on macroinvertebrates (e.g. small arthropods, crustaceans, mollusks) as food sources by using their bills which are specialized to probe through sediments at multiple depths, scoop up prey, overturn rocks, and more (Colwell 2010). They are generally long-lived with low reproductive rates, such that factors influencing adult mortality can increase the chance of population-level declines (Colwell 2010; Gratto-Trevor et al. 2010).

1.2.2 Declines and Threats

In North America, 61% of shorebird populations have declined over the last 30 years, with many declining by over 50% in the same period (Gratto-Trevor et al. 2010; Andres et al. 2012). There are additional concerns for 1) arctic-breeding species, which are collectively declining by 1.9% each year (Bart et al. 2007), and 2) populations (many arctic-breeding) migrating through the interior of North America, which are more prone to decline than coastal migrants (Thomas et al. 2006). Of the six species currently listed under the *Species at Risk Act* (SARA) as Special Concern, Threatened, or Endangered (Buff-breasted Sandpiper (*Tryngites subruficollis*), Eskimo Curlew (*Numenius borealis*) (may be extinct), Long-billed Curlew (*Numenius americanus*), Mountain Plover (*Charadrius montanus*) Piping Plover (*Charadrius melodus*) and Red Knot (*Calidris canutus*)), three are arctic breeders (Buff-breasted Sandpiper, Eskimo Curlew, and Red Knot) and all migrate through interior North America (Government of Canada 2017).

Shorebirds may be more susceptible to anthropogenic threats and population declines than other bird groups because of their migration ecology (Gratto-Trevor et al. 2010). Long migrations and specialization to shallow waters make shorebirds vulnerable to landscape-level habitat changes that may occur on wintering grounds, breeding grounds, and staging sites. These habitat changes include wetland drainage, coastal mudflat development, and sea level rise with climate change (Thomas et al. 2006; Sutherland et al. 2012). Additionally, large concentrations of shorebirds (sometimes over 50% of a given species' continental population) often concentrate at specific staging sites, making entire populations vulnerable to extinction from local disturbances such as pollution or disease (Payne 2010).

1.2.3 Research Needs

Increasing knowledge of migratory movements will help us understand the threats shorebirds face at each stage of their annual cycle. Given that the migratory period often poses the greatest risk to annual survival, characterizing behavioural patterns of migrating birds in space and time together with monitoring of local population dynamics can help to identify threats and ensure management plans are designed to protect birds at critical staging sites. More research is needed in the interior flyways of the Western Hemisphere, where data are lacking. The freshwater and hypersaline wetlands and lakes used as staging sites by interior-migrating

shorebirds are different from coastal staging sites (i.e. different macroinvertebrate communities, no tides, different wind patterns), suggesting different staging and flight patterns and requiring different management needs (Lank 1989; Åkesson 1993; Payne 2010).

Studying staging behaviour across sites may provide insights into causal factors related to population fluctuations. For example, changes in migration route or stopover duration (the amount of time a bird spends at a staging site), rather than population demography per se, may contribute to apparent population declines locally or regionally (Bart et al. 2007). A shift in migration route would mean that the strength of declines in one area should be matched by similar increases in another; however, this cannot be determined unless population size across sites is known. In contrast, migratory bird surveys typically rely on indices of population size based on raw abundance counts, which are not directly comparable across sites or regions. To estimate true passage population sizes for direct comparison, observer error and stopover duration must be included in analyses to correct raw abundance for over or underestimates of birds including double-counting over multiple surveys (Farmer and Durbian 2006). To complicate matters, increases or decreases in predator or prey populations may cause migrating birds to increase or decrease their stopover durations in response, which could again lead to apparent population decreases (or increases) when migration counts are used as an index of population size and are not corrected for stopover duration (Ydenberg et al. 2004). Thus, local stopover duration is a critical piece of information necessary for increasing the accuracy of migration monitoring data.

At a local scale, understanding patterns of staging and flight behaviours of migrating shorebirds will aid in management and mitigation of human usage and development at staging sites. For example, any sites found to be used by at least 1% of a shorebird species' population can be nominated as Western Hemispheric Shorebird Reserve Network (WHSRN) sites; formal recognition yields more consideration in development guidelines and land use plans (e.g. minimum distance buffers) (Donaldson et al. 2000; Saskatchewan Ministry of Environment 2016b). Because staging populations use sites for a limited time each year, some threats can be mitigated by temporarily halting or decreasing human activity. For example, Red Knots used a significantly larger area of a New Jersey beach when the beach was closed for a six day period during fall migration (Burger and Niles 2013). Adaptive and time-sensitive mitigation efforts are

also relevant with increasing wind energy development in migratory flyways. If migratory movements show consistent patterns in flight direction, time, and weather conditions, then predictions could be made about when and where large numbers of birds will be in the air and collision risk could be mitigated.

1.3 Wind Energy Developments and Potential Effects on Shorebirds

The need for renewable, clean energy to combat climate change from burning fossil fuels has resulted in an increasing array of alternative technologies to harness biofuel, solar, geothermal, hydro, ocean, and wind energies. Wind energy refers to the kinetic energy of moving air, which can be harnessed as electricity using large wind turbines onshore or offshore (IPCC 2011). Wind turbines are typically erected in clusters, forming wind energy developments (also referred to as wind farms), over areas of land or water that are associated with strong and regular winds. Canada currently totals 285 wind energy developments with a collective 11,898 megawatt (MW) capacity. Growing at a mean of 18% a year and currently representing 5% of Canada's domestic electricity demand, wind energy is among the fastest growing forms of renewable energy (CanWEA 2017a). Canada's prairies in particular are targeted for wind energy development because of their strong, consistent winds (Fargione et al. 2012). Saskatchewan currently relies on wind energy for three percent of its electricity profile, and hopes to increase that to 30% by 2030 (CanWEA 2017b).

Birds face direct and indirect impacts from wind energy developments (Saidur et al. 2011). Direct impacts occur when birds strike turbine blades. Indirect impacts occur from habitat destruction and disturbance which may cause birds to avoid the area or lead to reduced reproductive success. Although fatalities due to collision with wind turbines usually do not significantly affect bird populations, increasing density of wind energy developments necessitates a better understanding of this issue. Risk of collision depends on a multitude of factors including: species, bird behaviour, weather conditions, turbine structure, and importantly, the location of wind energy developments (Drewitt and Langston 2006). There is a need to understand how areas that are valued for wind energy developments may also overlap or interfere with bird populations that use these sites as migration corridors, stopovers or staging sites, or breeding areas.

Certain species are at greater risk of collision and declines because of their ecology. Behaviours such as aerial courtship displays (characteristic of grassland breeders), use of tall structures as perches (characteristic of raptors), and nocturnal migratory movements (characteristic of most landbirds and shorebirds) may increase risk of collision (Richardson 1998; Kingsley and Whittam 2005). Raptors and waterbirds are more vulnerable to population declines from turbine mortalities than passerines because they are long-lived, have low rates of reproduction, are slow to mature, and have specialized habitat requirements (Heppell et al. 2000; Saether and Bakke 2000; Beston et al. 2016). In one study at the Nysted offshore wind farm in Denmark, raptors and waterbirds (divers, waterfowl, shorebirds, gulls, skuas, terns, and cranes) had the highest risk of collision because of high relative abundance and demographic sensitivity (i.e. how strongly population growth rate responds to changes in adult survival) (Desholm 2009). Similarly, Beston et al. (2016) developed a prioritization system to identify species with the highest risk of population level declines by incorporating conservation status, proportion of fatalities due to turbines, a Fatality Risk Index based on the percent of a population living near turbines and reproductive metrics, and an Indirect Risk Index based on how many habitats are used by a given species. They found that four orders: Accipitriformes (diurnal raptors), Strigiformes (owls and nocturnal raptors), Charadriiformes (shorebirds, gulls and auks), and Pelecaniformes (large waterbirds) were among the bird groups most at risk. Finally, a meta-analysis of before and after control impact (BACI) bird abundance data from 19 wind energy developments, determined waterfowl (Anseriformes) to be the most sensitive group (experienced the most declines), followed by shorebirds, raptors, and then songbirds (Stewart et al. 2007). The authors note that it was not clear whether these declines were due to mortality or avoidance, or a combination of the two.

Risk of collision for all migrating species is influenced by extrinsic factors such as weather and turbine design. For example, more birds typically depart from an area in favorable weather conditions (assisting winds) than in poor conditions; developments located near take-off locations (stopover and staging sites) may see greater numbers of collisions when winds are blowing northward in spring and southward in fall (Richardson 1998). Following take-off, migrating birds tend to fly lower when they encounter poor weather conditions (high winds, rain, and/or fog). Nocturnal migrants, which typically fly at much higher altitudes than turbine height, can be forced down to turbine height during storms (Richardson 1998; Newton 2007). Birds have

been documented circling turbines and other tall, lit structures in fog and most mass mortality events have occurred at these structures on stormy nights (Richardson 1998; Erickson et al. 2005; Newton 2007).

Turbine structure and turbine arrangement are important for understanding avian collisions. Birds are attracted to turbine lights when visibility is poor; lights are only recommended when required and should be flashing rather than constantly lit (Richardson 1998). Birds may be less likely to collide with turbines built during and after the 1990s, which are taller with lower rotation speeds than older lattice turbine models (birds may be less likely to be hit when flying between blades), and do not allow for perching (Erickson et al. 2001). Turbine arrangement may affect mortality risk based on the number of blades in a bird's flight path. For example, a straight north – south line of turbines would concentrate risk in a small area for a bird flying northward through the development, whereas an east – west line would create a barrier over a larger area (Krijgsveld et al. 2009).

Location of wind energy developments is often the single most important factor in determining risk of collision. The Altamont Pass Wind Resource Area (APWRA) in Northern California is a well-known example for high raptor mortality. APWRA is in an area of high raptor use due to a large prey base and proximity to a canyon birds frequent (Erickson et al. 2001; Kingsley and Whittam 2005). Wind farms in areas supporting large numbers of migrating birds have reported similarly high mortality. For example, KW Tarifa has resulted in high mortality because it is located on the Strait of Gibraltar where thousands of migrating raptors and other birds are funneled (Kingsley and Whittam 2005). Researchers have concluded that siting wind energy developments in low bird use areas is the best way to prevent bird-turbine collisions (Erickson et al. 2001; Krijgsveld et al. 2009; Obermeyer et al. 2011; Graff et al. 2016). Developers are recommended to avoid areas with high densities of wintering or migrating waterfowl and/or shorebirds, areas with high raptor activity (especially in breeding areas and where topography would funnel birds through the development area), and sites with breeding, wintering, or migrating species of conservation concern (Drewitt and Langston 2006).

As described above, wind energy developments are not only associated with mortalities due to collision with turbines, but through habitat alteration and disturbance during both construction and operation phases. Habitat alteration occurs with installation of wind farm

infrastructure such as concrete foundations for turbines, electrical collection systems, electrical substations, transmission facilities, access roads, operation and maintenance buildings, and meteorological towers (Drewitt and Langston 2006). Birds may avoid areas altered by development or potentially experience lower reproductive success and survival (Drewitt and Langston 2006; Niemuth et al. 2013). An earlier control-impact study from 12 wind farms in the UK showed breeding bird (passerines, raptors, grouse, and shorebirds) densities were reduced by 15-53% within a 500 m radius of turbines (Pearce-Higgins et al. 2009). In a more recent, detailed BACI study on European Golden Plover (*Pluvialis apricaria*) at the Gordonbush wind farm in northern Scotland, plover abundance significantly declined by 79% in the wind farm area compared to the baseline counts (Sansom et al. 2016). No similar changes were observed in buffer or control areas indicating declines were most likely directly attributable to the wind energy development (Sansom et al. 2016).

An additional type of disturbance known as the “barrier effect” occurs when migrating birds alter their flight path to avoid a development (Drewitt and Langston 2006). Altering flight paths to go around barriers increases distance flown and consequently energy expended, which may have carry-over effects on feeding, roosting, and molting. For example, Common Eiders significantly altered their course when flying near an offshore wind energy development, increasing their distance flown by approximately 500 m (Masden et al. 2009). Although this distance appears minimal compared to total migration distance, multiple wind energy developments in a flight path could theoretically have cumulative effects.

Avian ecology must be considered when designing wind energy projects. Patterns in bird abundance and migratory movements are likely key predictors of mortality rates; areas with higher bird abundance would likely lead to greater numbers of collisions than areas with lower bird abundance. There is a need to evaluate risks on a site to site basis, which could then be incorporated more thoroughly into developing siting and mitigation guidelines.

1.4 Study Site

The Prairie Pothole Region (PPR) is a 780,000 km² ecoregion encompassing parts of the provinces of Manitoba, Saskatchewan, and Alberta and the states of North Dakota, South Dakota, Minnesota, and Montana (Mitsch and Hernandez 2013). Historically, it consisted of grasslands mixed with numerous seasonal to permanent wetlands created by glacial retreat

10,000 years ago during the Pleistocene (Ducks Unlimited 2016). These wetlands are rich in aquatic plant and animal life, providing excellent breeding and migratory stopover habitat for millions of waterfowl and shorebirds each year (Skagen et al. 2008; Ducks Unlimited 2016; Graff et al. 2016). This agricultural region is also characterized by rich soils, warm summers, periodic dry bouts, and some saline wetlands, caused by high evapotranspiration in comparison to precipitation (Mitsch and Hernandez 2013).

Chaplin Lake is a large saline wetland within the PPR located in southern Saskatchewan, covering 9,300 hectares (Beyersbergen and Duncan 2007). It is also an important migratory stopover in the Central Flyway. Large numbers of shorebirds stage at Chaplin Lake because of shallow water levels maintained by the Chaplin Minerals salt mine and high abundance of brine shrimp (*Artemia salina*) (a high energy food source) (Beyersbergen and Duncan 2007). More than 100,000 shorebirds use this area as a staging or breeding site each year (Beyersbergen and Duncan 2007). This includes Piping Plover (*Charadrius melodus*) and the *rufa* subspecies of Red Knot, which are listed as Endangered under SARA (Government of Canada 2017).

Shorebirds frequent two other neighbouring lakes: Reed Lake, 18 km west of Chaplin Lake and 3,300 hectares in size, and Old Wives Lake, 40 km southeast of Chaplin Lake and 33,020 hectares in size. Together these three lakes constitute a Western Hemispheric Shorebird Reserve (WHSRN) site and each lake is designated an Important Bird Area (IBA) (Beyersbergen and Duncan 2007). WHSRN sites and IBAs are areas designated as key habitat and high bird use by the non-profit organizations Manomet and BirdLife International. My research is focused on Chaplin and Reed Lakes, where an annual shorebird survey was established in 2014 (Rapolti Unpublished data). With large numbers of shorebirds using the lakes annually, changes in land use within the area such as agriculture and wind energy development may have significant implications for these populations.

Wind energy development is increasing in the Chaplin and Reed Lakes area. The Morse Wind Facility, a 10 turbine, 23 MW wind energy development, was established just southeast of Reed Lake by SaskPower and Algonquin Power Co. in 2015 (SaskPower 2018). The Chaplin Wind Energy Project, a 79 turbine, 177 MW development, was planned < 5 km north of Chaplin Lake, but it was denied approval by the Saskatchewan Ministry of Environment, in part due to potential conflicts with the large numbers of migratory birds in the area (Saskatchewan Ministry

of Environment 2016a). The development (now the Blue Hill Wind Project) has been proposed to now occur south of Reed Lake pending environmental assessment and ministerial approval (Algonquin Power and Utilities Corp. 2017). It would be more than 5 km away from the shoreline of Reed Lake, in accordance with the provincial government's recommended minimum 5 km buffer around WHSRNs and IBAs, but the effectiveness of this buffer size has not been assessed (Saskatchewan Ministry of Environment 2016b).

1.5 Study Species

I chose the Sanderling (*Calidris alba*) as my focal study species because it is the most common shorebird species recorded at Chaplin and Reed Lakes. Further, much is already known about the Sanderling's ecology and biology and it is a long distance migrant, which makes it a good model to study migratory movements and staging ecology (Myers et al. 1990; Payne 2010). Sanderlings winter along the coasts of the Americas and breed in the Canadian Arctic, and individuals often exhibit an elliptical pattern of migration which takes them north through the Central Flyway and south through the Atlantic Flyway (Myers et al. 1990). Similar migration patterns are seen in other arctic-breeding shorebirds, with the result that shorebird numbers at Chaplin and Reed Lake are much larger during spring than during fall migration. Sanderlings are widespread and have a similar ecology to many other shorebird species; thus, research and management of this species at Chaplin and Reed Lakes may benefit other shorebirds which use the same flyway, habitat and resources (Payne 2010).

1.6 Research Objectives

My thesis evaluates shorebird migration and staging ecology at Chaplin and Reed Lakes. Specifically, I studied multiple species' temporal abundance patterns and Sanderling stopover duration, population size, and arrival and departure movements. My specific thesis objectives were to:

- 1) Examine time of peak abundance by multiple migratory shorebird species using Chaplin and Reed Lakes during spring and fall migration, and spring stopover duration and population size of Sanderlings (chapter 2).

- 2) Investigate arrival and departure movement patterns of migratory shorebirds at Chaplin and Reed Lakes, using the Sanderling as a model, and the extrinsic factors influencing observed flight patterns (chapter 3).

By characterizing abundance and movement patterns, my project has implications for wind energy development siting and mitigation in the Chaplin and Reed Lakes area, a region with current and proposed wind development projects.

CHAPTER 2:

SHOREBIRD MIGRATION TIMING AND STOPOVER DURATION AT AN IMPORTANT STAGING SITE IN THE CENTRAL FLYWAY

This chapter describes overall spring and fall shorebird migration chronology during 2014-2017 at Chaplin and Reed Lakes, Saskatchewan, with focus on the staging ecology of Sanderlings (*Calidris alba*). This chapter is written in manuscript style. Data were analyzed and the manuscript writing was led by Jessica Howell, in consultation with and editing by Drs. Christy Morrissey, Ann McKellar, Rick Espie, and Kirsty Gurney and additional statistical consultation with Drs. Bob Clark and Mark Drever. Point count data were collected in the springs of 2014-2017 and falls of 2016-2017 by Jessica Howell with support from other field staff and partners. Birds were trapped and radio-tagged in 2015-2017 in both Chaplin and in the Gulf of Mexico with support from my supervisors and field staff as well as local expert, David Newstead (Texas Coastal Bays and Bends).

2.1 Introduction

Migration is a crucial phase of many birds' annual cycles, but a shortage of bird use data from many staging sites hinders its incorporation into management strategies. Migrating birds depend on resources at multiple staging sites within one or more continents, exacerbating impacts of habitat disturbance. High motility and transience at staging sites makes migrating birds difficult to study, but identification of temporal patterns of migratory activity and estimation of population sizes of staging birds are needed to highlight where habitat management should be focused.

Migratory birds are particularly vulnerable when concentrated at a single staging site. Events such as major storms, disease outbreaks or pollution could eliminate a significant portion of the global population (Payne 2010; Sutherland et al. 2012). Delays at migratory staging sites can strongly influence overall migration speed with carry-over effects for successful reproduction and survival (Newton 2006; Harrison et al. 2011). Shorebirds as a group are susceptible since they are known to use common staging sites in high densities employing a "jumping" strategy with long distance flights (often thousands of km) interspersed with staging periods of one or more weeks to refuel (Warnock 2010). Sixty-one percent of arctic-breeding shorebird populations in North America are exhibiting long term declines (declining for >30

years) (Andres et al. 2012). Therefore, factors influencing duration and timing of stopovers at important staging areas remains an important research area for species conservation.

Stopover duration is influenced by time, weather, and predator and prey abundance. Birds arriving later in the season may accumulate fuel deposits two to three times faster than birds arriving earlier in the season to compensate for lost time (Atkinson et al. 2007a). Poor weather (i.e. rain, strong headwinds) may delay departure and extend stopover duration even after birds have deposited enough fuel to undertake the next flight (Richardson 1990). Increased predation risk and decreased prey availability can decrease fueling rates and shorten or lengthen stopover duration (Ydenberg et al. 2004; Jonker et al. 2010). Changes in stopover duration (the amount of time a bird spends at a staging or stopover site) could be responsible for apparent shorebird declines if unaccounted for in population estimates (Ydenberg et al. 2004).

Since migrating populations are transient, stopover duration must be considered along with raw abundance when estimating population size. For example, some birds will be double-counted if a survey interval is shorter than stopover duration or abundance underestimated if a survey interval is longer (Farmer and Durbian 2006). Stopover duration is typically estimated by using mark and recapture techniques, but this poses a challenge because the length of time locally-marked birds were at the site prior to capture is typically unknown, and detectability may be low in large/inaccessible sites and when birds are marked with bands only. Radio telemetry is one of the most accurate options available for recording stopovers of small birds because detectability is not dependent on movement patterns within the site (Chernetsov 2012). Many analytical methods have been used to estimate stopover duration, including minimum stopover duration (number of days from capture to last resight) (e.g. Myers et al. 1990; Scott et al. 2004) and Cormack-Jolly-Seber models (e.g. Lehen and Krementz 2007; Gillings et al. 2009; Gómez et al. 2017). While the best method is not universally agreed upon, comparing minimum stopover durations of birds tagged on site with true stopover durations from radio-tagged birds with known arrival dates (e.g. birds tagged elsewhere prior to arrival) would allow for more accurate estimates.

Many coastal shorebird staging sites in North America, such as Delaware Bay, the Bay of Fundy, the Fraser River Delta, and the Copper River Delta are well characterized in terms of bird usage, but many central interior sites are less well-studied. The Central Flyway is used by almost

40 species of shorebirds, with large percentages of certain species' populations, including Sanderling (*Calidris alba*), Red-necked Phalarope (*Phalaropus lobatus*), and Semipalmated Sandpiper (*Calidris pusilla*), traveling through the Prairie Pothole Region (PPR) of the Central Flyway during migration (Morrison et al. 2001; Skagen et al. 2008; Gratto-Trevor et al. 2010). The total number of shorebirds migrating through the US PPR is estimated at 7.3 million in spring and 3.9 million in fall (Skagen et al. 2008); counts at single sites in the Canada PPR during the peak of spring migration are often over 25,000 and occasionally over 100,000 (Alexander and Gratto-Trevor 1997; Beyersbergen and Duncan 2007; Beyersbergen 2009a; Beyersbergen 2009b).

Here, we used point count surveys and automated radio telemetry to examine staging behaviour and migration chronology at a major staging area of Chaplin and Reed Lakes in southern Saskatchewan, Canada. The lakes are an important staging site in the Central Flyway used by as many as 100,000 shorebirds or more each spring, but systematic survey data are lacking (Beyersbergen and Duncan 2007). The Sanderling served as our primary study species because it is the most common shorebird at Chaplin and Reed Lakes, is widely distributed on a global scale, and like many arctic-breeding shorebirds has experienced population declines (Payne 2010)- features that make it a good model for other arctic-breeding shorebirds. Our objectives were to characterize temporal patterns of shorebird abundance for multiple species during spring and fall migration and to estimate spring stopover duration and population size of Sanderling using radio-tagged birds. We specifically asked: what is the pattern of shorebird abundance and Sanderling stopover duration at Chaplin and Reed Lakes during spring and fall migration? We hypothesized that total shorebird abundance would be larger during spring migration than fall; that Sanderling peak abundance based on point counts would follow a unimodal distribution related to consistency in individuals' arrival and departure dates based on telemetry; and that mean Sanderling stopover duration would be longer than the interval between point counts. We hope our results will demonstrate the value of tagging birds prior to arrival at staging sites in estimating stopover duration and highlight the importance of Chaplin and Reed Lakes as a key habitat in the Central Flyway to a globally significant number of shorebirds.

2.2 Methods

2.2.1 Capture and Radio Telemetry

From 2015-2017, we captured Sanderlings in the Gulf of Mexico (GOM) at 3 locations early in spring migration (mid-April to mid-May): Grand Isle, Louisiana (29° 10' N, 90° 4' W), Bolivar Peninsula, Texas (29° 22' N, 94° 43' W), and North Padre Island, Texas (27° 20' N, 97° 20' W). We also captured Sanderlings later in spring migration (mid-May to early-June), at Chaplin Lake, Saskatchewan, Canada (50°25' N, 106° 40' W) (Table 2.1). We used several capture techniques, depending on time of day and location: mist netting from dusk to dawn (Chaplin Lake only), and cannon net (GOM only) or noose carpets (Chaplin Lake and GOM) during daylight hours. We did not trap during adverse weather conditions (high winds and/or rain). We banded birds with one aluminum band, one colour band, and one alpha numeric coded plastic flag (green for USA, white for Canada), in a combination unique to each year. We glued coded radio transmitters (Lotek Avian NanoTag Model NTQB-3-2 (6 - 8 s burst rate, 0.67 g mass, and ~90 - 105 day battery life)) directly to the skin (beneath feathers) between the scapulae of each bird with a 5 min curing marine epoxy. Trapping, banding, and radio transmitter attachment protocols were approved by the University of Saskatchewan Animal Research Ethics Board as Animal Use Protocol 20120021 and by the Canadian Bird Banding Office as banding permit 10268.

We used radio telemetry to monitor individual birds' daily presence. Specifically, we made use of the Motus Wildlife Tracking System, developed by Bird Studies Canada, which consists of an expanding network of automated radio-telemetry towers (receivers) operated by researchers primarily in the Americas in combination with long life avian nano-tags (transmitters) (Taylor et al. 2017). Stations continuously scan for tags, logging data for the duration a tagged bird is in the area. Our local telemetry array consisted of six towers around Chaplin and Reed Lakes (Figs. A.1-A.3), each with three 9-element Yagi antennas (Model: Laird PLC1669) oriented 120° from one another and a SensorGnome receiver that scans for tags on all antennas continuously (www.sensorgnome.org). Towers operated from late-April to mid-October of each year of the study. Towers were approximately 7 m tall, at elevations ranging from ~660 to 725 m above sea level. Two separate experiments (one using a helium-filled balloon and one using a UAV) yielded an approximately 12 km range of the front lobe (Taylor et al. 2011; Howell et al. Unpublished data) and a 3 km range of side and back lobes of each antenna (Fig. A.4) (Howell et al. Unpublished data); giving us substantial coverage of both lakes.

For each bird detected by the tower, the tag number (id), date and time (hh:mm:ss), antenna and signal strength (dBm) were automatically recorded. Analyses using raw radio telemetry data were restricted to the springs when tagging occurred (2015 – 2017), but the results (mean stopover duration) were applied to population size analysis of all years of the study (2014 – 2017).

2.2.2 Point Count Surveys

We conducted weekly point counts for all shorebird species ($n = 32$) at Chaplin and Reed Lakes during spring (2014 - 2017) and fall (2016 - 2017) migrations. Eighteen points were established along the shoreline and roads running through Chaplin Lake, and six along the shoreline of Reed Lake (Rapolti Unpublished data). Points had a 200 m observation radius, with some points including an additional 200-500 m observation radius, depending on topography and proximity to other points (Figs. A.5-A.6). Every point was surveyed weekly typically by two observers during spring migration, and surveys ran from the first week of May until the second week of June. All Chaplin Lake survey points were also surveyed during fall migration, with one Reed Lake point also surveyed in fall 2016. Fall surveys ran from mid-July through late August/early September. Spring and fall surveys were conducted any time between sunrise to sunset, wind speeds of zero to 40 kph, and zero to light precipitation.

We used a distance sampling method in 2016 to estimate shorebird detectability. Distance sampling better estimates animal densities as it assumes that detection probability decreases with increasing distance from the point center (Thomas et al. 2010). Distance sampling also includes the following assumptions: individual birds at the point center are detected with certainty, individuals do not move during the survey, and distance measures are exact. Distances from point center to birds (individuals or flocks (clusters)) were recorded using a Leupold RX-1000i laser rangefinder.

2.2.3 Relative Abundance and General Chronology of Shorebird Migration

We obtained arrival and departure timing of birds at Chaplin and Reed Lakes from radio telemetry data, and relative abundance of staging birds from point count data. We isolated sets of detections from birds in flight using the following criteria: 1) most detections inside the set are separated from each other in time by the interval between transmitter signals (6 or 8 s in our case), 2) detections inside the set are separated from detections outside of the set by five or more

minutes, and 3) detections inside the set have a curved shape when plotted as signal strength vs. time (Mitchell et al. 2012). We defined an arrival as the moment of maximum signal strength during the first set of detections of a bird at the study site. We defined a departure as the moment of maximum signal strength during the last set of detections of an individual bird at the study site (Mitchell et al. 2012). We identified non-stop flight detections or “fly-overs” (birds that pass over the towers and site without stopping) as single sets of detections. We excluded these birds (n= 7) from our analyses of stopover duration.

For data from each year of the study (spring migration = 2014 – 2017, fall migration = 2016 – 2017), we identified peaks in migrating shorebird abundance using histograms of raw bird numbers over time (survey week). We averaged total abundance across all years with a LOESS-smoothing function in R (ggplot2) to identify patterns in arrival, staging and departure. We assessed consistency in temporal trends across years through visual inspection of confidence intervals; narrow confidence intervals indicate a more consistent trend. We assessed all migratory activities (arrival, staging and departure) for Sanderling (2015 – 2017). We also analyzed staging bird abundance for the two next most common arctic migrants (birds that stage at Chaplin and Reed Lakes and then breed in the Arctic): Red-necked Phalarope and Semipalmated Sandpiper, as well as for all arctic migrants combined.

2.2.4 Sanderling Stopover Duration and Population Size

Although towers were active through the fall, we focused on Sanderling spring migration only for the analysis of stopover duration (2015 – 2017), due to much larger sample sizes and staging abundance. We calculated true stopover duration (TSD) of birds tagged in the Gulf of Mexico and first detected at Chaplin/Reed Lake as:

$$TSD = \text{date of departure} - \text{date of arrival} + 1 \quad \text{equation 2.1}$$

We calculated minimum stopover duration (MSD) of birds tagged at Chaplin Lake as:

$$MSD = \text{date of departure} - \text{date of capture} + 1 \quad \text{equation 2.2}$$

Because birds tagged at Chaplin Lake were present prior to capture for an unknown period of time, MSD may not equal TSD. We tested for a difference between MSD of Chaplin-tagged birds and TSD of Gulf-tagged birds using an analysis of variance (ANOVA). We estimated total stopover duration of Chaplin-tagged birds in program MARK using Pradel

Survival and Seniority models (Pradel 1996). Models estimate a survival (ϕ), recapture (p), and seniority parameter (γ). The survival parameter (ϕ) is equal to the product of probabilities true survival (S) * site fidelity (F). All radio-tagged birds successfully departed from Chaplin or Reed Lake (based on examination of signal strength vs. time plots), so we assumed $S = 1$. Therefore, we were able to define ϕ as equal to site fidelity (F), i.e. the probability of remaining at the site after capture (Sandercock 2006). Recapture probability (p) was assumed to be 1 because the telemetry towers detect any bird in the vicinity at any time. The seniority parameter γ was the probability of having been at the site before capture.

Both ϕ and γ were held constant over time in models such that estimated stopover duration (ESD) could be calculated using equation 2.3 (Schaub et al. 2001). Data from each year (2015 – 2017) were analyzed separately, with all encounter histories beginning on the date that the first individual was captured and ending on the date after the last tagged bird departed the area. We included capture date as a covariate to test for an effect of capture date on ϕ ; birds captured later in the season are likely to remain for a shorter period after capture. Top models were selected using ΔAIC_c (Burnham and Anderson 2003).

$$ESD = -\frac{1}{\ln \phi} + -\frac{1}{\ln \gamma} \quad \text{equation 2.3}$$

To estimate population size of Sanderling at our study site (Chaplin and Reed Lakes, 2014 - 2017) while accounting for population turnover throughout migration, we corrected raw point count abundance data with: 1) stopover duration of radio-tagged birds (see above) to account for birds arriving and departing between sampling dates, 2) detectability of shorebirds at each lake to account for birds not seen, and 3) an estimate of minimum usable area at the lakes to account for area not covered during surveys (Farmer and Durbian 2006).

To increase our sample size to estimate detectability (d_j) for Sanderling, we used distance measurements of all short-legged, non-swimming shorebird species (because other long-legged or swimming species may be detected at different rates due to differential habitat use) taken during spring 2016 point counts, and we analyzed detectability rates in R (package Distance). Mean detectability is computed as the integral of the detectability function divided by the survey point radius. Our preliminary analyses resulted in a very low estimate of mean detectability: 39±4% at Chaplin Lake and 20±8% at Reed Lake, and the Reed Lake detection function was poorly fit. The habitat at all point count stations was open and flat, providing high visibility and

consequently high detectability. We concluded that our detectability rates were biased low because birds were generally clustered near the point centers (shoreline). Detectability rates that are biased low would result in large overestimates of population size. Instead of using these rates, we researched the literature for detectability rates reported in other studies of shorebird migration in similar habitat. Based on the detectability rates reported by Farmer and Durbian (2006), Brown et al. (2007), and Ellis et al. (2014), we used 75% as our detectability rate for Sanderling in population estimates, which we judged would be a more conservative and realistic rate than the one computed in our distance analysis.

The sampled proportion of each lake (j) was calculated as:

$$p_j = \frac{\text{sampled area of } j}{\text{minimum usable area of } j} \quad \text{equation 2.4}$$

Minimum usable area for all short-legged, non-swimming shorebird species was calculated as the total area of the shoreline + 200 m into the water, excluding locations we considered non-habitat calculated using Google Earth Pro (Figs. A.7-A.8).

The estimated number of birds on survey date t (b_t) was calculated as:

$$b_t = \sum_{j=1}^m \frac{s_{tj}}{a_j} * \frac{1}{p_j} \quad \text{equation 2.5}$$

Where m = the total number of lakes (2), s_{tj} = the total survey count in lake j on survey date t .

Because not every day of the migration season was surveyed, we modeled the total number of birds over the season and then bootstrap-sampled to generate random numbers of birds for each day (Drever et al. 2014). We calculated a total number of bird-days (bd) by modeling number of birds by Julian day of the year for each year, generating random numbers of birds from the models, and then summing the predicted numbers for all days for each year. Julian date was centered on 145 for modeling. A random slopes and intercept linear mixed effects model included count as the response variable, with fixed effects of year, day of the year (DOY), and the polynomial term (DOY²), and with DOY and DOY² as random slopes and year as a random intercept. This model assumes that migration chronology has a certain shape but allows for within-season temporal variation (Drever et al. 2014).

We divided bd estimates by mean TSD and used the percentile method for the median, 0.025, and 0.975 percentiles as population estimates and confidence intervals. These estimates assume that stopover duration is constant across the season and among years (Drever et al. 2014).

$$\text{Population size} = \frac{bd}{TSD} \quad \text{equation 2.6}$$

2.3 Results

2.3.1 Relative Abundance and General Chronology of Shorebird Migration

Spring migration was characterized by high species richness (17 arctic-breeding species), high abundance (highest counts of most common species in thousands or tens of thousands), and consistency in timing among years (Fig. 2.1; Table B.1). The 3 most common species – Sanderling, Semipalmated Sandpiper, and Red-necked Phalarope – peaked in abundance at different times during spring migration, but total abundance of all arctic-breeding shorebirds consistently peaked during the third and fourth week of May (raw mean peak count = 13988 ± 4336, predicted mean peak count = 13924 ± 2140, CI = 9423 - 18424).

Sanderling and Red-necked Phalarope contributed the most to the overall pattern, each being several times more abundant than any other species. Spring Sanderling numbers peaked (raw mean peak count = 7297 ± 1742, predicted mean peak count from LOESS-smoothed mean = 6584 ± 1264, CI = 3935 - 9232) during the third and fourth week of May. Nineteen of 24 Sanderlings radio-tagged in the Gulf of Mexico arrived within a week of the Chaplin/Reed staging population peak. Departures based on data from radio-tagged birds were concentrated during the first week of June and corresponded with declines in numbers of staging birds detected using point counts. Departure timing of Sanderlings was consistent over the three years, with narrow confidence intervals and occurring over a short time window (Figs. 2.2 – 2.3).

Spring Red-necked Phalarope numbers showed a consistent peak, occurring during the third week of May of each year (raw mean peak count = 7720 ± 2007, predicted mean peak count from LOESS-smoothed mean = 7711 ± 1074, CI = 5461 - 9962). Semipalmated Sandpiper spring abundances were the most variable among years, occurring as one or two peaks between the first and fourth week of May (depending on year) (raw mean peak count = 964 ± 330, predicted mean peak count from LOESS-smoothed mean = 665 ± 226, CI = 191 - 1139).

Fall migration involved lower species richness (10 arctic-breeding species), lower abundance, and was less consistent in timing among years (Fig. 2.4, Table B.1). Semipalmated Sandpiper was the most abundant arctic migrant in fall 2016 and Red-necked Phalarope was the most abundant arctic migrant in 2017 (Table B.1). Total staging abundance during fall migration showed two peaks, one in late July (raw mean peak count = 1766 ± 709, predicted mean peak

count = 980 ± 293 , CI = 327 - 1633) and the other in late August (raw mean peak count = 1343 ± 132 , predicted mean peak count = 983 ± 313 , CI = 287 - 1679) (Fig. 2.4). Sanderling numbers peaked in the third week of August (raw mean peak count = 388 ± 253 , predicted mean peak count = 344 ± 89 , CI = 146 - 543). Red-necked Phalarope peaked in late July (raw mean peak count = 1007 ± 994 , predicted mean peak count = 449 ± 249 , CI = 0 - 1003). Semipalmated Sandpiper numbers peaked in early to mid-July that may not have been fully captured by our sampling window and a larger peak in late August (raw mean peak count = 745 ± 234 , predicted mean peak count = 489 ± 133 , CI = 192 - 786). The numbers of birds observed on the first and last surveys of spring and fall migration were on average 6% and 11% of the highest number of birds observed that season. Much lower numbers of birds on both ends versus the middle of our survey period are evidence that our surveys covered the majority of the migratory season.

2.3.2 Sanderling Stopover Duration and Population Size

Mean TSD of Gulf-tagged birds was longer than mean MSD of Chaplin-tagged birds in 2016 and 2017 but not 2015. However, the groups were not significantly different ($F = 0.549$, $df = 139$, $p = 0.46$). Mean ESD from Pradel models was 7 days longer than MSD (Table 2.2). Capture date as a covariate was in the top model of all years, and a regression of minimum stopover duration vs. capture/arrival date showed a significant, negative relationship ($p < 0.001$) for both Chaplin and Gulf-tagged birds suggesting that stopover duration was shorter for birds that arrived or were captured later in the season (Fig. 2.2).

Estimated Sanderling population size during spring was highly variable among years (as were raw counts) and had wide confidence intervals (Fig. 2.5; Table 2.3). The median population estimate was lowest in 2016 at 55,617 birds and highest in 2014 at 90,832 birds. Averaging all years to the nearest 1,000 gives a population size of 75,000 Sanderlings staging at Chaplin and Reed Lakes in spring.

2.4 Discussion

Our hypotheses were supported by our data; total shorebird abundance was higher at Chaplin and Reed Lakes in spring than fall, Sanderling peak abundance followed a unimodal distribution with a peak that was consistent with arrival and departure dates from radio-tagged birds, and mean Sanderling stopover duration (11 days) was longer than the interval between point counts. In addition to an estimated total population of ~75,000 Sanderlings based on our

calculations, a large number of Red-necked Phalarope (over 13,000 recorded as the peak daily count during surveys in 2017) used the area each spring. More Semipalmated Sandpiper and Red-necked Phalarope used the lakes during fall migration than Sanderling, but peak counts of all species were only in the hundreds to low thousands, compared to upwards of thousands to tens of thousands in the spring. Consistent patterns in migrating shorebird abundance over time and large numbers of migrating shorebirds at Chaplin and Reed Lakes have implications for management of this site and conservation of the large number of species present.

2.4.1 Relative Abundance and General Chronology of Shorebird Migration

The mean peak in total spring shorebird numbers at Chaplin and Reed Lakes occurred during the third week of May, but individual species peaks occurred from mid-May to early-June. Timing of peak Sanderling, Semipalmated Sandpiper, and Red-necked Phalarope abundances are similar to past records from Chaplin and Reed Lakes as well as other lakes in Saskatchewan and Alberta (Alexander and Gratto-Trevor 1997; Beyersbergen and Duncan 2007; Beyersbergen 2009a; Beyersbergen 2009b), suggesting that migration chronology is not only consistent among years but also within the PPR. However, different temporal patterns in species abundances may indicate different migration origins and destinations both among species, and among individuals within species.

The unimodal migration pattern of Sanderling abundance extended over the entire six week survey period, and may indicate steady inflow and outflow from populations with varying migration distances. The majority of the Sanderling's wintering range spans from the coasts of the US to southern South America (Myers et al. 1990; Sibley 2000). Cluster analysis of isotope samples from feathers, grown on the wintering grounds, of birds captured at Chaplin Lake in the springs of 2012 – 2015 resulted in three clusters which also had differing wing and tarsus sizes; this suggests different wintering populations with the largest birds wintering farthest south. However, there was no significant difference in peak or mean capture date among clusters (Labarrère 2016). Most of the Sanderling's breeding range is directly north of Chaplin and Reed Lakes in the high Arctic. A smaller portion is northwest on the North Slope of Alaska (Myers et al. 1990). Myers et al. (1990) banded almost 6,000 Sanderlings along the coasts of the US and Central and South America from 1983 and 1987 and the northern-most resighting was in the Northwest Territories (62 ° latitude). Although the exact breeding destinations of Sanderlings

tagged at Chaplin Lake are unknown, we have had detections of our birds at Motus network sites as far north as Southampton Island, NU (63° latitude) and near Churchill, MB (55° latitude) (Howell et al. Unpublished data). Whether birds stop at another site after Chaplin and Reed Lakes prior to reaching the breeding grounds is also unknown. Thus, it is not known whether different cohorts of arriving birds traveled to different breeding destinations, but it is likely that birds arrived from multiple wintering sites that overlapped in their arrival, staging, and departure times at Chaplin and Reed Lakes.

The shorter (two to three week) unimodal migration pattern of Red-necked Phalarope at Chaplin and Reed Lakes may indicate a single population. DNA from Red-necked Phalaropes across North America clustered those migrating through the Quill Lakes (approximately 230 km northwest of Chaplin Lake) in the fall to a breeding population in Prudhoe Bay, Alaska (Haig et al. 1997). The spring staging population at Chaplin and Reed Lakes may be part of the Prudhoe Bay breeding population; this could be investigated by assessing the stable isotope signatures of feathers, a method that has been used to differentiate between migratory populations of some species (Atkinson et al. 2007b). A brief, single peak in Red-necked Phalarope also means that the staging population is likely more vulnerable to decline or extinction by single catastrophic events (bottleneck situation) (Newton 2006).

In contrast with the unimodal temporal patterns of Sanderling and Red-necked Phalarope during spring migration, the almost bimodal trend in Semipalmated Sandpiper abundance could be indicative of separate populations. Semipalmated Sandpipers tracked using geolocation that staged at lakes in Saskatchewan and Alberta in spring and fall were from populations breeding in western Alaska, northern Alaska, and the Mackenzie Delta and wintering across Central America, the Caribbean, Western South America, and Northeastern South America (Brown et al. 2017). Steeves and Holohan (1995) suggested that the early peaks on western Canadian prairie lakes could be composed of Alaska breeders, because earlier melt and thaw in southern Alaska allows for earlier arrivals on the breeding grounds. This could be confirmed via stable isotope analysis of feathers, moulted on the breeding grounds, from Semipalmated Sandpipers staging at Chaplin and Reed Lakes.

The apparent smaller and longer fall migration at Chaplin and Reed Lakes is typical of prairie staging sites (Alexander and Gratto-Trevor 1997; Beyersbergen and Duncan 2007;

Beyersbergen 2009a; Beyersbergen 2009b) and may be better explained by differences in behaviour and habitat availability between seasons than by differences in our sampling effort between fall and spring surveys. Although more points were surveyed in the spring, spring numbers were still much larger at the subset of points sampled in both seasons. Some species, such as Sanderling and Semipalmated Sandpiper, tend to undergo elliptical migration- taking the Central Flyway in the spring and the Atlantic Flyway in the fall (Myers et al. 1990; Gratto-Trevor and Dickson 1994; Payne 2010). Elliptical migration is thought to occur because 1) tailwinds can be exploited on either flyway in the spring but headwinds are less severe on the Atlantic Flyway in fall (La Sorte et al. 2014) and 2) the sun compass, which is the only compass available when birds are leaving the high Arctic in the fall due to a distortion in the magnetic field, guides birds on a southerly arc to the Atlantic coast (Alerstam 2001). Indeed, more of the Sanderlings we tagged at Chaplin Lake in the spring were detected on Motus telemetry towers along the Atlantic coast than at our towers in Saskatchewan during the fall (Howell et al. Unpublished data). Drying of prairie ponds in the summer and fall is also associated with fewer birds at the local scale. Shorebirds preferentially use habitats with mud and shallow water, responding to dry periods by restricting use to the ponds that remain wet (Skagen and Knopf 1994). We witnessed a contraction of available habitat and shorebird presence to the westerly, deeper portions of Chaplin Lake during the drier fall of 2017 (Howell, Personal observation), as was reported during fall surveys in 1994 (Beyersbergen and Duncan 2007). One potential cause of the greater length of fall migration is that fueling at individual staging sites may take longer because days are shorter than in spring, allowing less time each day for foraging. Juveniles migrating for the first time may take additional time to fuel due to lack of experience (Nilsson et al. 2013).

2.4.2 Sanderling Stopover Duration and Population Size

The mean total stopover duration (TSD) of Gulf-tagged Sanderlings was more similar to the mean minimum stopover duration (MSD) than to mean estimated stopover duration (ESD) of Chaplin-tagged birds. TSD is the most accurate measure, for which the mean was 11.1 (95% CI = 8.59 –13.6) days (Table 2.2). Results for Sanderlings at other spring staging sites were somewhat longer than TSD, but considerably shorter than ESD. Gudmundsson and Lindström (1992) estimated 13-14 days from when 50% of birds had arrived to when 50% of birds departed

from southeast Iceland and Scott et al. (2004) estimated staging durations of 14-15 days based on radio-tagged birds in northeast England. Stopover durations of other shorebird species at other sites range from 11-12 days earlier in the season and 8-10 days later in the season for Red Knots (*Calidris canutus*) at Delaware Bay (Gillings et al. 2009), 10 days at wetlands for Pectoral (*Calidris melanotos*) and Least Sandpipers (*Calidris minutilla*) in northwestern Missouri (Farmer and Durbian 2006), and 6.7 days for Semipalmated Sandpipers at prairie sites (Brown et al. 2017).

The fact that we observed similar TSD and MSD of Gulf- and Chaplin-tagged birds, when one would expect minimum stopover to be shorter, may have been caused by a local capture and handling effect on Chaplin-tagged birds. Stress of capture and handling could have short-term effects of slowed fuel deposition or mass loss (Schaub and Jenni 2000). There may be additional stress with radio transmitter attachment; both control birds (captured only) and birds fitted with a harness and radio-transmitter lost mass in a study on Common Yellowthroats (*Geothlypis trichas*), but experimental birds lost more mass (Sykes et al. 1990). Thus, short-term effects over a few days may have occurred at our site and contributed to slightly longer stopover durations of Chaplin-tagged birds than would be expected. Indeed, of 35 birds captured at Chaplin with a subcutaneous fat score of ≥ 4 (scale of 0 – 5; lean to fat), only one bird departed the following day. These birds presumably had acquired enough fat at capture to depart soon after, as a regression of MSD vs. fat at capture showed a significant, negative relationship ($p < 0.001$), but had a mean MSD of 9.43 (95% CI = 8.51 – 10.3) days. However, we do not suspect any longer-term capture effects occurred in our study because birds tagged in the Gulf of Mexico (using the same methodology as at Chaplin) migrated to and staged at Chaplin Lake and other spring staging sites successfully, all birds detected at Chaplin and Reed Lakes departed the area (no mortality observed), and multiple spring-tagged birds were detected during fall migration at locations in the Central and Atlantic Flyways.

Rather than capture effects, another possible explanation for similar TSD and MSD is that our Chaplin Lake captures may have been biased towards birds early in their staging period. Exploratory flights, undertaken soon after arrival to identify the best habitat (best prey access, minimum predation risk) or find and join conspecifics, could result in a greater likelihood of capture (Moore and Aborn 2000; Paxton et al. 2008). Similarly, lean birds, which is typically the

condition upon arrival, move more each day than fat birds (Smith and McWilliams 2014). If our captures were biased towards birds early in their staging, fat score at capture should have been skewed towards lower scores, and yet fat score at capture was normally distributed (Howell et al. Unpublished data).

Despite a lack of direct evidence, a capture bias towards early staging birds deserves further consideration because Pradel models would have resulted in overestimates of stopover duration. Because the seniority parameter is estimated by inverting the capture history, it effectively assumes that birds are captured in the middle of their stopover rather than at or near the start. ESD from Pradel models were 30 – 40% longer than each year's mean TSD (Table 2.2). Although the use of Pradel models in estimating stopover duration is debated because birds arriving and departing between sampling times are ignored, this is not relevant in automated radiotelemetry studies where scanning for tags is continuous (Efford 2005; Pradel et al. 2005; Chernetsov 2012). Nonetheless, we suggest that Pradel survival and seniority modeling may not be an appropriate method regardless of data collection technique if probability of capture is biased towards either end of a stopover.

Median Sanderling population estimates ranged from a low of 55,617 in 2016 to a high of 90,832 in 2014 (Table 2.3); large fluctuations may indicate interannual variation in migratory routes and staging sites (low fidelity). Myers et al. (1990) characterized Sanderling migration as heterogeneous, meaning that breeding and wintering areas are connected by many routes intersecting at sites rather than a few, well-defined paths. Within the PPR, the extreme fluctuations in water levels may make staging site fidelity maladaptive (Skagen and Knopf 1994). In addition to Chaplin and Reed Lakes, Sanderlings tagged in the Gulf of Mexico were detected at other shorebird staging sites in Saskatchewan (the Quill Lakes, Last Mountain Lake, and Manitou Lake); it is possible that birds vary use of available sites among years (Howell et al. unpublished data). Although different prairie staging sites were used by individual Semipalmated Sandpipers in a multiyear study using geolocation, migration routes were distinct and consistent at the population level (Brown et al. 2017). Empirical evidence for broader geographic variation (e.g. alternating flyways used for spring migration) is lacking but cannot be ruled out (Myers et al. 1990; Bart et al. 2007).

Differences in population sizes at staging sites may also be explained by population dynamics. Reproductive success, recruitment, predation on the breeding grounds, wintering grounds, and migration route, disease, and human disturbances all have direct impacts on population size (Bart et al. 2007; Sutherland et al. 2012; Drever et al. 2014). Our study was too short to examine long-term population trends, but the point counts used in our surveys are part of an annual monitoring program that could be used in the future to estimate local trends and/or contribute to larger-scale trend analyses based on migration monitoring sites across Canada and the United States (e.g. Andres et al. 2012).

Estimated mean Sanderling population size at Chaplin and Reed Lakes was ~75,000, which is significant from the local to global scale. This represents 58, 25, and 12% of the total estimated numbers of Sanderling using the Central Flyway, in North America's population, and in the global population (Andres et al. 2012; Morrison et al. 2001). High numbers of staging Sanderling are part of the reason the Chaplin/Old Wives/Reed Lake complex was designated as a WHSRN site in 1997. Comprehensive surveys of all available habitat at Chaplin Lake (Beyersbergen and Duncan 2007) revealed peak counts of 51,084 and 52,984 birds in 1993 and 1994. Our study shows that the area continues to support some of the largest numbers of Sanderling observed at any North American staging site (Beyersbergen and Duncan 2007; Payne 2010).

2.4.3 Conclusion

The transience of staging shorebird populations make stopover duration and population size difficult to estimate, but our study gives a novel perspective using birds radio-tagged prior to arrival at the study site. First, we were able to obtain full (true) stopover durations from Sanderlings tagged in the Gulf of Mexico. Second, comparison of TSD of Gulf-tagged birds with MSD and ESD of Chaplin-tagged birds informed us that Pradel Survival and Seniority models overestimated stopover duration. Observed variability of stopover duration among individuals and years opens new research questions into its causes. Weather at the staging site, weather between the wintering grounds and staging site, differential site use by multiple populations, arrival date, and interactions between these variables likely all affect stopover duration. This could be investigated with a larger sample size of birds tagged prior to arrival in order for stopover duration to be modeled as a function of weather, arrival date, and year. Accounting for

any interannual and intraseasonal variability in stopover duration (TSD of Gulf-tagged birds and MSD of Chaplin-tagged birds significantly differed when regressed on years at $p < 0.05$ and $p < 0.001$ and arrival or capture date at $p < 0.001$ and $p < 0.001$), would refine Sanderling population size estimates. Population estimates could be further refined by verifying that detectability is close to 0.75 through a double-observer sampling method and inclusion of habitat covariates in detectability functions (see chapter 4). In addition to Sanderling, monitoring of Red-necked Phalarope - the population dynamics of which are poorly understood - at Chaplin and Reed Lakes as well as other Central Flyway staging sites may help elucidate whether declines observed on the Atlantic coast are due to true population declines or changes in distribution, where threats are occurring, and consequently where conservation efforts should be focused (Andres et al. 2012). Not only will continued use of the Motus telemetry array improve stopover duration estimates (and consequently staging population size estimates) of these and other species if more individuals are tagged prior to arrival at staging sites, it could also elucidate the breeding and wintering destinations if more telemetry towers are established in the Arctic and in South America.

Our population estimates affirm that Chaplin and Reed Lakes support a globally significant number of Sanderlings, which is important from a site management perspective. Habitat features at Chaplin Lake include shallow and reasonably stable water levels, brine shrimp, and generally uninterrupted airspace (few large structures that birds could collide with) – all ideal conditions for shorebirds. However, climate change predictions include increased drought and lower primary productivity in the PPR, with the most significant changes in the Canadian prairies (Werner et al. 2013). Increased water conflicts and intensified agriculture will exacerbate habitat loss (Payne 2010; Sutherland et al. 2012; Werner et al. 2013). Human use will need to be balanced with habitat needs of Sanderling and other species such as Red-necked Phalarope (designated as Special Concern under the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2014)) and Red Knot (listed as Endangered in Canada (Environment and Climate Change Canada 2017)), going forward if this and other Central Flyway staging sites are to continue to provide vital staging habitats for migratory shorebirds in a changing world.

Table 2.1. Summary of numbers (n), percentage, and Julian dates of tagging for radio-tagged Sanderlings by location and year.

	Sanderling Sample Sizes and Trapping Dates		
	2015	2016	2017
Gulf of Mexico (n)	24	37	59
n (%) of birds tagged in the Gulf of Mexico that staged at Chaplin Lake	7 (29)	4 (11)	13 (22)
Mean Gulf of Mexico Julian tagging dates (range)	110 (109 – 110)	115 (111 – 119)	125 (117 – 132)
Chaplin Lake (n)	38	40	39
Mean Chaplin Lake Julian tagging dates (range)	146 (133 – 158)	151 (140 – 159)	149 (139 – 152)

Table 2.2. Total (TSD), minimum (MSD), and estimated (ESD) stopover durations of Sanderling staging at Chaplin and Reed Lakes by original radio-tagging location in the Gulf of Mexico or Chaplin Lake, SK for each year of the study (2015-2017). The mean is shown with 95% confidence intervals and sample size (n) in parentheses for total and minimum stopover durations.

Year	TSD Gulf-tagged Birds	MSD Chaplin-tagged Birds	ESD Chaplin-tagged Birds
2015	6.29 (3.28 – 9.31) (7)	14.8 (13.4 – 16.2) (38)	23.2 (17.2 – 31.3)
2016	14.8 (7.03 – 22.6) (4)	11 (9.58 – 12.4) (39)	18.6 (13.8 – 25.3)
2017	12.6 (9.57 – 15.6) (13)	10 (8.88 – 11.1) (39)	16.4 (12.3 – 22.1)
All Years	11.1 (8.59 – 13.6)	11.9 (11.1 – 12.7)	19.9 (17.5 – 22.7)

Table 2.3. Median (0.5), lower (0.025), and upper (0.975) annual population size estimates for Sanderlings staging at Chaplin and Reed Lakes during spring 2014 – 2017, based on raw abundance from point count surveys, the sampled proportion of each lake, a detectability of 0.75, and a mean stopover duration of 11 days.

Year	Highest Raw Count	Median (0.5) Population Estimate	Lower (0.025) Population Estimate	Upper (0.975) Population Estimate
2014	9,303	90,832	70,005	120,477
2015	5,583	71,591	58,003	89,858
2016	3,316	55,617	45,309	68,441
2017	10,987	81,698	61,483	148,639
Mean (all years)	7,297	74,935	58,700	106,854

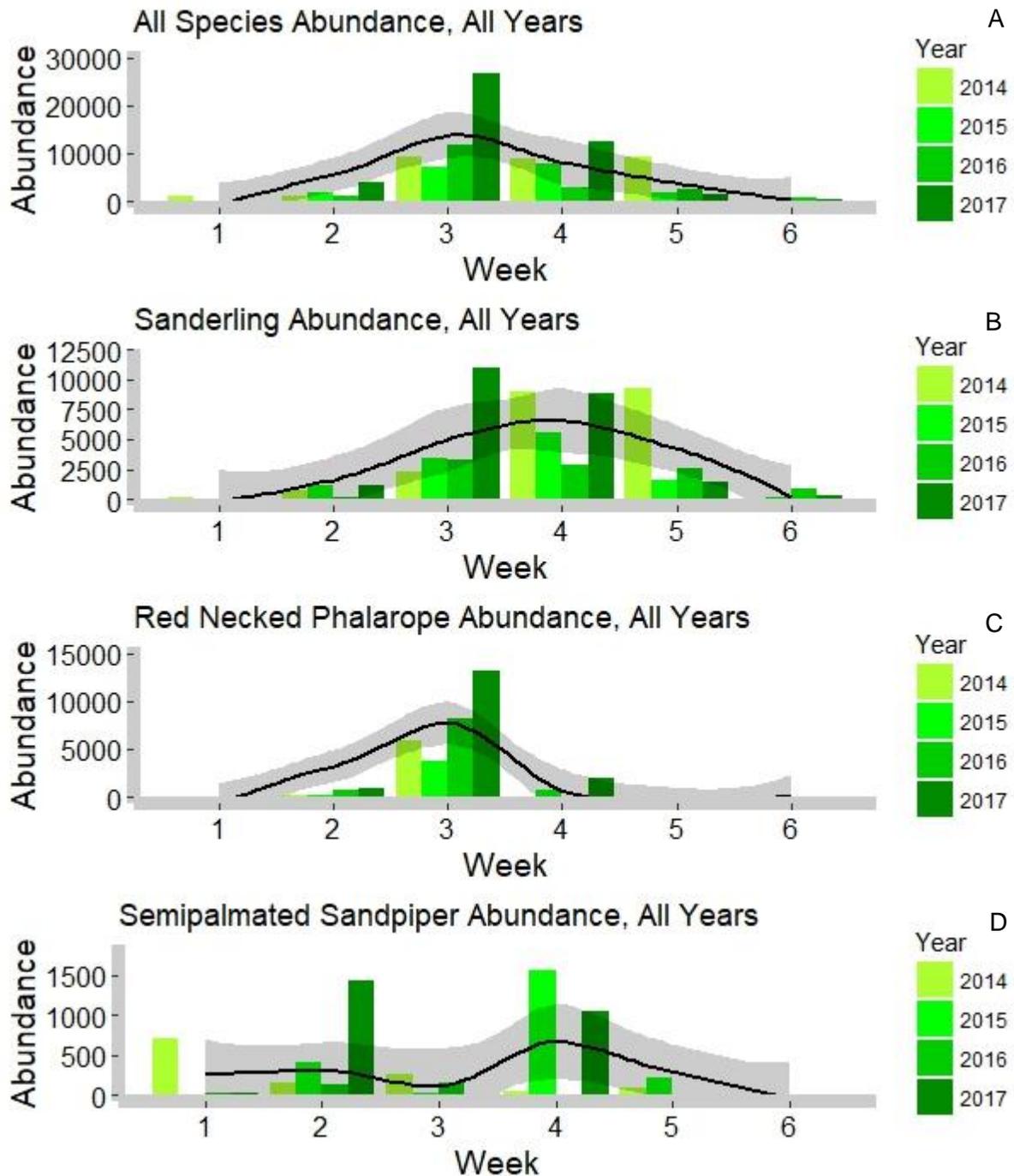


Fig. 2.1. Numbers of staging shorebirds observed during spring migration point counts at Chaplin and Reed Lakes by week (1 = first week of May). A) Arctic-breeding species combined, B) Sanderling, C) Red-necked Phalarope, and D) Semipalmated Sandpiper are shown. Bars are colored by year (2014-2017). The black line is a total (all years) LOESS-smoothed mean with surrounding 95% CI's (gray).

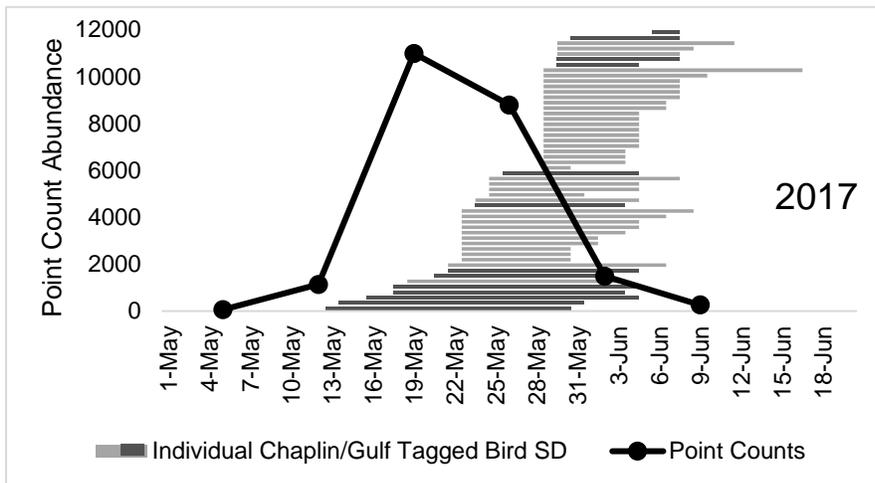
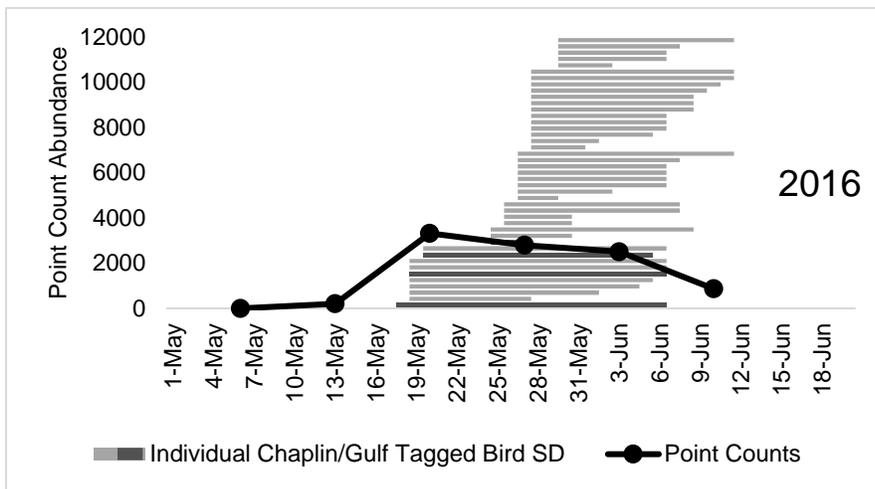
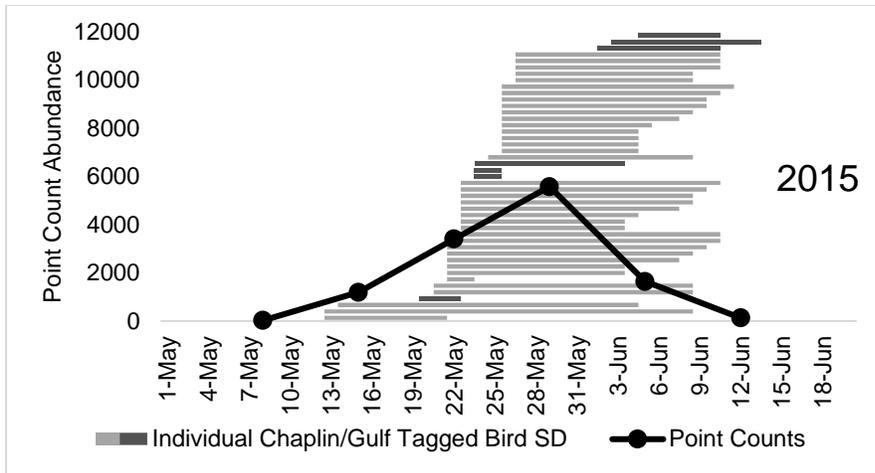


Fig. 2.2. Individual stopover durations of radio-tagged Sanderlings marked at Chaplin (light gray) and Gulf of Mexico (dark gray). Length of each horizontal line indicates time from capture/arrival date to departure date. Overlaid are total numbers of Sanderlings counted during weekly point counts (black line) at Chaplin and Reed Lakes for each year of the study.

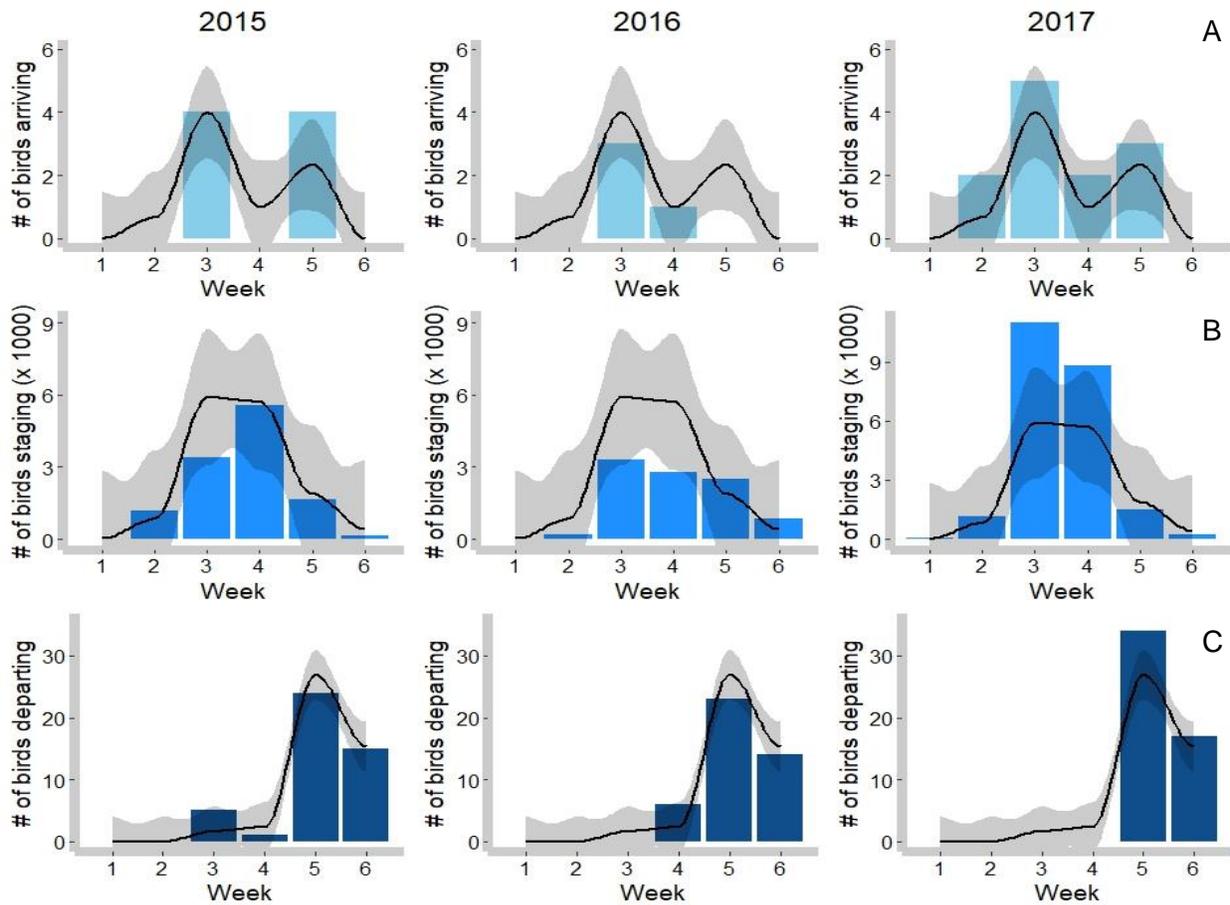


Fig. 2.3. Numbers of A) arriving radio-tagged Sanderlings (top row), B) staging Sanderlings (point count abundance) (middle row, in thousands), and C) departing radio-tagged Sanderlings (bottom row) at Chaplin and Reed Lake in columns by week of migration (1 = first week of May). Columns are by year (2015-2017). The black line is a total (all years) LOESS-smoothed mean with surrounding 95% CI's (gray).

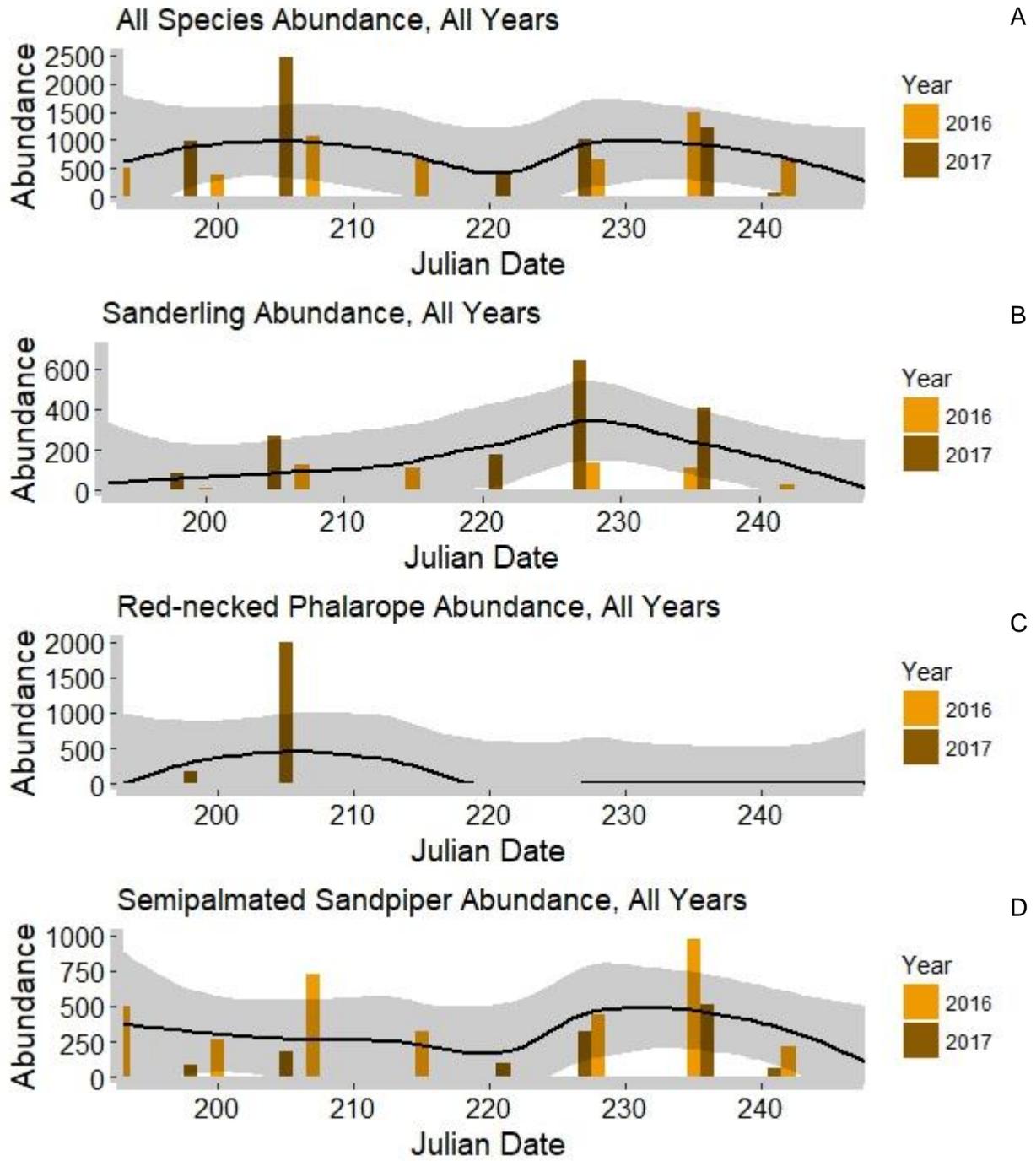


Fig. 2.4. Numbers of staging shorebirds observed during fall migration point counts at Chaplin and Reed Lakes by week (1 = first week of May). A) Arctic-breeding species combined, B) Sanderling, C) Red-necked Phalarope, and D) Semipalmated Sandpiper are shown. Bars are colored by year (2016-2017). The black line is a total (all years) LOESS-smoothed mean with surrounding 95% CI's (gray).

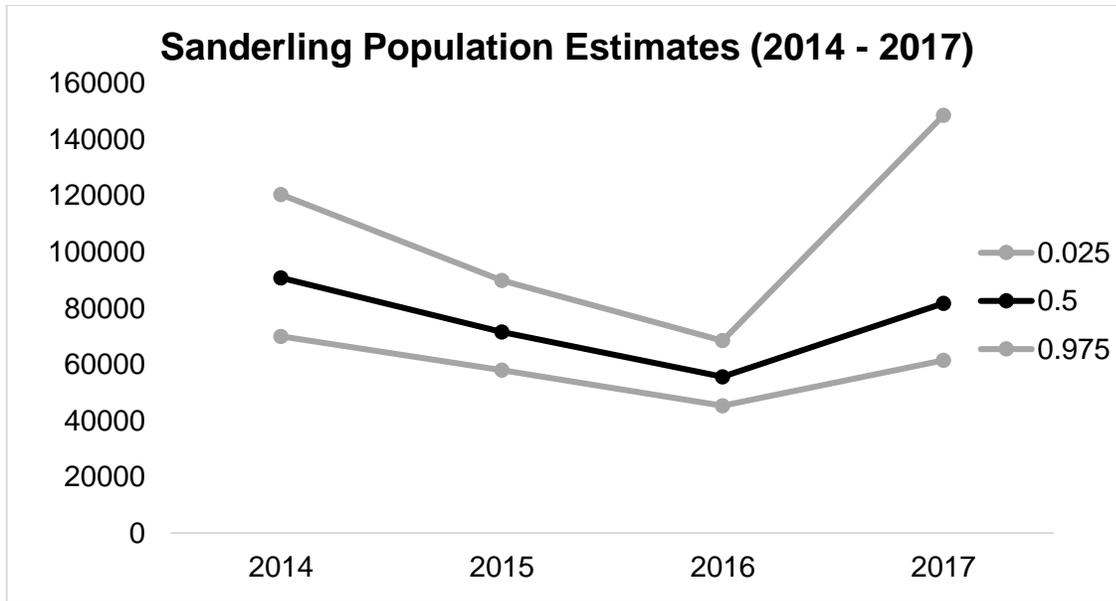


Fig. 2.5. Median (0.5), lower (0.025), and upper (0.975) annual population size estimates for Sanderlings staging at Chaplin and Reed Lakes during spring 2014 – 2017. Estimates are based on raw abundance from point count surveys adjusted for the sampled proportion of each lake, a detectability of 0.75, and a mean stopover duration of 11 days.

CHAPTER 3:

WEATHER AND TIME INFLUENCE SANDERLING (*CALIDRIS ALBA*) MIGRATORY MOVEMENTS AT AN IMPORTANT SPRING STAGING SITE IN THE CENTRAL FLYWAY

This chapter describes Sanderling migratory movements and flight patterns to assess the effects of time of day and weather at Chaplin and Reed Lakes, Saskatchewan, with implications for wind energy developments. This chapter is written in manuscript style. Data were analyzed and the manuscript was written by Jessica Howell, in consultation with and editing by Drs. Christy Morrissey, Ann McKellar, Rick Espie, and Kirsty Gurney. Birds were trapped and radio-tagged in 2015-2017 by Christy Morrissey, Kristin Bianchini, David Newstead, Jessica Howell, Rick Espie, Laura Messett, Kirsty Gurney, Katelyn Luff, Carla Labarere, Leanne Flahr, Alex Vien, Nicholas Shephard, Steve Simpson, and others.

3.1 Introduction

Many shorebird species undergo long distance migrations, relying on a restricted set of staging sites for rest and refueling between flights (Warnock 2010). Shorebirds may be particularly vulnerable to threats during migration because of their reliance on multiple habitat patches across one or more continents, and because a large portion of a population may use the same staging sites (Gratto-Trevor et al. 2010). Thus, understanding factors influencing migratory movements at staging sites is important as an aspect of migratory behaviour and has implications for management of human activity (e.g. development, industry).

Optimal migration theory predicts that migrating birds should minimize travel time, energy expenditure, or mortality risk in an attempt to maximize their chances of survival and reproductive success. Shorebirds may minimize both time and energy expenditure by flying in winds that blow in the desired direction of travel (assisting winds), drifting as much as possible, and compensating for lateral movement away from the destination when necessary (Alerstam and Lindström 1990). Flying at night can minimize energy expenditure because birds encounter less turbulence at night (the lower atmosphere is generally more stable than during the day), diurnal foraging opportunities are not wasted, and predation risk is lower (Richardson 1990; Alerstam 2009). Previous studies have indicated that shorebirds tend to depart on nocturnal

flights around sunset and in assisting winds (Gudmundsson and Lindström 1992; Gudmundsson 1994; Butler et al. 1997; Ma et al. 2011; Grönroos et al. 2012).

Many studies on shorebird migration to date have been conducted in the Eastern Hemisphere and on the coasts of the Americas in the Western Hemisphere; research is lacking on migration patterns in the Central Flyway, which runs through the interior of North America. Coastal staging sites such as Delaware Bay (Atlantic coast) and the Copper River Delta (Pacific coast) differ from interior sites in extrinsic factors (e.g. weather, landscape) potentially influencing migratory decisions. Atlantic coast sites often are associated with stronger tailwinds in spring and weaker headwinds in fall than interior sites, but also with more dangerous crosswinds that could force birds over the ocean and more severe weather events (La Sorte et al. 2014; Richardson 1990). All coastal sites are characterized by tides and coastlines- absent from interior sites- which may be used as departure and navigational cues (Åkesson 1993; Lank 1989). These extrinsic factors may result in different behavioural responses between the coastal flyways and the Central Flyway.

Radio telemetry is a suitable technology for studying migratory decisions because of its high temporal and spatial resolution. Recent developments in automated telemetry, such as the Motus Wildlife Tracking System (henceforth Motus), allow for continuous monitoring within ~12 km of receivers (Howell et al. Unpublished data; Taylor et al. 2017). This enables a more precise indication of the timing, orientation, and ground speed of migratory movements at the local scale compared to other tracking techniques, features which can then be matched with local weather data (Mitchell et al. 2015; Taylor et al. 2017).

The Prairie Pothole Region (PPR) in the Central Flyway hosts millions of migrating shorebirds on its lakes and ponds each year (Skagen et al. 2008). Chaplin and Reed Lakes are part of a large, saline wetland complex in the PPR regularly used as a staging site by at least 15 shorebird species that feed on abundant brine shrimp (*Artemia salina*) and other macroinvertebrates (Table B.1). Each lake is designated an Important Bird Area (IBA) and together with neighbouring Old Wives Lake constitutes a Western Hemispheric Shorebird Reserve Network (WHSRN) site of Hemispheric Importance.

We used radio-tagging and an automated radio telemetry array to examine arrivals and departures of Sanderlings (*Calidris alba*) from Chaplin and Reed Lakes. The Sanderling is a

good model species for studying migratory movements because it is the most common arctic-breeding migrant staging at Chaplin and Reed Lakes, with an estimated 75,000 individuals using the area each year (see chapter 2) constituting 58% of the Central Flyway population as a whole (Payne 2010). Our objectives were to identify which extrinsic environmental cues (time of day, wind direction, wind speed, temperature, pressure, visibility) were related to Sanderling arrival and departure decisions on spring stopover. We hypothesized that arrivals would show weak or no relationships with environmental conditions, and that departures would be related to both time and weather - birds would depart around sunset and in winds blowing towards the north (assisting winds). We characterize bird movements on a fine temporal scale (minutes and hours) and hope our results will provide insight into migratory patterns that can be used in management of the Chaplin and Reed Lakes area.

3.2 Methods

3.2.1 Shorebird Capture and Radio Telemetry

From 2015-2017, we captured Sanderlings in the Gulf of Mexico (GOM) at 3 locations early in spring migration (mid-April to mid-May): Grand Isle, Louisiana (29° 10' N, 90° 4' W), Bolivar Peninsula, Texas (29° 22' N, 94° 43' W), and North Padre Island, Texas (27° 20' N, 97° 20' W). We captured Sanderlings later in spring migration (mid-May to early-June), at Chaplin Lake, Saskatchewan, Canada (50°25' N, 106° 40' W) (Table 2.1). We used several capture techniques, depending on time of day and location: mist netting from dusk to dawn (Chaplin Lake only), and cannon net (GOM only) or noose carpets (Chaplin Lake and GOM) during daylight hours. We did not trap during adverse weather conditions (high winds and/or rain). We banded birds with one aluminum band, one colour band, and one alpha numeric coded plastic flag (green for USA, white for Canada), in a combination unique to each year. We glued coded radio transmitters (Lotek Avian NanoTag Model NTQB-3-2 (6 - 8 s burst rate, 0.67 g mass, and ~90 - 105 day battery life)) directly to the skin (beneath feathers) between the scapulae of each bird with a 5 min curing marine epoxy. Trapping, banding, and radio transmitter attachment protocols were approved by the University of Saskatchewan Animal Research Ethics Board as Animal Use Protocol 20120021 and by the Canadian Bird Banding Office as banding permit 10268.

We made use of the Motus Wildlife Tracking System (Taylor et al. 2017) to monitor individual birds' daily presence. Stations (receivers) continuously scan for tags (transmitters), logging data for the duration a tagged bird is in the area. Our local telemetry array consisted of six towers around Chaplin and Reed Lakes (Figs. A.1-A.3), each with three 9-element Yagi antennas (Model: Laird PLC1669) oriented 120° from one another and a SensorGnome receiver that listens to all antennas continuously (www.sensorgnome.org). Towers operated from late-April to mid-October of each year of the study. Towers were approximately 7 m tall, at elevations ranging from ~660 to 725 m above sea level. Two separate experiments (one using a helium-filled balloon and one using a UAV) yielded an approximately 12 km range of the front lobe (Taylor et al. 2011; Howell et al. Unpublished data) and a 3 km range of side and back lobes of each antenna (Fig. A.4) (Howell et al. Unpublished data); giving us adequate coverage of both lakes. For each detection of each tagged bird by the tower, the tag number (id), date and time (hh:mm:ss), antenna and signal strength (dBm) were automatically recorded.

We isolated sets of detections from birds in flight using the following criteria: 1) most detections inside the set are separated from each other in time by the interval between transmitter signals (6 or 8 s in our case), 2) detections inside the set are separated from detections outside of the set by five or more minutes, and 3) detections inside the set have a curved shape when plotted as signal strength vs. time (Mitchell et al. 2012). We identified an arrival as the moment of maximum signal strength during the first set of detections of a bird at either Chaplin or Reed Lake. We obtained arrival data from birds tagged farther south in the GOM that later were detected at the Chaplin and Reed Lakes study site. We identified a departure as the moment of maximum signal strength during the last set of detections of a bird at Chaplin or Reed Lake- which ever lake the bird initiated flight from (Mitchell et al. 2015). We obtained departure data from the birds tagged in the GOM and birds tagged at Chaplin Lake. Arrivals and departures were often captured on multiple towers simultaneously and in succession, but arrivals were often characterized by detections at southerly towers while departures were often characterized by detections at the northernmost towers. Departures were also often characterized by simultaneous detections on all antennas at towers, which indicates that the bird was very close (~3 km or less) to the tower (Howell et al., Unpublished data). We identified non-stop flight detections or “fly-overs” (birds that pass over the towers and site without stopping) as single sets of brief

detections. We excluded these birds ($n = 7$) from our movement analyses (i.e. birds did not stage at the study site).

3.2.2 Weather Data Compilation

We compiled weather data for the hour preceding an arrival or departure from Chaplin Lake at the time and date that the movement occurred, and for the mean hour of all recorded arrivals or departures on each of the three days preceding the movement (Matthews and Rodewald 2010). Because departures tended to be clustered in morning and late evening, we used weather conditions for the days preceding each movement from either a morning (0:00 – 12:00) or evening (12:00 – 23:59) mean time compiled from arrivals or departures (see sections 3.3.1 and 3.3.2 of Results). Weather data were compiled from Environment Canada weather stations at Lucky Lake (50° 57' N, 107° 9' W), Moose Jaw (50° 19' N, 105° 32' W), and Swift Current, SK (50° 17' N, 107° 41' W) (<http://climate.weather.gc.ca/>), which are roughly 75 km North, East, and West of Chaplin Lake, respectively (Fig. A.9). Data included temperature (°C), relative humidity (%), wind direction (10's degrees), wind speed (km/h), visibility (km, available for Swift Current only), and pressure (kPa). Each variable was averaged among all locations for each hour.

3.2.3 Analysis of Arrivals and Departures of Tagged Birds

We tested whether a relationship existed between time of day and arrival through angle histograms and Rayleigh's Uniformity Test. We examined whether birds responded to sun position by plotting minutes from sunrise or sunset for each observation. We assessed the relationship between time of arrival at Chaplin or Reed Lake and weather conditions using generalized linear mixed models (GLMMs) in R (lme4). Whether or not a bird arrived on a given date (1 = Yes, for the day of arrival; 0 = No, for the three days preceding arrival; see above) was the binomial dependent variable (Grönroos et al. 2012). Temperature, wind speed, wind speed², visibility, barometric pressure, and year were independent fixed effects. We included the polynomial term "Wind speed²" to account for a non-linear relationship between arrival and wind speed, which improved model fit. We did not include relative humidity in analyses because it was highly negatively correlated with temperature ($r = -0.76$, $p < 0.001$). Because each bird was tracked repeatedly (see section 3.2.2), we included bird (individual) as a random effect. We ranked models using Akaike Information Criterion adjusted for small sample sizes (ΔAIC_c)

(Burnham and Anderson 2003). We analyzed wind direction separately using angle histograms. We plotted wind directions from the day of arrival and three days preceding arrival in individual angle histograms. Each wind direction observation was weighted by wind speed. We tested whether wind data were uniformly distributed (nonsignificant) with Rayleigh's Uniformity Test. All times are reported in Saskatchewan local time (GMT – 6 h). We repeated the above processes (time of day, GLMMs and wind analysis) for departures.

We inferred flight direction of departing tagged birds when birds were detected on multiple towers in succession, with different methods depending on the distance between towers. For departures in which a bird was detected in succession on two or more towers more than 15 km apart, we inferred a coarse scale cardinal direction from the direction of travel required to make the movement between towers. We inferred finer scale intercardinal direction when the antenna on which the strongest signal was recorded at the first tower passed was angled on a different plane than of that on the subsequent tower. For example, if a departing bird was detected most strongly on the southeast facing antenna of Chaplin North then later detected most strongly on the southwest facing antenna of Halvorgate, the inferred departure direction would be northwest (Fig. A.10). For departures in which a bird was detected simultaneously or in succession on two or more towers less than 15 km apart, we performed bi-angulations between signals on two antennas on different towers, which was validated by the orientation of the last antenna the bird was detected on to infer the direction of travel (similar to a vanishing bearing) (Fig. A.11). We excluded departures during which the last detections of a bird were simultaneous on multiple opposing antennas on single or multiple towers from analyses of departure orientation ($n = 22$). We visualized flight direction using angular histograms in the circular statistics program Oriana (version 4). We tested whether there was a significant mean flight direction using Rayleigh's Uniformity Test; a significant non-uniform result indicates the population is orienting in a particular direction (Zar 1998).

3.2.4 Visual Tracking of Departing Flocks

On nights when we trapped birds in 2017, we monitored flying shorebird flocks from a road going through the middle of Chaplin Lake (Fig. A.12) starting at 20:00 until it became too dark to see. We watched for flocks of ≥ 10 birds coming from any direction, and flocks flying more than ~20 m above ground that were not seen to land were assumed to be departing. We

counted birds in each migrating flock and observed through binoculars until birds were no longer visible. Although we could not identify birds to species, most flocks appeared to consist of small shorebirds. We took compass bearings when the flock was first observed and as it vanished (Grönroos et al. 2012; Covino et al. 2014). For each flock, we recorded start and end time of observation, approximate horizontal distance from observer at start time, compass bearing at start time, compass bearing at end time, and number of birds. We calculated flight directions of visually observed migrating flocks with equations 3.1 – 3.2.

$$b_2 + \beta \quad \text{equation 3.1}$$

Where b_2 is the compass bearing taken as a flock vanished (vanishing bearing), and β is the angle for parallax compensation, calculated by:

$$\beta = \arcsin \left[\left(\frac{d_1}{d_2} \right) \sin(b_1 - b_2) \right] \quad \text{equation 3.2}$$

Where d_1 is the horizontal distance of the flock from observer at start time, d_2 is the distance flown by the flock during the observation period, and b_1 is the compass bearing of the flock at start time (Grönroos et al. 2012). Distance flown by the flock (d_2) was calculated by assuming a ground speed of 16 m/s (Alerstam et al. 2007). We tested whether there was a significant mean flight direction using Rayleigh's Uniformity Test.

3.3 Results

3.3.1 Arrival Conditions

We could not estimate arrival direction given the low sample size. The mean hour of arrival was 22:00, but arrivals were not significantly influenced by time of day (95% CI = 17:00 – 2:00, $r = 0.22$, $p = 0.30$, $N = 24$; Fig. 3.1). Morning arrivals ($n = 10$) averaged 25 ± 74 min before sunrise. Evening arrivals ($n = 14$) averaged 130 ± 64 min before sunset.

The null model containing no weather variables was the top model ($\Delta AIC_c = 2.5$) (Table 3.1). Angle histograms showed that wind direction was not significantly different during arrivals than at other times (mean wind directions of 2° (95% CI = $147^\circ - 218^\circ$, $r = 0.11$, $p = 0.74$) vs. 356° (95% CI = $58^\circ - 294^\circ$, $r = 0.15$, $p = 0.20$); both sets of data were uniformly distributed (Fig. 3.2).

3.3.2 *Departure Flight Direction and Conditions*

We were able to infer flight direction from 73 departures of radio-tagged birds recorded on two or more towers more than 15 km apart and 24 departures recorded on two or more towers less than 15 km apart. Mean flight direction of departing radio-tagged birds was north and data were non-uniformly distributed (mean = 357°, 95% CI = 349° – 5°, $r = 0.78$, $p < 0.001$) (Fig. 3.3). One bird (tag 123) was detected on 3 towers in succession, covering 90 km heading north (360°).

The mean hour of departure was 20:10, and departures were significantly influenced by time of day (95% CI = 19:40 – 20:40, $r = 0.72$, $p < 0.001$, $N = 140$; Fig. 3.4). Morning departures ($n = 18$) averaged 16 ± 23 min after sunrise. Evening departures ($n = 122$) averaged 56 ± 7 min before sunset.

We found a positive effect of temperature and a negative effect of wind speed on probability of departure. The top model included temperature ($\beta = 0.24 \pm 0.11$, $p = 0.02$), wind speed ($\beta = -0.52 \pm 0.12$, $p < 0.001$), and wind speed² ($\beta = 0.09 \pm 0.09$, $p = 0.31$). This model was supported over the next best model ($\Delta AIC_c = 3.1$) (Table 3.2). Angle histograms showed that wind direction was significantly different during departures than at other times (mean wind directions of 297° (95% CI = 279° – 315°, $r = 0.37$, $p < 0.001$) vs. 157° (95% CI = 146° – 167°, $r = 0.36$, $p < 0.001$)); wind directions from both departure and non-departure times were non-uniformly distributed (Fig. 3.5). Birds had a higher probability of departure when winds were blowing towards the northwest at intermediate speeds; whereas birds generally did not depart when winds were blowing towards the southeast at higher wind speeds.

3.3.3 *Flight Direction of Visually Observed Flocks*

We calculated vanishing bearings from 18 flocks averaging 126 ± 27 individuals. Flight directions averaged northwest and were non-uniformly distributed (mean = 317°, 95% CI = 296° – 339°, $r = 0.72$, $p < 0.001$) (Fig. 3.6).

3.4 Discussion

3.4.1 *Characterization of Migratory Movements*

Our hypotheses were supported by our data; Sanderling arrivals showed no relationships with environmental conditions but departures took place primarily around sunset and in assisting

winds. Departing birds oriented north (radio tagged Sanderling) to northwest (visually observed small shorebird flocks). Thus, departures appeared to be controlled by extrinsic factors while arrivals may be a consequence of intrinsic factors (fat) and extrinsic factors experienced previously along the migratory route.

Sanderlings took advantage of assisting tailwinds, generally departing towards the north when winds blew to the west-northwest at low or intermediate speeds but not departing when winds blew to the southeast and at higher speeds. Visually observed small shorebird flocks generally departed northwest, and the difference in mean flight direction between these and radio-tagged Sanderling flight directions could be due to greater resolution in visual observations or species behavioral differences. Flying in winds blowing at least partially in the desired direction (i.e. towards arctic breeding grounds) minimizes energy expended, whereas flying into headwinds is more energetically costly and potentially hazardous if accompanied by high wind speeds and/or storms (Alerstam and Lindström 1990; Newton 2007). Wind assistance may be essential to shorebird migration. Flying without wind assistance would theoretically require over three times as much fat (fuel) measured in staging birds to arrive on the breeding grounds in good body condition (Butler et al. 1997). Ma et al. (2011) observed more departing birds, fewer arriving birds, and fewer birds on the ground in tailwinds, and the reverse pattern in headwinds. Increased departures of shorebirds in tailwinds rather than cross or headwinds were also recorded by Gudmundsson and Lindström (1992), Gudmundsson (1994), and Grönoos et al. (2012), and similar patterns have been observed in passerines (e.g. Covino et al. 2014; Sjöberg et al. 2015).

Whether a bird departed or not was significantly positively related to temperature, which parallels our results for wind given that winds blowing to the north are typically associated with increased temperature and decreased humidity (Richardson 1990). Temperature and humidity were significantly negatively correlated; thus, our tagged Sanderlings may have responded to either or both variables. Higher temperatures and lower humidity is often indicative of lower precipitation and better overall weather conditions (Richardson 1990).

In addition to relationships with weather, tagged Sanderlings departed ~ one h before sunset on average, which agrees with the nocturnal migratory movements reported in other shorebird studies but highlights an important difference between shorebird and passerine migration. Spring departures of Sanderlings along the coast of southwest Iceland were primarily

in the hour approaching and slightly following sunset (Gudmundsson and Lindström 1992). The median departure time of Red Knots (*Calidris c. canutus*) leaving staging sites in spring along the southern Scandinavian coast was 1.5 h before sunset (Gudmundsson 1994). Fall departures of Semipalmated Sandpipers (*Calidris pusilla*) at a coastal site in New Brunswick peaked with both rising tides in the day and as sunset approached, while at an inland site in North Dakota there was a single strong peak in the half hour before sunset (Lank 1989). These and other studies show that shorebirds depart more often before sunset in contrast to passerines which depart more often after sunset (Lank 1989; Gudmundsson and Lindström 1992; Gudmundsson 1994; Åkesson and Hedenström 2000; Mills et al. 2011; Sjöberg et al. 2015). Shorebirds may leave earlier in the evening to maximize their flight time during longer “jumps” associated with staging strategy while passerines often make shorter “hops” associated with stopover strategy (Warnock 2010). Shorebirds could also be relying more on the sun’s position and angle to calibrate their internal compass for successful navigation. For example, the migratory orientation of Sanderlings significantly improved (towards the direction of their breeding grounds) between clear (sun visible) and overcast (sun obscured) skies in caged experiments (Gudmundsson and Sandberg 2000). The use of the sun as a navigation tool could explain why a subset of tagged birds (13%) left the staging site on average just after sunrise. Morning departures in a generally nocturnal migrant may be explained as a compensation for poor weather. If weather conditions are suboptimal for extended periods after a bird has gained the amount of fat needed to make its next flight, it may choose to leave as soon as weather improves (Alerstam and Lindström 1990). Birds departing in the morning may also fly shorter distances, enabling them to join flocks and find foraging opportunities at their next stop during daylight hours (Alerstam 2009).

Arrivals to our study area did not show any consistent patterns with time or weather, which may indicate that either certain times and conditions are not selected for by arriving birds or that the arrivals we recorded were from birds already in the nearby area. While birds appeared to select optimal departing conditions, arrival patterns are likely a consequence of previous decisions and conditions at previous departure sites and along the migratory route. Environmental conditions as far south as the wintering grounds can affect arrival times as far north as the breeding grounds (Saino et al. 2004). Total travel time will also be influenced by weather conditions or other unanticipated obstacles (e.g. predators, human-made structures) along the route (Richardson 1990). As described above, assisting winds will decrease travel time,

opposing winds will increase travel time, and storms may force birds to land at least temporarily (Butler et al. 1997; Newton 2007). The distance a bird is capable of flying non-stop without consideration of weather is determined by internal fuel loads (Alerstam and Lindström 1990). Arriving birds typically have low mass and low fat, suggesting that they stop when they are out of fat reserves (Krapu et al. 2006). Indeed, the fly-overs that we observed at our study site ($n = 7$) presumably were by individuals that had enough fuel to continue on migration either to another more northerly staging site or to their breeding grounds. Alternatively, some of the arrivals we observed may have been birds already present in the area (i.e. not arriving from long distances), but not yet detected by our towers. Our towers were located north, east, and west of Chaplin Lake and east and west of Reed Lake, with partial coverage to the south from one antenna at each tower, as antennas face south, southeast, and southwest. Thus, a recorded “arrival” may be delayed until the bird is on the northern half, east, or west sides of Chaplin Lake or the east or west sides of Reed Lake. Similarly, arrivals may show no patterns with time or weather if birds originated from local sites, because these short flights would presumably be less energetically expensive and less dangerous.

3.4.2 Conclusion

Our results suggest that different stages of a migratory flight are likely controlled by different extrinsic and intrinsic factors. Departures were significantly related to time and wind conditions, while arrivals were not related to any variables we examined. Broadly, the interplay of factors influencing migratory activities is important for understanding the evolution of migration and how migratory birds may respond to changes in extrinsic factors associated with climate change. As Arctic breeding grounds warm faster than southern wintering grounds, birds may reach breeding grounds late and have lower reproductive success if weather conditions farther south serve as cues to initiate movement. If approached in combination with genetics and physiology, behavioral research like in this study may show whether Arctic migrants such as many shorebirds have the plasticity to cope with climate change (Knudsen et al. 2011). At a smaller scale, the consistency we observed in migratory departures with flight direction, timing, and weather have implications for management of human activities that have the potential to negatively affect migrating shorebirds.

Wind energy development is an increasing human activity in the area surrounding Chaplin and Reed Lakes. Risk of bird collisions with turbines is high when large numbers of migrating birds are moving through a development (Drewitt and Langston 2006; Aschwanden et al. 2018). The significant relationships between departures and time and weather can be used to predict when birds will be aloft. Developments operating near the staging site and in the flight path of departing birds (i.e. north during spring migration) could mitigate collision risk by temporarily shutting off turbines at times during migration when weather is advantageous for initiation of migratory movements (Subramanian 2012). As an example, a 79 turbine development to be sited < 5 km north of Chaplin Lake was proposed but denied approval (Saskatchewan Ministry of Environment 2016a). Had that development been approved, recommended mitigation would be to monitor weather conditions throughout spring migration (second week of May through the second week of June), curtailing turbine operation within two hours of sunset and sunrise when winds are blowing towards the northwest to north at light to intermediate wind speeds (<22 kph) during that time. The quality and quantity of data from migrating tagged birds will continue to improve as technologies advance, and ongoing research into the intricacies of shorebird migration ecology advance our understanding of migration ecology as well as yield applications for conservation and management.

Table 3.1. Model selection of results of GLMMs assessing factors influencing the probability of radio-tagged Sanderlings arriving at Chaplin and Reed Lakes on a given date (yes or no; binomial dependent variable) with independent variables of temperature, wind speed, visibility, pressure, and year. Models were ranked by ΔAIC_c .

Model	<i>AIC_c</i>	ΔAIC_c	Deviance	<i>w_i</i>
Arrival ~ 1	112.1	0	108	0.57
Arrival ~ Wind Speed ² + Wind Speed	114.6	2.5	106	0.16
Arrival ~ Wind Speed ² + Wind Speed + Visibility	114.7	2.6	104	0.16
Arrival ~ Temperature + Wind Speed ² + Wind Speed + Visibility	116.1	4	103	0.08
Arrival ~ Temperature + Wind Speed ² + Wind Speed + Visibility + Pressure	118.2	6.1	103	0.03
Arrival ~ Temperature + Wind Speed ² + Wind Speed + Visibility + Pressure + Year	123	10.9	103	0.0

Table 3.2. Model selection results from generalized mixed models assessing factors influencing the probability of radio-tagged Sanderlings departing from Chaplin and Reed Lakes on a given date (yes or no; binomial dependent variable) with independent variables of temperature, wind speed, visibility, pressure, and year. Models were ranked by ΔAIC_c .

Model	<i>AIC_c</i>	ΔAIC_c	Deviance	<i>w_i</i>
Departure ~ Temperature + Wind Speed^2 + Wind Speed	617.1	0	607	0.67
Departure ~ Temperature + Wind Speed^2 + Wind Speed + Year	620.2	3.1	606	0.14
Departure ~ Wind Speed^2 + Wind Speed	620.6	3.5	613	0.12
Departure ~ Temperature + Wind Speed^2 + Wind Speed + Pressure + Year	622.1	5	606	0.05
Departure ~ Temperature + Wind Speed^2 + Wind Speed + Visibility + Pressure + Year	623.8	6.7	605	0.02
Departure ~ 1	633.8	16.7	628	0.0
Departure ~ Temperature	633.9	16.8	630	0.0

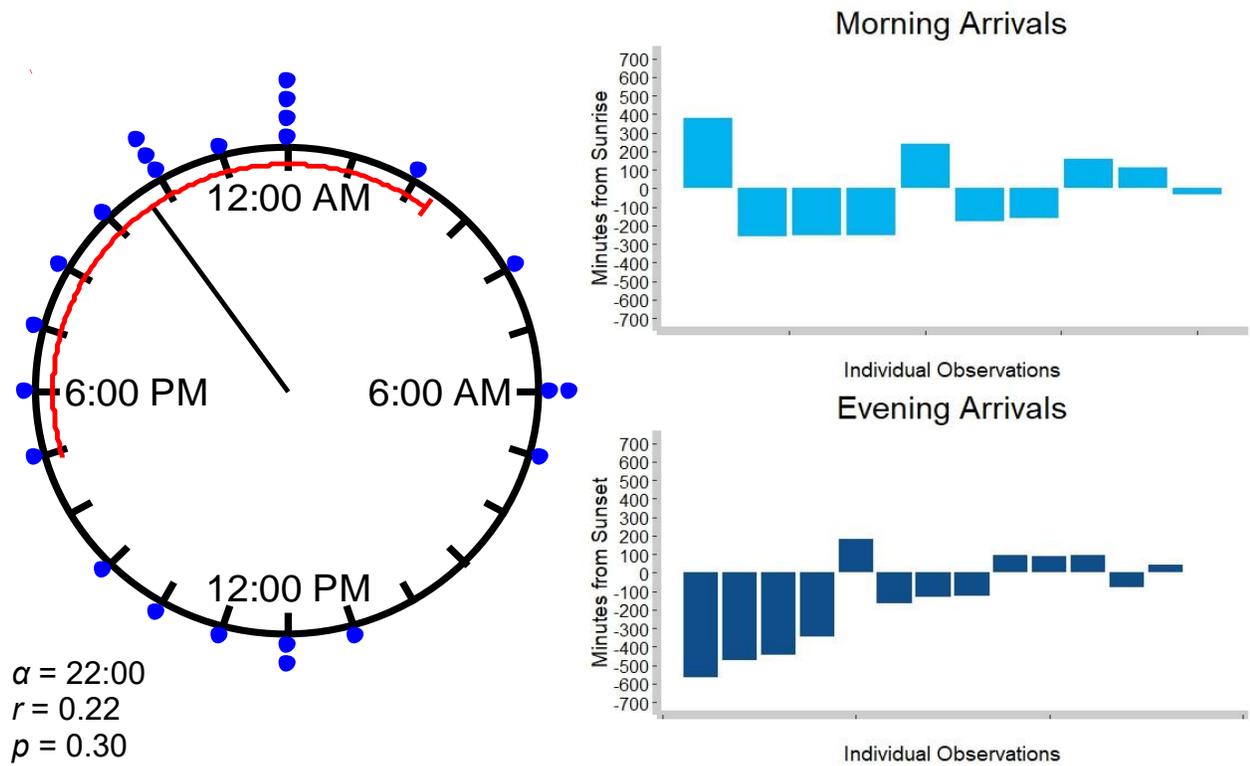


Fig. 3.1. Hour of arrival for each Gulf-tagged Sanderling at Chaplin and Reed Lakes is represented as a blue dot on the 24 hour clock ($n = 24$) (left). The mean hour (α) is shown as a black line from the center of the clock with confidence interval in red. Mean vector length (r), sample size, and the p value of Rayleigh's test (p) are shown below and to the left of the clock. Individual birds' arrival times in min prior to (- values) and following (+ values) sunrise ($n = 10$) and sunset ($n = 14$) are shown as bars at the top and bottom right.

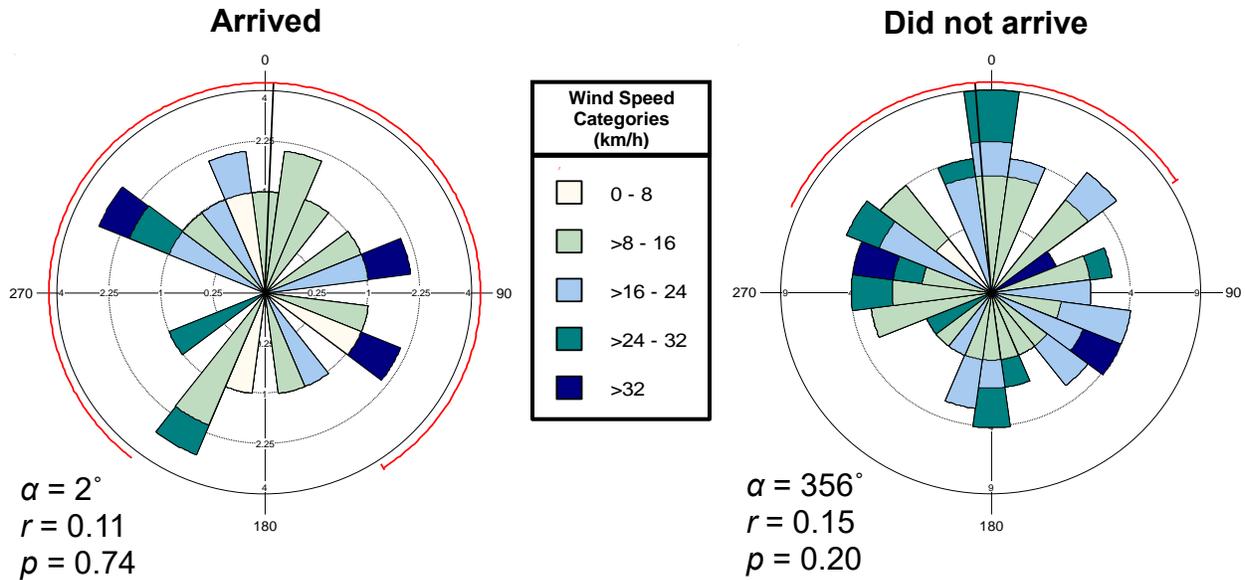


Fig. 3.2. Wind direction weighted by wind speed for hours that tagged Sanderlings arrived ($n = 24$) (left) and hours that birds did not arrive (right) ($n = 72$) at Chaplin and Reed Lakes. The angular histogram is arranged as a compass ($0^\circ = \text{North}$), the size of each wedge is equivalent to the number of observations in that direction, and wind speed categories are shown as different colors. Mean wind direction (α), mean vector length (r), sample size, and the p value of Rayleigh's test (p) are shown below and to the left of the plots.

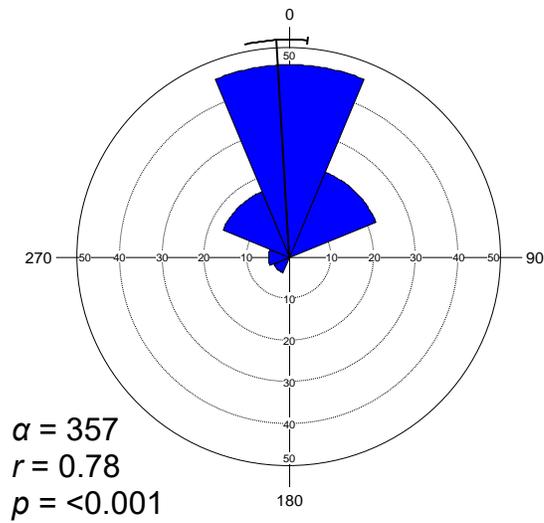


Fig. 3.3 Flight direction of departing radio-tagged Sanderlings (n = 97 birds) at Chaplin and Reed Lakes. The angular histogram is arranged as a compass (0° = North) and the size of each wedge is proportional to the number of observations of that direction.

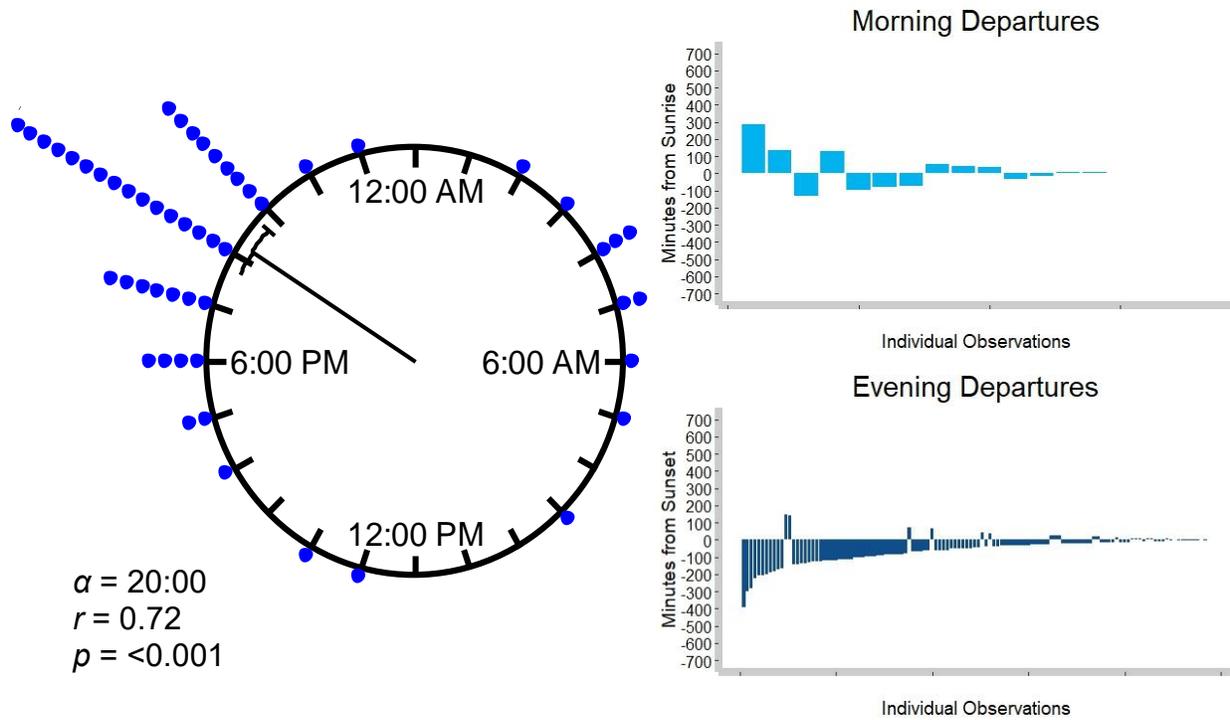


Fig. 3.4. Hour of departure for radio tagged Sanderlings from Chaplin Lake are represented as blue dots (one dot = 3 birds) on the 24 hour clock ($n = 140$) (left). The mean hour (α) is shown as the black line stretching out from the center of the clock with surrounding confidence intervals in red. Mean vector length (r), sample size, and the p value of Rayleigh's test (p) are shown below and to the left of the clock. Individual departure times in min prior to (- values) and following (+ values) sunrise ($n = 18$) and sunset ($n = 122$) are shown as bars at the top and bottom right.

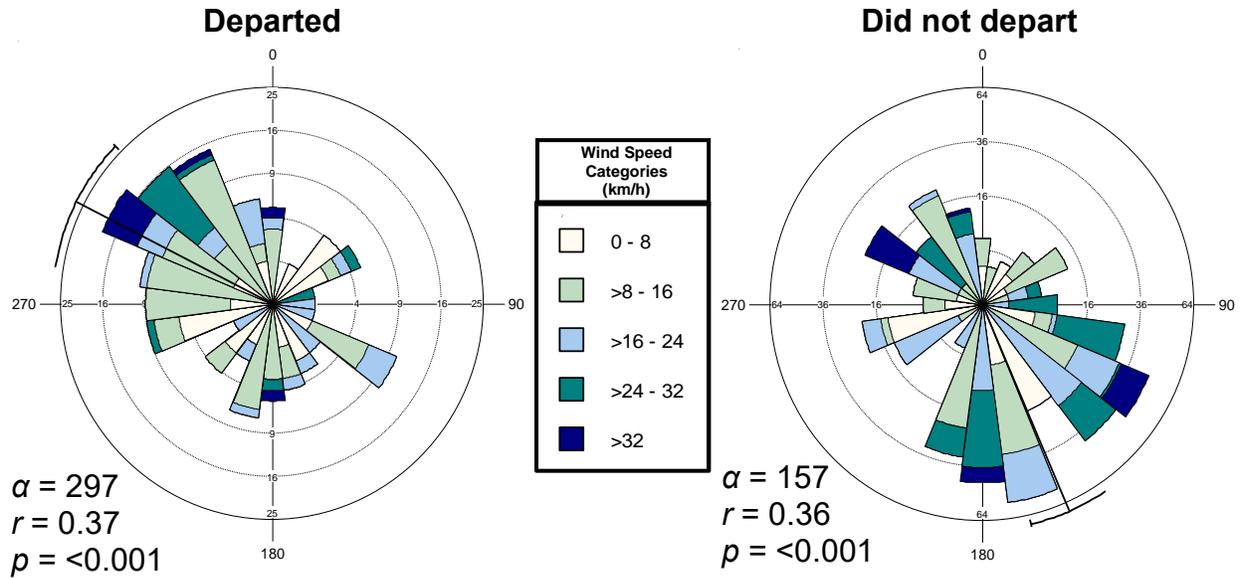


Fig. 3.5. Wind direction weighted by wind speed for hours that radio-tagged Sanderlings departed ($n = 140$) (left) and hours that birds did not depart ($n = 420$) (right) from Chaplin Lake. The angular histogram is arranged as a compass ($0^\circ = \text{North}$), the size of each wedge is equivalent to the number of observations of that direction, and wind speed categories are shown as different colors. Mean wind direction (α), mean vector length (r), sample size, and the p value of Rayleigh's test (p) are shown below and to the left of the plots.

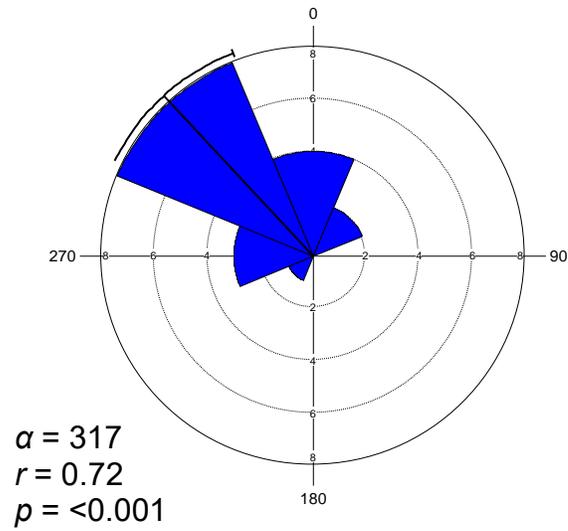


Fig. 3.6 Flight direction of departing visually observed shorebird flocks ($n = 18$ flocks) at Chaplin Lake. The angular histogram is arranged as a compass ($0^\circ = \text{North}$) and the size of each wedge is proportional to the number of observations of that direction.

CHAPTER 4:

CONCLUSIONS AND RECOMMENDATIONS

My thesis demonstrates the importance of Chaplin and Reed Lakes as a staging site both at a local and global scale, and underscores the need for continued work in shorebird migration ecology. My thesis objectives were to 1) characterize general migration chronology for arctic-breeding shorebird migrants in spring and fall at Chaplin and Reed Lakes, as well as estimate spring stopover duration and population size of Sanderling; and 2) investigate migratory movement and orientation patterns of Sanderlings and the influence of time and weather on those movements. My results show that Chaplin and Reed Lakes are consistently used as a staging site by a globally significant number of Sanderlings (estimated population of ~75,000, 12% of the global population) as well as large numbers of Red-necked Phalaropes (mean spring peak count = 7720 ± 2007) and Semipalmated Sandpipers (mean spring peak count = 964 ± 330). Eight times as many birds use the area during northward spring migration than southward fall migration; however, both spring raw counts of all migrants and estimated population size of Sanderling can vary by thousands of birds or more among years. Total stopover duration calculated using data from radio-tagged Sanderlings marked prior to arrival and raw abundance from systematic point counts at the lakes improved the population size estimates, but potentially uneven habitat usage by staging birds as well as site-specific detectability estimates should be accounted for in future models. Tagged Sanderlings staged for a mean of 11.1 (95% CI = 8.59 – 13.6) days, following which birds departed towards the north or northwest from Chaplin or Reed Lake with apparent wind assistance (winds towards the northwest at intermediate speeds) and most frequently around sunset and sunrise during the first two weeks of June. These predictable patterns of bird migration and staging behaviour may be used to direct management of this and other key staging sites in the Central Flyway, and continued research will elucidate migration risks that may affect conservation plans for arctic-breeding species.

4.1 Implications for Wind Energy and Other Developments at Chaplin and Reed Lakes

Under the threat of climate change, wind is increasingly being harvested as a renewable form of energy. However, wind energy developments can create wildlife conflicts when sited near high bird usage areas, because large numbers of birds may fatally collide with turbines (Drewitt and Langston 2006). Wind energy development is increasing in the area surrounding

Chaplin and Reed Lakes because of the consistent and strong winds in this region (Fargione et al. 2012). A 79 turbine development originally sited for less than 5 km north of Chaplin Lake (Chaplin Wind Energy Project) but denied approval by the Saskatchewan Ministry of Environment may now be developed more than 5 km south of Reed Lake (Blue Hill Wind Project), where a 10 turbine development is currently operating (Morse Wind Facility).

My departure orientation results showed that Sanderlings departing from Chaplin Lake flew through the area originally sited for the Chaplin Wind Energy Project (Fig. A.13). Although I did not have sufficient data to examine flight direction of arriving birds in spring or departing birds in fall, a large proportion of these birds would likely arrive from and depart towards the south in spring and fall respectively. These birds would be at risk of collision with turbines in the Blue Hill Wind Project south of Reed Lake. This would be particularly true for individuals and species (e.g. Red Knot and Black-bellied Plover (*Pluvialis squatarola*) in spring) that had consistently higher abundances at Reed Lake than Chaplin Lake. Collisions with turbines may be more likely to have a population-level impact in Red Knots (*rufa* subspecies) relative to other shorebird species because the population is already in decline and is relatively small (Beston et al. 2016).

I recommend that managers of this and other wind energy projects sited near high bird usage areas consider the following management and mitigation efforts: 1) in the siting stage, avoid siting north or south of any staging/stopover site, between two adjacent habitat patches within a staging/stopover site, or within 5 km of a staging/stopover site, and 2) in the operation stage of developments north or south of staging/stopover sites, shut off turbines within two hours before and after sunset and sunrise when winds are blowing at intermediate speeds in the direction of breeding or wintering grounds (north in spring, south in fall) during peak migration times (second week of May through the second week of June), and/or integrate an automatic shut down when large numbers of birds are in the air using radar. A minimum 5 km buffer around IBAs and WHSRN sites, as implemented by the Ministry of Saskatchewan in 2016, may be a crucial management effort (Saskatchewan Ministry of Environment 2016b). Using mean ground speed (21.4 ± 1.12 m/s) from this study's radio-tagged Sanderlings and climb rates of Sanderlings and similarly sized shorebird species reported by Piersma et al. (1997), I calculated a Sanderling's approximate altitude at various distances after taking off from the north shoreline of

Chaplin Lake (Table 4.1). Although birds with low climb rates (0.25 m/s) would need more than 10 km to clear turbine height, birds with high (2.0 m/s) and medium (1.25 m/s) climb rates would clear turbine height (165 m) by 5 km. Although beyond the scope of this study, I also recommend that managers of this and other wind energy projects consider potential risks to breeding resident birds, migrating waterfowl, and migrating bats (Arnett and Baerwald 2013).

Similar mitigation strategies to those for wind energy developments could also be implemented in other development types in the Chaplin and Reed Lakes area. For example, a road running across Reed Lake, which was closed for the past three years due to erosion damage, has recently been reconstructed and reopened for public use (Howell Personal observation). Red Knots and other shorebird species roost in high densities on the road during the spring migration season (indeed, the northern and southern tips of the road form two of our point count stations at Reed Lake), which could be disturbed or killed by vehicles. Human disturbance of foraging and roosting could interfere with fuel deposition and cause staging birds to expend additional energy to avoid humans (Burger et al. 2004). Collisions with vehicles were recorded when the road was previously open (one Sanderling and 11 Red Knot carcasses were found on June 1, 2011) (Johnston 2011). The Red Knot population at Chaplin and Reed Lakes appears to be in the low hundreds by peak point count numbers, but numbers could be in the high hundreds or more by personal observations and those of local birders; which heightens the potential for a population level impact from disturbance and collisions. I recommend considering temporary road closures to vehicular traffic from the second week of May to the second week of June, thus providing habitat and protection for at risk shorebirds during the peak period of migration.

4.2 Recommendations for Future Research at Chaplin and Reed Lakes

My study raised further questions and research needs regarding shorebird migration and stopover ecology at Chaplin and Reed Lakes. For example, future research could aim to improve Sanderling population estimates by directly measuring and incorporating habitat use and features affecting detectability. I calculated a minimum useable area to Sanderlings within 200 m of all shoreline, excluding areas Sanderlings did not occupy based on anecdotal observation. However, there is a further need to collect habitat data along with species presence, then model species habitat associations, and finally use the models to predict usable area over the entirety of the lakes. This would be a multi-year study, as models should also incorporate annual and seasonal

variability in water depth (and consequently available shoreline), which significantly fluctuates due to variation in precipitation and evapotranspiration in the PPR. In addition, historical satellite imagery of the area could be used to examine changes in habitat availability among years, which could be modeled to test for relationships with Sanderling population size. Furthermore, I also concluded in my study that program “Distance” detectability estimates were biased low because birds were clustered in shallow water near point count centers. Detectability estimates could be refined by measuring relationships between water depth and Sanderling presence and including these as a covariate in detectability functions. The above study would therefore fill an important research need regarding how habitat use and heterogeneity affect detectability and thus contribute to improved population estimates.

Further work on Sanderling will extend beyond Chaplin and Reed Lakes in a study of radio-tagged bird detections across the entire Motus network in combination with band resights. The network-wide data will be used to examine total migration speed, differences in routes taken by different individuals in spring and fall, and tag retention. In addition to providing insight into these finer details of migration, the study will serve as an update to the study by Myers et al. (1990) on Sanderling migration routes which used band resights only. By demonstrating the use of multiple staging sites by individuals on multiple migration routes, the study will highlight the importance of hemisphere-wide conservation of shorebird habitat.

In addition to Sanderling, large numbers of Red-necked Phalarope use Chaplin and Reed Lakes as a staging site and because population dynamics and migratory movements of this species are poorly understood (Andres et al. 2012), further research could examine migratory connectivity of Red-necked Phalarope between the wintering and breeding grounds. A pilot study was initiated at Chaplin and Reed Lakes in spring 2017, which could be expanded by establishing telemetry towers at Prudhoe Bay, Alaska (Haig et al. 1997), and other potential northern breeding locations. The population could be studied at both locations to examine migration speed and adult survival. This is particularly relevant in the context of anthropogenic threats throughout the annual cycle; while Chaplin and Reed Lakes are flagged for increasing wind development (potential for mortality from collisions and habitat loss), arctic breeding sites such as Prudhoe Bay are experiencing increasing oil development and predator pressure (Liebezeit et al. 2009).

4.3 Application of Motus Migration Network for Conservation

Long distance migrants can be difficult to study, but regular use of staging sites by shorebirds means that these sites can provide important information on population status. Several key challenges in shorebird research include distinguishing separate breeding populations at staging sites, incorporating stopover duration into population estimates, and determining where monitoring should be focused with limited funding and staffing (Thomas et al. 2006; Payne 2010; Taylor et al. 2017). These challenges could be better met with standardization and synthesis of monitoring and tracking efforts. For example, the existing Program for Regional and International Shorebird Monitoring (PRISM) aims to establish standardized, annual surveys at key staging, breeding, and wintering sites across the Americas (Bart et al. 2002), while the Motus Wildlife Tracking System aims to identify migratory routes and stopover durations of individual tagged birds (Taylor et al. 2017). The data sets are complimentary; PRISM collects total bird abundance at sites while Motus collects information on stopover duration and migration route from individual birds.

Establishment of Motus towers at staging sites with simultaneous abundance counts could provide powerful datasets for more accurate population estimates. Indeed, studies estimating staging population size have relied on both count and telemetry data (i.e. Farmer and Durbian 2006; Drever et al. 2014). I was able to estimate a population size of ~75,000 Sanderlings at Chaplin Lake by using a modeling approach combining data from abundance counts (which may become a part of PRISM in the future) and Motus tracking, which is important for Sanderling conservation as 25% of North America's Sanderling population may depend on this site. Establishment of Motus towers at all staging and stopover sites may not be financially feasible, but species-specific, general estimates gleaned from sites with towers could be used as constants to calculate population sizes for smaller sites with resources for only abundance counts. For example, the estimated Sanderling spring stopover duration of 11 days from my study is similar to spring stopover durations of Sanderlings recorded at other staging sites, making this estimate potentially applicable to analyses of data from other northern locations (Gudmundsson and Lindström 1992; Scott et al. 2004). However, population size estimates are extremely sensitive to stopover duration (Drever et al. 2014), and more work needs to be done to examine the degree of site and seasonal variation in stopover duration.

My project addressed temporal use of Chaplin and Reed Lakes, a single major staging site, by arctic-breeding shorebirds with implications for mortality risk from increasing wind energy development. While there are many questions still to be answered regarding shorebird migration ecology at the hemispheric and global scale, shorebird conservation benefits from research at the local and regional scale. International collaboration among researchers, landowners, industry, and the public will be key to preserving migratory shorebird populations that are highly interconnected.

Table 4.1. Estimated flight height of departing shorebirds at increasing horizontal distances from the northern edge of Chaplin Lake, using our mean radio- tagged Sanderlings ground speed of 21.4 m/s, and climb rates from Piersma et al. (1997). Flight heights under total turbine height (165 m, ground to blade tip) are shown in bold.

Climb Rate (m/s)	Flight Height (m) at various horizontal distances from water's edge		
	2.5 km	5 km	10 km
Low (0.25)	29	58	117
Medium (1.25)	146	292	467
High (2.0)	234	467	935

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Appendix A: Relevant Maps

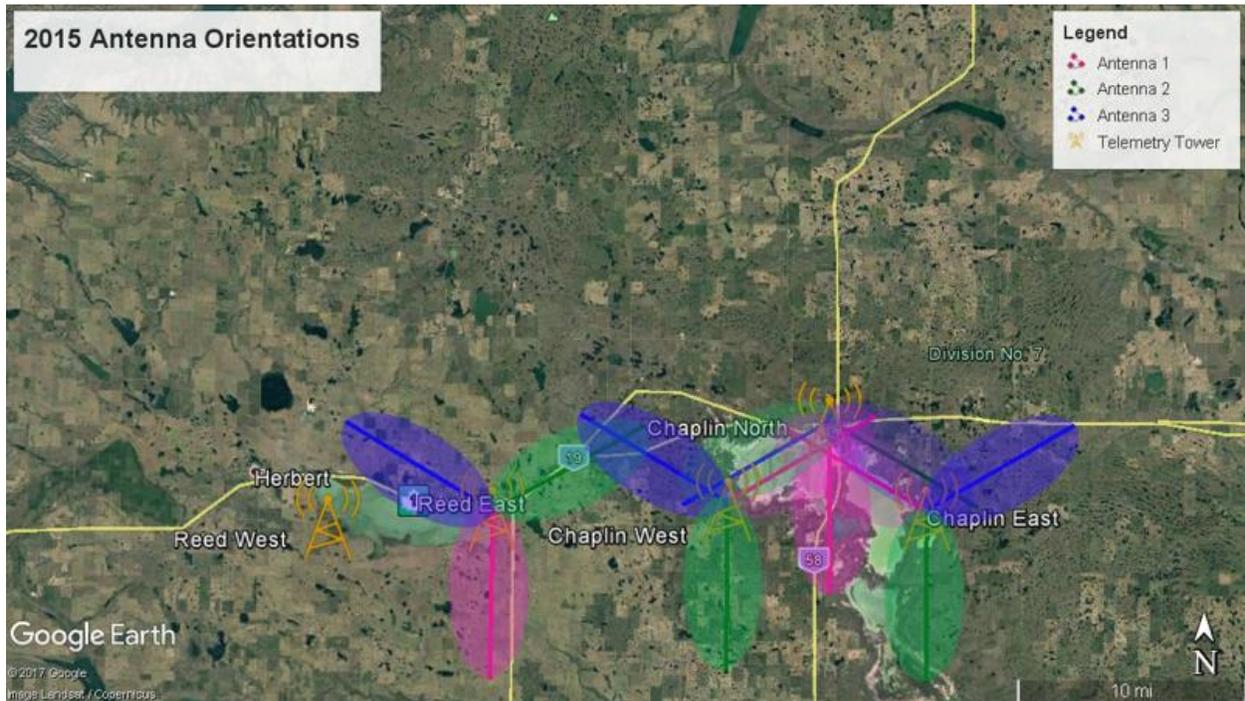


Fig. A.1. Telemetry towers around Chaplin and Reed Lakes, with arrangements of antennas in 2015. Five telemetry towers were established in 2015: 3 at Chaplin Lake and 2 at Reed Lake. Ovals represent the approximate horizontal beamwidth, or detection range, of each antenna. The tower at the west end of Reed Lake (Reed West) was destroyed by cattle during fall of 2015 and orientations of antennas were not recorded.

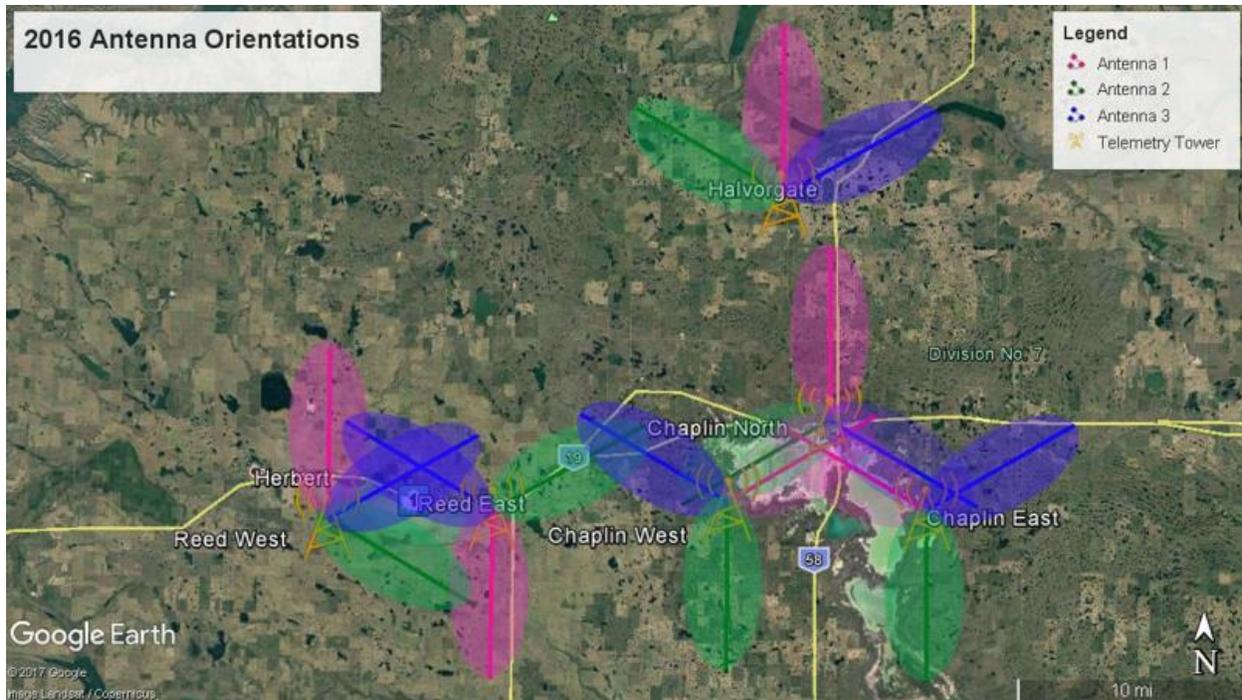


Fig. A.2. Telemetry towers around Chaplin and Reed Lakes, with arrangements of antennas in 2016. A sixth telemetry tower was established north of Chaplin Lake (Halvorgate) in 2016, the Reed West tower was replaced, and the antenna orientations of Chaplin North were changed. Ovals represent the approximate radiation pattern, or detection range, of each antenna.

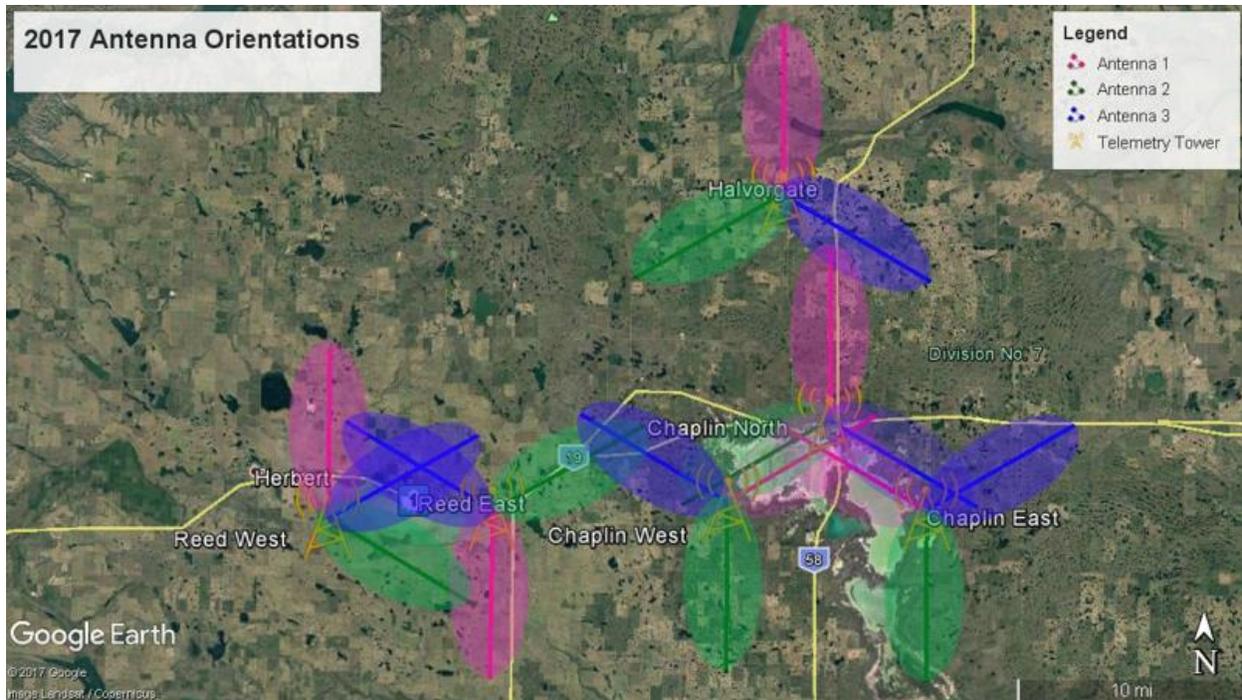


Fig. A.3. Telemetry towers around Chaplin and Reed Lakes, with arrangements of antennas in 2017. The antenna orientations of Halvorgate were changed in 2017. Ovals represent the approximate radiation pattern, or detection range, of each antenna.

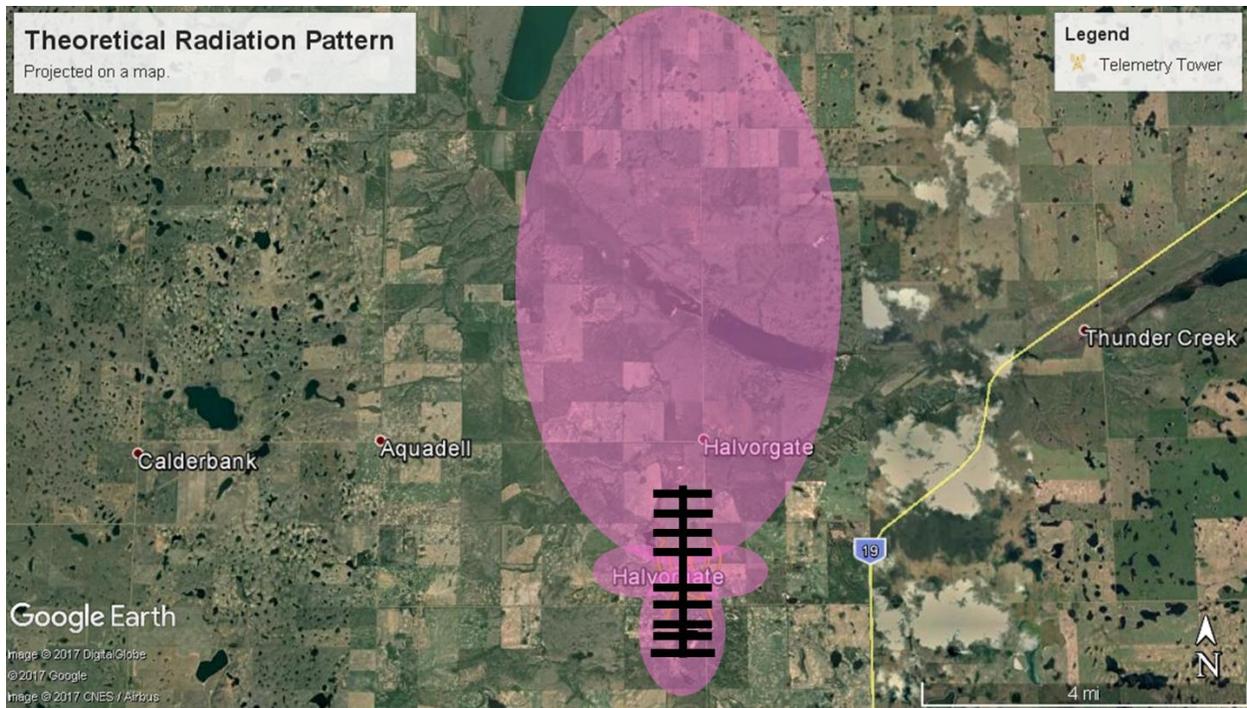


Fig. A.4. Theoretical radiation pattern of a 9-element Yagi as determined from calibration with a UAV, projected over the Halvorgate telemetry tower (Howell et al. Unpublished data).

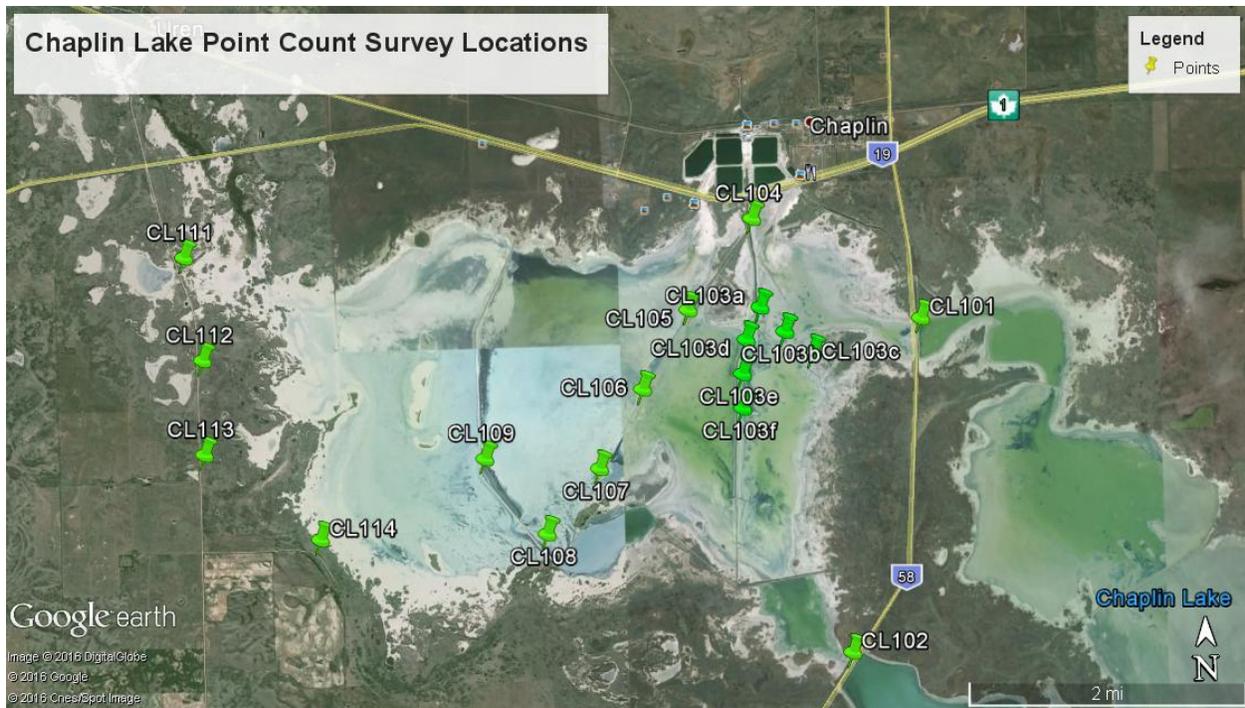


Fig. A.5. Shorebird point count survey locations at Chaplin Lake (18).

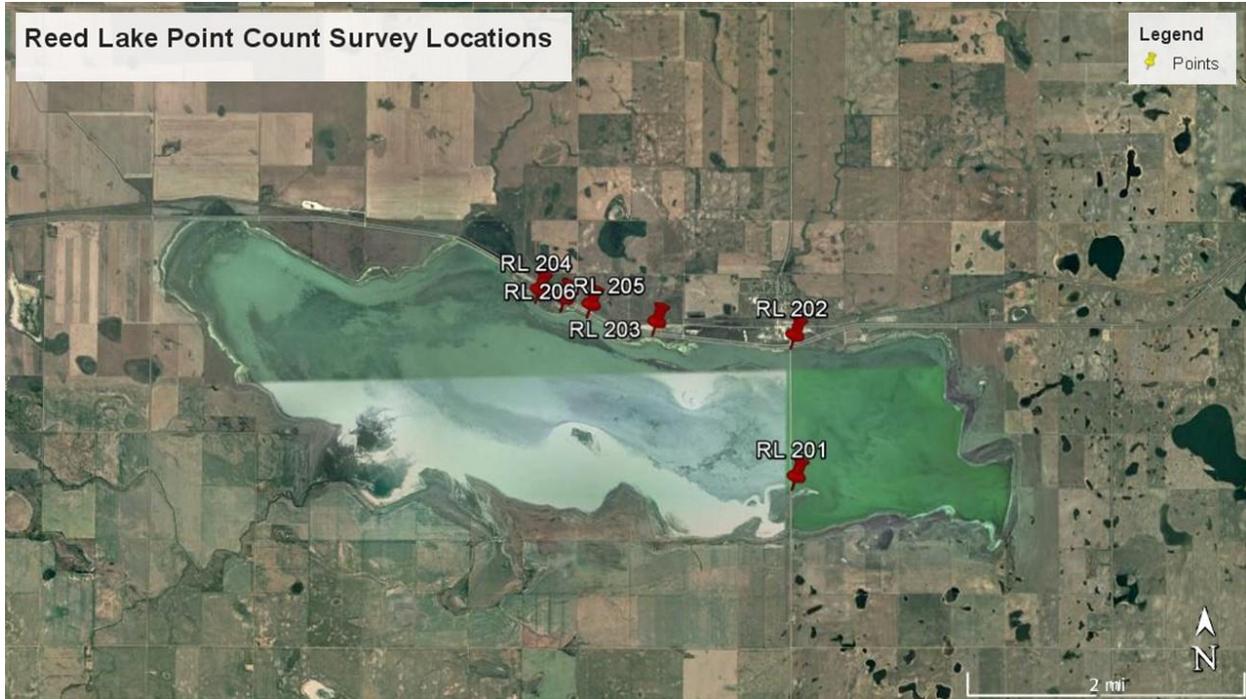


Fig. A.6. Shorebird point count survey locations at Reed Lake (6).



Fig. A.7. Minimum usable area (shaded yellow) for short-legged, non-swimming shorebird species at Chaplin Lake.



Fig. A.8. Minimum usable area (shaded yellow) for short-legged, non-swimming shorebird species at Reed Lake.

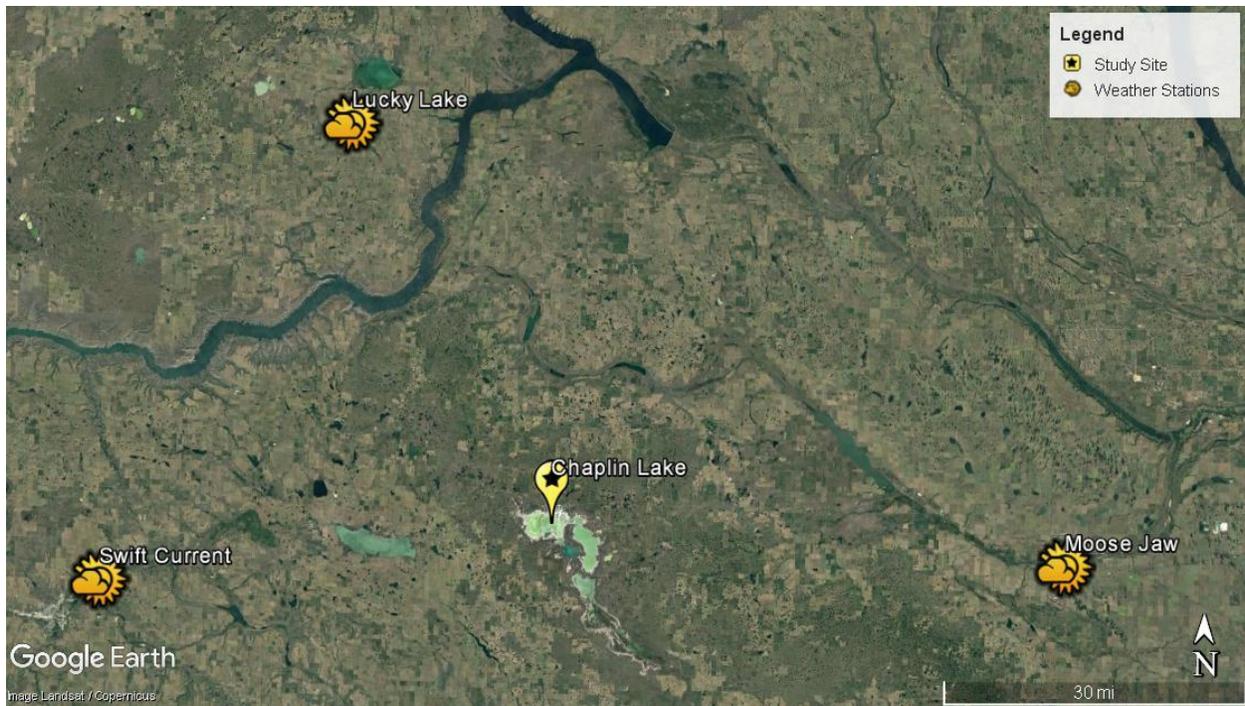


Fig. A.9. Chaplin Lake and the three weather stations averaged for analysis during arrivals and departures in mixed models.

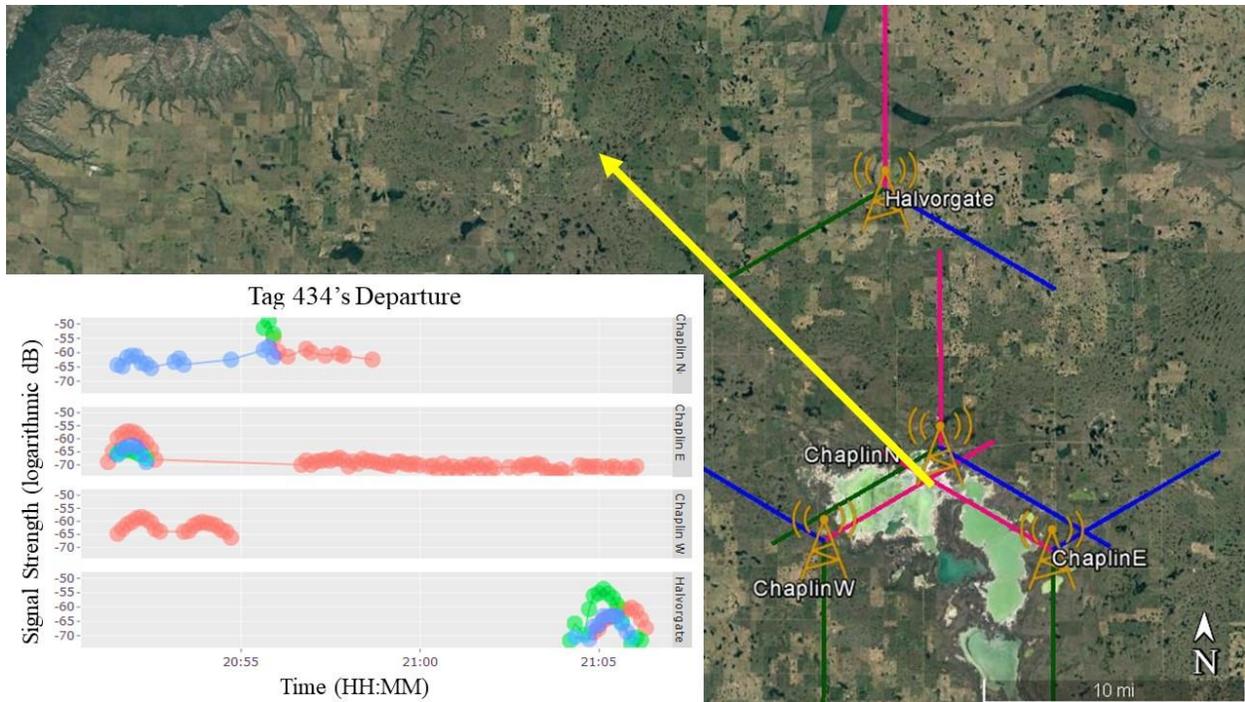


Fig. A.10. Departure of tagged Sanderling 434 (June 8, 2017). The map shows Chaplin Lake, telemetry towers, and 2017 antenna orientations (pink, blue, and green lines). The plot superimposed on the bottom left over the map was created using the Shiny application (Mitchell, Unpublished data). Each plot includes detections of the bird on a tower and each circle represents a signal detected on an antenna of matching colour. Time is on the x-axis and signal strength is on the y-axis. The yellow line shows the bird's estimated flight path.

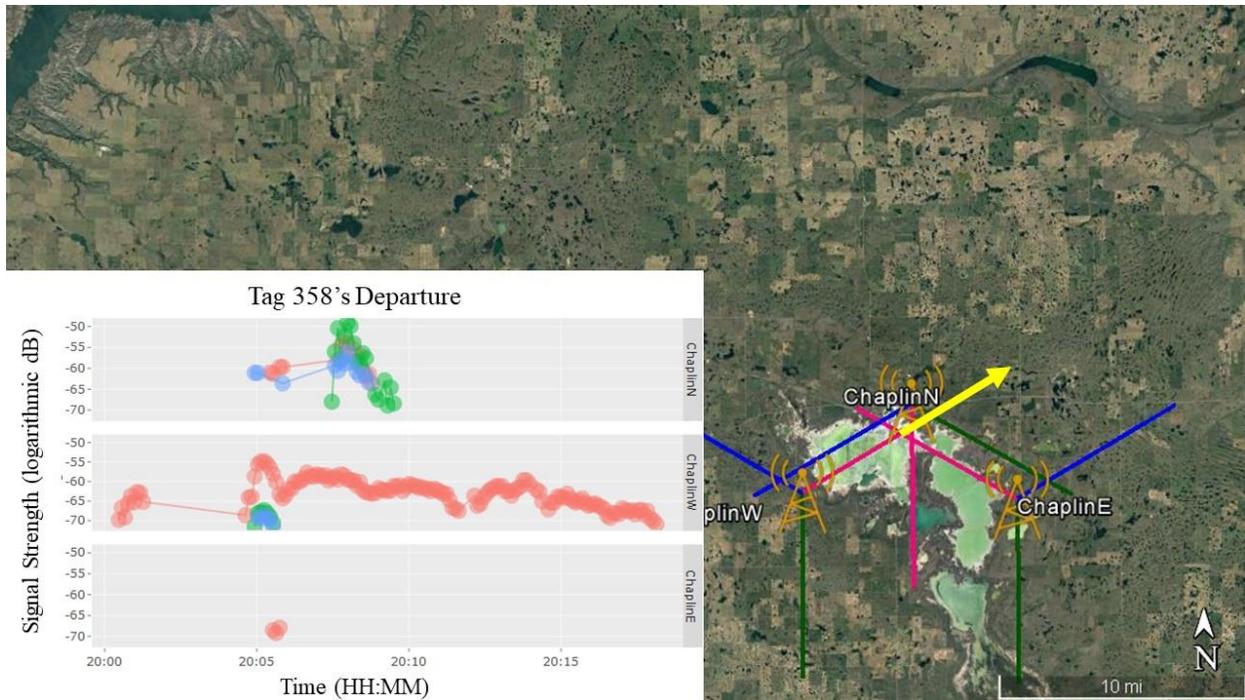


Fig. A.11. Departure of tagged Sanderling 358 (June 8, 2015). The map shows Chaplin Lake, telemetry towers, and 2015 antenna orientations (pink, blue, and green lines). The plot superimposed on the bottom left over the map was created using the Shiny application (Mitchell, Unpublished data). Each plot is detections of the bird on a tower and each circle represents a signal with colors matching the antennas detected on. Time is on the x-axis and signal strength is on the y-axis. The yellow line shows the bird's projected flight path.



Fig. A.12. Location within Chaplin Lake where departing flocks of shorebirds were monitored.

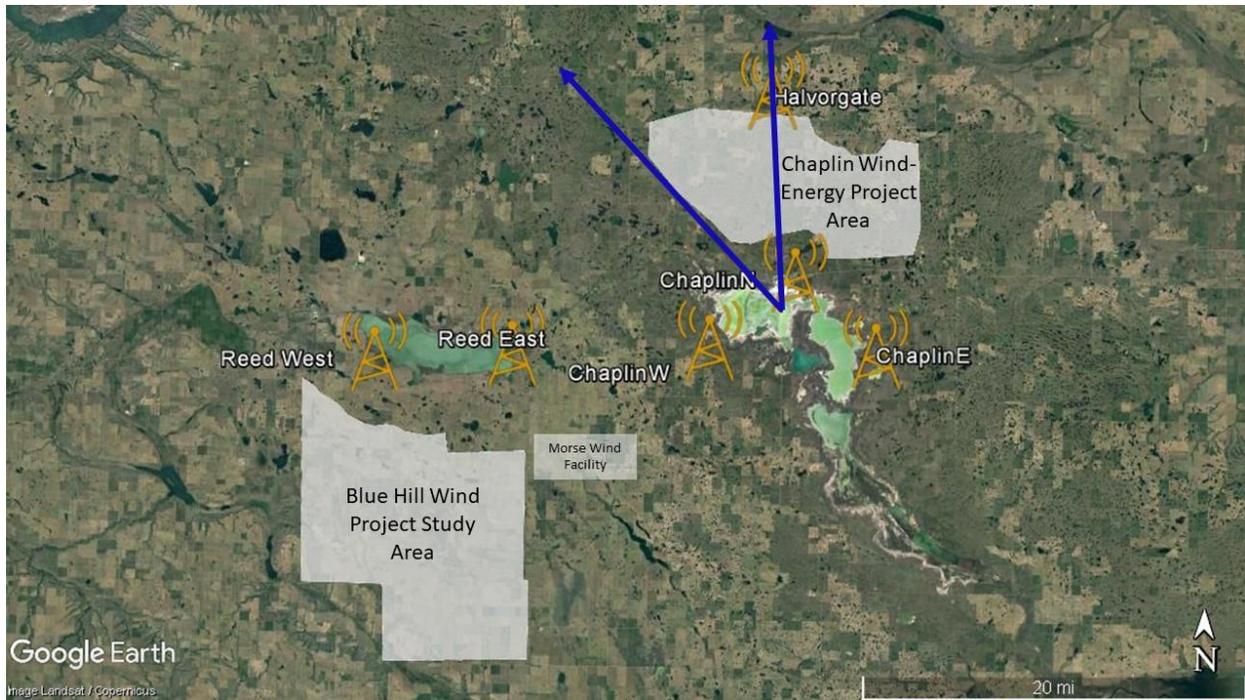


Fig. A.13. Proposed and active wind energy development locations with predicted flight paths of departing birds. Areas shaded white are the approximate areas of the proposed Chaplin Wind-Energy Project (denied approval), the Blue Hill Wind Project study area (environmental assessment in progress), and Morse Wind Facility (active). The blue arrows are predicted flight paths of radio-tagged birds and visually-observed flocks based on average flight directions of each (357° and 317°).

Appendix B: Point Count Survey Summary

Table B.1: List and maximum count of all shorebird species observed at Chaplin and Reed Lakes during spring (2014-2017) and fall (2016-2017) migration point count surveys. Local and boreal breeding species are in regular font and Arctic breeding species are in bold font.

Species	2014 Max Count (Spring Only)	2015 Max Count (Spring Only)	2016 Max Counts		2017 Max Count	
			Spring	Fall	Spring	Fall
American Avocet (<i>Recurvirostra americana</i>)	503	459	183	747	250	424
American Golden Plover (<i>Pluvialis dominica</i>)	0	0	0	0	10	0
Baird's Sandpiper (<i>Calidris bairdii</i>)	7	1	16	204	1	0
Black Bellied Plover (<i>Pluvialis squatarola</i>)	0	35	34	48	256	12
Black-necked Stilt (<i>Himantopus mexicanus</i>)	2	5	7	6	1	0
Dunlin (<i>Calidris alpina</i>)	0	1	11	0	90	0
Greater Yellowlegs (<i>Tringa melanoleuca</i>)	1	0	1	23	0	1
Hudsonian Godwit (<i>Limosa haemastica</i>)	3	2	1	0	2	0
Killdeer (<i>Charadrius vociferus</i>)	5	20	24	35	15	5
Long-billed Dowitcher (<i>Limnodromus scolopaceus</i>)	7	25	0	0	43	0
Least Sandpiper (<i>Calidris minutilla</i>)	2	0	2	0	0	0
Lesser Yellowlegs (<i>Tringa flavipes</i>)	0	0	7	6	1	1
Marbled Godwit (<i>Limosa fedoa</i>)	14	24	87	64	15	6

Pectoral Sandpiper (<i>Calidris melanotos</i>)	0	2	7	11	62	0
Piping Plover (<i>Charadrius melodus</i>)	20	20	14	21	10	2
Red Knot (<i>Calidris canutus</i>)	22	26	115	0	95	0
Red-necked Phalarope (<i>Phalaropus lobatus</i>)	5846	3788	8125	13	13123	2000
Ruddy Turnstone (<i>Arenaria interpres</i>)	0	2	17	1	11	0
Sanderling (<i>Calidris alba</i>)	9303	5583	3316	135	10987	640
Short-billed Dowitcher (<i>Limnodromus griseus</i>)	8	0	39	1	0	0
Semipalmated Plover (<i>Charadrius semipalmatus</i>)	9	10	8	9	27	25
Semipalmated Sandpiper (<i>Calidris pusilla</i>)	702	1567	154	979	1434	511
Snowy Plover (<i>Charadrius nivosus</i>)	1	0	0	0	0	0
Solitary Sandpiper (<i>Tringa solitaria</i>)	0	1	4	0	0	0
Spotted Sandpiper (<i>Actitis macularius</i>)	8	4	5	1	0	0
Stilt Sandpiper (<i>Calidris himantopus</i>)	1000	147	78	18	2500	2
Upland Sandpiper (<i>Bartramia longicauda</i>)	3	4	0	1	5	0
Whimbrel (<i>Numenius phaeopus</i>)	1	0	0	0	0	0
Willet (<i>Tringa semipalmata</i>)	17	11	33	56	25	5
Wilson's Phalarope (<i>Phalaropus tricolor</i>)	454	145	156	1077	123	6373
Wilson's Snipe (<i>Gallinago delicata</i>)	0	0	1	2	0	0
White-rumped Sandpiper (<i>Calidris fuscicollis</i>)	1	0	0	1	30	30