Migration Routes and Stopovers of North Puget Sound Snow Geese

by

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ABSTRACT

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Snow geese are one of the most abundant waterfowl species in North America and have been studied for decades. However, their migratory routes and stopovers remain largely unresolved due to their remoteness. Advancements in satellite tracking methods have allowed researchers to study regional snow geese population migration patterns in much more detail then presently possible. Washington State Department of Fish and Wildlife captured seven lesser snow geese (*Chen caerulescens caerulescens*) in North Puget Sound (NPS) Washington, USA, fitted them with PTT model satellite tags, and tracked them from 27 February 2013 to 5 October 2014. Study geese were tracked using two different migratory routes from their wintering grounds in the Fraser-Skagit region along the border of Washington and British Columbia (BC), Canada to their breeding ground on Wrangel Island, Russia. Five of the study geese used a Pacific coastal route to fly from the Fraser-Skagit region to upper Cook Inlet in Alaska (AK), USA before cutting across the SW corner of the AK, crossing the Bering Sea, and migrating along the northern coast of the Chukchi Peninsula in Eastern Siberia to Wrangel Island. The second group used an inland route and headed east towards Alberta, Canada prior to heading NW across the Northern and Yukon Territories in Canada, across AK, the Bering Sea, along the coast of Eastern Siberia and to Wrangel Island. Study geese were tracked to staging regions, areas were geese were on the ground for 7 or more days, in the Fraser River delta in BC and the Stikine River delta, AK. Stopovers regions, areas where geese were on the ground for 2 to 7 days, were located in the Stikine, Knik, Serpentine, and Bering River deltas in AK and the Fraser and Klinakline Rivers in BC. Continuous satellite telemetry provided original data for managers and researchers for spring migrations in the remote regions of BC and AK and confirmed that Midcontinent and NPS snow geese migration routes overlap. Further research is needed to determine if Midcontinent lesser snow geese are using the same wintering grounds as NPS lesser snow geese, while current stopover and staging data will help managers in their conservation efforts for the NPS population of lesser snow geese.

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CHAPTER ONE: INTRODUCTION TO THE THESIS

Introduction

Snow geese (*Chen caerulescens*) are one of the most abundant species of waterfowl in North America (Baldassarre 2014). Their numbers have increased dramatically in recent decades as they adapted quickly to using agricultural fields for forage and favorable nesting conditions on Arctic breeding grounds (Boyd and Cooke 2000; Hupp et al. 2001; Pacific Flyway Council 2006). For example, the lesser snow geese (*Chen caerulescens caerulescens)* population breeding on Wrangel Island, Russia has increased 25% from 2015 to 2016 and the Midcontinent population of lesser snow geese has increased 300% since the 1970s (Abraham and Jefferies 1997; U.S. Fish and Wildlife Service 2016). However, prior to the 1970s, some populations of snow geese were in danger of becoming extinct. The Wrangel Island population of lesser snow geese was one of these (Kerbes and Meeres 1999; Pacific Flyway Council 2006). Wrangel Island lesser snow geese are currently in recovery, but they still represent the last major snow goose population breeding in Asia and wintering in North America, making the population a high priority for the Russian, Canadian, and U.S. wildlife service's (Kerbes and Meeres 1999; Pacific Flyway Council 2006).

The Wrangel Island lesser snow goose population became a concern in the early 1970s when the population dropped to historically low levels from decades of overharvesting (Baranyuk 1999, Kerbes et al. 1999, Baldassarre 2014). In an effort to try and protect the species and promote recovery, the Soviet Union made Wrangel Island into a State nature preserve (Bousfield and Syroechkovsky 1985). This helped protect the population by eliminating goose hunting and egg harvesting. Removing most of the introduced reindeer prevented them from destroying goose-nesting grounds. However, in the 1980s the lesser snow goose population had dropped by 50% to fewer than 110,000 geese and did not appear to be recovering (Kerbes and Meeres 1999). It was during this period that an international effort was made by Russia, Canada, and the United States to improve and update information on the distribution, survival, and size of Wrangel Island lesser snow geese in order to form better management and conservation plans to preserve the species (Kerbes and Meeres 1999). Their objectives were met through the use of cooperative neck banding programs from 1987 to 1992, the analysis of recovered leg bands from the 1950s to 1980s, and annual ground surveys of nesting colonies (Kerbes and Meeres 1999). However, these methods still left large gaps in the literature on migration routes and behaviors of Wrangel Island lesser snow geese leaving their breeding grounds and entering North America to winter. As a result, managers and researchers have made a large number of assumptions about Wrangel Island lesser snow geese migration. A different approach was needed to address these research gaps.

Preliminary satellite studies done by Takekawa et al. (1994) and Baranyuk and Takekawa (1998) were the first to more accurately document the migration routes of the Wrangel Island lesser goose population using a non-banding method. Their work found previously undocumented migration routes, stopovers, and staging areas, which addressed some of the research gaps from earlier banding studies. This data will help managers maximize their conservation efforts by setting aside reserves, refuges, and nature preserves, along with modifying hunting regulations to reduce hunting pressure during key migration times and at key staging locations. However, further studies have yet to be contributed to the literature with similar findings from satellite transmitter data for the Wrangel Island lesser snow geese population. This thesis is designed to reproduce their work with the Northern Puget Sound population of lesser snow geese and address the following question: What are the migration patterns and behaviors of the Northern Puget Sound population of lesser snow geese (*Chen caerulescens caerulescens*) in response to temporal changes in the environment over the course of the 2013 migration season based on satellite telemetry?

Satellite telemetry provides a useful and unbiased tool for describing migration routes and identifying stopover sites over the large uninhabited wilderness areas commonly found in our study area. The data provided by modern satellite telemetry technology will be more accurate and precise then previous studies on Wrangel Island lesser snow geese, which will enable future researchers to be more efficient with their research efforts in future studies. For example, by locating new staging or stopover areas with satellite data and then using traditional leg or neck banding techniques to strategically band large numbers of lesser snow geese, researchers can begin to answer questions about populations intermixing between flyways, conduct local movement pattern studies (e.g., feeding patterns, inter and intra species behaviors), population shifts due to climate change and mortality assessments. Using traditional banding methods is cheaper than using an equivalent number of satellite tags, which allows researchers to increase sample size at the same cost and to increase the statistical power of the study. Hence, identification of new stopover sites and associated migration patterns of lesser snow geese is important for the current and future management of the lesser snow geese population.

This thesis introduces the reader to the general topic and the specific research question being addressed within the thesis in Chapter 1. Chapter 2 is the literature review, which covers the Wrangel Island lesser snow goose population and research gaps in the literature up to 2016. Chapter 3 is a manuscript formatted for the Journal of Wildlife Management to be submitted after the completion of this thesis and Chapter 4 is a more in-depth discussion and conclusion section than was covered in the manuscript in Chapter 3.

CHAPTER TWO: LITERATURE REVIEW

Introduction

Snow geese are one of the most abundant species of waterfowl in North America (Baldassarre 2014). Their numbers have increased dramatically over the last few decades, since snow geese adapted quickly to use agricultural fields for forage and favorable nesting conditions on Arctic breeding grounds (Boyd and Cooke 2000; Hupp et al. 2001; Pacific Flyway Council 2006). In some areas of the United States, the population of snow geese has increased by 300% since the 1970s; however, the average rate of population growth over the last ten years has ranged from 4-8% per year depending on the population (Abraham and Jefferies 1997; U.S. Fish and Wildlife Service 2016). In Washington State, flocks of thousands of lesser snow geese migrating south from their breeding grounds on Wrangel Island, Russia can often be seen landing at their wintering grounds on the Fraser and Skagit River deltas along the British Columbia (BC) border. This population of lesser snow geese represents the last major snow goose population breeding in Asia and the primary Russian goose population that winters in North America, making the species a high priority for the Pacific Flyway Council and the subject of long standing international cooperative management and conservation efforts with Russian, Canadian, and U.S. wildlife service's (Pacific Flyway Council 2006).

Since the early 1970s, when this population was at a historical low, the Russian and Canadian wildlife services used banding studies and nesting ground surveys to track population changes over time. The ground surveys show the current population of Wrangel Island snow geese in recovery, but a recovering population presents a new set of problems and questions for researcher and managers. For example, large flocks of recovering snow geese are now overbrowsing their natural resources (mainly marsh plants in estuaries) in some areas and shifting their foraging habits to agricultural products, creating conflicts between conservationists, managers, and agricultural land owners. In addition, the effects of overbrowsing can have deleterious effects on the ecological processes, species and habitats in the marshes where snow geese are feeding. However, ground surveys do not give any insight as to how snow geese are dispersing from their breeding grounds and migrating south to their wintering grounds in North America. The Canadian Wildlife services have conducted banding studies of Wrangel Island snow geese and determined that 90% of the Wrangel Island lesser snow goose population uses a coastal migration route to transit from their breeding grounds on Wrangel Island to their wintering grounds in North America (Armstrong et al. 1999). The other 10% was shown to take an inland route down through Alaska (AK) into their wintering grounds in the southern regions of North America. Further research into the migration patterns of the Wrangel Island lesser snow geese to gather more accurate and precise data is difficult due to the remoteness and inaccessibility of the wilderness areas in Canada, AK, and the Bering Sea the geese fly over.

The Washington State Department of Fish and Wildlife (WDFW) captured Wrangel Island lesser snow geese overwintering in the Puget Sound region of the state in 2013 and implanted them with satellite transmitters. By utilizing satellite transmitters WDFW was able to overcome the limitations of previous traditional banding studies and collect migration data in the remote and inaccessible areas of Canada, AK, the Bering Sea, and Eastern Siberia. Data collected from the geese implanted with a satellite transmitter will provide a wealth of original data on Wrangel Island snow geese migration patterns that can be used for management purposes or serve as baseline data for future studies investigating migration patterns of lesser snow geese.

The purpose of this literature review is to summarize what is currently known about the migration routes, stopovers, and management of Wrangel Island lesser snow geese wintering in North Puget Sound. The first section will be an overview of the general migration behaviors and patterns relevant to all snow geese populations. The next section explains the taxonomy of snow geese and why the literature uses two scientific names for the lesser snow geese covered in this thesis. The subsequent section will describe the causes and consequences of changes in the Wrangel Island snow geese population specifically and the known migration destinations of this population. The following sections will focus on the WI population wintering in North Puget Sound and management practices for the population. The last portion of the literature review will outline the current research gaps, how this research will fill some of these gaps and make suggestions for future research.

Snow Geese Overview

Snow geese are one of the world's most abundant waterfowl species and one of the most well studied birds in North America (Baldassarre 2014). Their distribution is split into two seasons. During the breeding season (spring and summer months), much of their time is spent in northern latitudes in order to find mates, raise chicks, and molt (losing and then regrowing their flight feathers) in large colonies on the open tundra. During this time, they range across the Arctic from Wrangel Island (Eastern Russia), the coastal regions and islands in the Arctic and subarctic areas across AK and Canada, to the northwestern coast of Greenland (Bechet et al. 2004; Baldassarre 2014). During the fall, snow geese undertake extensive migrations from their Arctic breeding grounds to the mid-Atlantic seaboard states, the lower Mississippi River valley, the Gulf Coast, the Central Valley of California, and northern Mexico (Baldassarre 2014). Upon completing their fall migration south, snow geese will spend the remainder of the fall and winter months foraging to build fat reserves for the return trip back to the breeding grounds in the spring.

There are two recognized subspecies of snow geese. The widely distributed and smaller lesser snow goose (*Chen caerulescens caerulescens*) and the larger and more discretely distributed greater snow goose (*Chen caerulescens atlantica*), whose breeding distribution is restricted to a few islands in the Canadian high Arctic (Cooke et al. 1995; Baldassarre 2014). Lesser snow geese are grouped into three populations groups based on their breeding and or wintering grounds as follows: the Wrangel Island population, the Western Arctic population, and the Midcontinent population (Hines et al. 1999;

Baldassarre 2014). A fourth population, the Western Central Flyway population, is solely based on the winter distribution (Baldassarre 2014). Lesser snow geese breeding and wintering grounds are not specific to only lesser snow geese. Intraspecies overlap with other waterfowl populations is common. For example, Ross' Geese (*Chen rossii*) and lesser snow geese have overlapping wintering grounds in the Midcontinent and Western Central Flyway populations.

All populations of snow geese have extensive migration, from their breeding grounds to their wintering grounds. Round trips in excess of 11,000 kilometers (km) are not uncommon, especially for those breeding on WI. In general, nonbreeding snow geese will depart the breeding grounds first from mid to late August followed by the adults with their young in early September (Bellrose 1980; Baldassarre 2014). The geese will head south along either the Central or Pacific flyway to their wintering grounds in southwestern United States and northern Mexico, making stops along the way to rest and forage. Migration typically begins in the early daylight hours or from dusk to early nocturnal hours, with flocks of thousands of individuals and family groups flying continuously day and night until the geese reach their destination (Bellrose 1980; Baldassarre 2014). Flocks of migrating snow geese have been observed flying at speeds between 64 to 80 kilometers per hour (km/h) and tracked by radar at altitudes of 1,500 to 3,000 meters (m) with some reports from pilots observing snow geese as high as 6,100 m (Bellrose 1980; Baldassarre 2014). However, most snow geese have a flying altitude between 600 and 900 m during migration (Bellrose 1980; Baldassarre 2014). Alisauskas et al. (2011) using band data from several lesser snow geese colonies in the central and eastern Arctic from 1989 to 2006 during the fall migration, determined these flocks travel through Canada at a rate of 25 km per day and 22 km per day through the United States. During their migrations, snow geese fly in an undulating pattern with individuals staggered at different heights throughout a U-shaped formation rising and descending slightly. Snow geese rarely use the well-formed V formations of Canadian geese. However, both formation styles have been showed to save energy on long flights (Denny 2016).

The timing of these migrations is dependent on population and location, but some general associations for snow geese departing their wintering areas (northbound geese) correlate with maximum daily temperature. For example, in Texas (1972-1977) lesser snow geese initiated migration after temperatures exceeded 28 degrees Celsius (C) for five days (Flicker 1981; Baldassarre 2014). Departures from wintering grounds have not been strongly correlated with minimum temperatures, relative humidity, sky cover, precipitation, surface wind, or atmospheric pressure (Blokpoel 1974; Blokpoel and Gauthier 1975; Baldassarre 2014). For geese arriving at their wintering grounds (southbound geese), evidence suggests their arrival could be correlated to higher mean April temperatures melting snow earlier and thus increasing access to forage (Cooke et al. 1995). The most likely scenario is a combination of environmental factors (e.g., atmospheric pressure, wind, and sky cover), such as the passage of a frontal system, initiates the start of a migration (Blokpoel and Gauthier 1975; Blokpoel 1974; Baldassarre 2014).

Taxonomy

The lesser snow goose (*Chen caerulescens caerulescens*, Linnaeus, 1758) belongs in the family Anatidae (ducks, geese, and swans) and in the Anserini tribe of True Geese (Cooke et al. 1995). The Anserini tribe is divided into two genera: *Chen* (white and grey geese) and *Branta* (black geese; Clements et al. 2016). Snow geese (*Chen caerulescens*) are one of 11 recognized species within the genus *Chen* with two recognized subspecies: the greater snow goose (*Chen caerulescens atlanticus* [Kennard 1927]) and the lesser snow goose (Clements et al. 2016; Ottenburghs et al. 2016). The two subspecies can be identified (as adults) by differences in size, range, and plumage color morphs. The lesser snow goose is the smaller of the two subspecies, but has a much wider distribution across North America and its plumage comes in two color phases: dark, sometimes referred to as the, "blue phase" or "blue goose", and all white. The greater snow goose is larger, its plumage stays white all year and its distribution is limited to a few islands in the eastern Arctic (Baldassarre 2014).

Within the literature, the lesser snow goose will also be found under the genus *Chen* instead of *Anser*. Both scientific names (*Chen caerulescens caerulescens* and *Anser caerulescens caerulescens*) are synonymous with the common name of lesser snow goose and are genetically the same subspecies of goose. The difference in the naming convention is explained by authors and journals choosing to classify the lesser snow geese by the amount of white in their plumage instead of their genetic makeup (Cooke et al. 1995; Ogilvie and Young 2002). The argument for using *Chen* over *Anser* is primarily based on research that shows there is a high degree of hybridization within the *Anser* genus resulting in genetic similarities in the different species and therefore the amount of white in a bird's plumage is a preferred tool for its classification and identification (Avis et al. 1992; Quinn 1992; Cooke et al. 1995). In this literature review, I follow the American Ornithological Society's convention of using *Chen* (American Ornithologists' Union 1983).

Wrangel Island Lesser Snow Geese

The Wrangel Island population of lesser snow geese (hereafter referred to as snow geese or goose) represents the last major snow goose population breeding in Asia and the primary Russian goose population that winters in North America. This distinction makes it a high priority for the Pacific Flyway Council and the subject of long standing international cooperative management and conservation efforts with Russian, Canadian, and U.S. wildlife service (Kerbes and Meeres 1999; Pacific Flyway Council 2006). The remaining breeding populations of snow geese in Russia are thought to still be nesting in low densities of around 100 to 300 birds along the northern coastal mainland around the Chukochya and Kolyma River deltas (Coordinates for geographical locations can be found in table 1; Figure 3 [Baranyuk 1999; Kerbes, et al. 1999; Hines 1999; Baldassarre 2014]). Over the course of the last century, starting around the mid-1800s, the hundreds of thousands of snow geese that breed all along the Russian Arctic coast from the Lena River to the Northeastern coast of Siberia and wintered in Japan were extirpated by humans (Takekawa et al. 1994; Baldassarre 2014). In 1976, Wrangel Island was designated a State Nature Preserve by the Russian Ministry of Natural Resources and Environment in order to manage and protect this last remaining population of snow geese (Bellrose 1980).

Wrangel Island is an 800,000 hectares (ha) island located at 71˚ N off the coast of northeastern Siberia and is surrounded by the Arctic Ocean (to the north), the Eastern Siberian Sea (to the east), and the Chukchi Sea (Figure 1). Since 1969, the main nesting colony of snow geese on the island have used the same 2,600 ha area, along the middle reaches of the Tundra River valley in the Severnye Mountains (Pacific Flyway Council 2006). Starting in 1970, an annual survey was conducted on nesting adults using systematic ground surveys of the main colony in the Tundra River valley (Bousfield and Syroechkovsky 1985; Kerbes et al. 1999). The surveys were conducted in July after broods had left the nest by running an 8m wide and 250 m long transects, spaced 200 meters apart through the entire colony, and counting current year nests (done by counting the presence or absence of the egg membrane). The number of nests (two birds per nest) were then averaged by transect and multiplied by the total area of the main colony to estimate the islands breeding population of adults. The nonbreeding birds tend to congregate in areas of low nest density prior to the arrival of breeding adults in July (typically early June), which allows observers to make estimates of the populations using binoculars and spotting scopes from nearby vantage points. The observers then add the population number to the nesting survey for a total population estimate of the islands Snow geese.

The results from these surveys show (Figure 2) a decline in the population of snow geese from 1970 to 1975 from 150,000 to 56,000 (total population, breeding, and nonbreeding), a recovery during the 1980s back up to a total population level close to 100,000 and then a decline again in the early 1990s to an average of around 65,000 total birds (Bousfield and Syroechkovsky 1985; Kerbes et al. 1999). The population has steadily been recovering since then, with the current population estimated to be around 300,000 birds (Pacific Flyway Council 2006; U.S. Fish and Wildlife Service 2016). This amounts to an annual average growth rate of 8% over the last ten years, with a 25% increase in population from 2015 to 2016 when the total population increased from 240,000 to 300,000 birds (U.S. Fish and Wildlife Service 2016). Key factors affecting breeding population success and growth for Wrangel Island snow geese (WISG) are the amount of snow cover in spring and the date by which the snow cover is cleared or melted, allowing birds access to forage (Bousfield and Syroechkovsky 1985; Kerbes et al. 1999). These factors suggest that this population is growing from the effects of climate change due to warmer annual temperatures melting snow earlier in the year (Hupp et al. 2001; Aubry et al. 2013). The effects of a warmer climate have also been linked to an increasing population of younger snow geese in the total population relative to historical total populations in the 1970s, 1980s, and early 1990s as reproductive success increases by year (Pacific Flyway Council 2006). The consequences, if any, have not been well studied.

The increasing WISG population is leading to changes in behavior relative to traditional habitat and foraging resources. For example, WISG historically foraged primarily in intertidal estuaries in the Fraser (BC, Canada) and Skagit River deltas (Washington, USA) on plants such as the American three-square bulrush (*Scirpus americanus*) during their migrations prior to the late 1970s (Boyd 1995; Boyd and Cooke 2000). After the 1970s, agricultural products (e.g. cereal, rye, barley, wheat, oats, etc.) became more available to a growing WISG's population that has increasingly become reliant on agricultural products as available estuarine plants decreased due to overbrowsing. Over the last twenty years, an increasing WISG population has gradually shifted from their traditional feeding habitats in the marshes in the Skagit and Fraser River deltas to more inland agricultural resources to increase their winter energy reserves for the upcoming spring migration to the breeding grounds on Wrangel Island (Pacific Flyway Council 2006).

Wrangel Island snow goose population dynamics are complex, with at least three subpopulations migrating to different locations to overwinter (Kerbes and Meeres 1999; Baldassarre 2014). The first is located in the Fraser and Skagit River deltas. The second is located in the Central Valley in California. A third and much smaller population of around 1,600 birds also winter along the lower Columba River in Washington and Oregon. In the 1960s and 1970s, most (78% - 90%) of the WISG population wintered in California and 10% wintered in the Fraser and Skagit River delta regions (Hines et al. 1999; Baldassarre 2014). Hines et al. (1999) used neck and leg banding field studies to show the population had shifted to a more northern winter distribution in the 1980s with 47% of the WISG population wintering in California and 52% wintering in the Fraser and Skagit River deltas. Boyd (1995) confirmed a northern shift in the WISG population using data from annual photos. These photos show an estimated number of geese wintering in the Fraser and Skagit deltas with 22% of the population wintering there in 1968 and increasing to 56% in 1992. A study by Boyd and Cook (2000) showed the ratio has shifted to 60% in the Fraser-Skagit region by 2000. This result suggests a continuing trend in the foreseeable future, but further studies are needed to confirm this trend from 2000 to present day.

Hines et al. (1999) hypothesized that this northward shift in the population hit its peak in the 1970s, when snow geese first started to feed on agricultural fields and no longer had to entirely depend on salt marsh habits. The timing of this peak shift in habitat has been correlated to four consecutive years of reproductive failure due to weather resulting in a depressed population and reduced competition for resources during their migration southward (Hines et al. 1999). With limited competition during stopovers in areas such as the Fraser-Skagit region on route to the Central Valley in California, many birds opted to remain in the area rather than continue further south. However, with contemporary populations on Wrangel Island at 300,000 birds, the population has recovered and surpassed the WISG population estimates of the 1970s. With current high populations of snow geese on Wrangel Island, the recovered population would imply that the competition of the resources in the Fraser-Skagit region have increased since the 1970s and more birds would be heading further south to take advantage of the resources in the Central Valley, a geographically larger area then the Fraser-Skagit region with potentially more resources and less competition. However, the population trend through 2000 shows this assumption to be incorrect. There must be some other mechanism at work to allow such a large population of snow geese to winter in the Fraser-Skagit region and a continued northward shift in habitat from the Central Valley. Much of the current literature suggests a connection to additional anthropogenic resources, such as increased agricultural capacity and production of grains along with earlier snow melts, as possible mechanisms for reducing competition through easier access to forage and further increases in the carrying capacity of the Fraser-Skagit region (Boyd 1995; Hines et al. 1999; Boyd and Cooke 2000; Hupp et al. 2001; Kraege et al. 2008). Additional works by

Armstrong et al. (1999) and Williams et al. (2008) suggest a high philopatry rate of 74% to 97% as an additional mechanism for the northward shift from the southern wintering areas to the Fraser-Skagit region. Their findings suggest snow geese tend to stay in the same wintering and breeding areas, unless various stochastic events, such as reproductive failure due to weather, force them to leave the wintering and breeding grounds (e.g. in the 1970s). Once the geese moved to new northern wintering areas with improved weather, their reproductive success increased on Wrangel Island. The total numbers of snow geese increased at a higher rate in the Fraser-Skagit region than in the Central Valley due to the new influx of previously displaced snow geese and their offspring. 74-97% of this group stayed, further explaining the observed mechanism for the observed northward shift from the Central Valley to the Fraser-Skagit region, but further studies are needed to verify these findings.

North Puget Sound Population of Snow Geese

The North Puget Sound (NPS) population of snow geese winter in the Skagit and Fraser River deltas along the western border of the United States and Canada. This population of snow geese is referred to by its geographic location as the Fraser-Skagit region population and not by the NPS moniker, but either name refers to the same population. I use the term "NPS population" to refer to snow geese residing in Washington, since wildlife managers in the State of Washington follow this convention.

The NPS population historically wintered on Fir Island and in the northern portions of Port Susan Bay (Figure 3) and exhibited red facial staining due to the high iron content of the intertidal marsh plants (bulrush; *Scirpus americanus*) they were consuming (Boyd 1995; Baranyuk et al. 1999). Prior to the 1970s, this was a reliable method to tell the NPS population apart from those continuing further south to the wintering grounds in the Central Valley of California (Baranyuk and Syroechkovsky 1994; Baranyuk et al. 1999; Pacific Flyway Council 2006). After the 1970s, agricultural products, such as cereals, became more readily available and many geese started to utilize these alternative food sources, reducing the reliability of using face staining for visual identification of the NPS population compared to the Central Valley population (Boyd and Cooke 2000; Pacific Flyway Council 2006). However, body size can be used as an alternative to face staining due to the NPS population's significantly larger body sizes (for both sexes) compared to wintering Central Valley geese using the Fraser-Skagit region as a staging area (Baranyuk 1999; Pacific Flyway Council 2006). Since the early 1970s, the population of NPS snow geese has increased from a low of 12, 356 in 1974 to an average of over 68, 517 between 2001 and 2005. Many NPS snow geese now seek new food sources and expand their wintering range from traditional marshland habitats on Fir Island and Port Susan Bay to more inland agricultural habitats in Skagit, Snohomish, and Island counties in Washington (Pacific Flyway Council 2006).

The annual population growth prior to 2001 shifted from an average of 5% to an average of 7% from 2001 to 2004. This rapid increase in population has put pressure on snow geese foraging resources in the Puget Sound region and changed the composition of the NPS population of snow geese (Pacific Flyway Council 2016). For example, in some areas of the Skagit River delta, intense grubbing by large numbers of snow geese have resulted in low biomass levels in the upper bulrush zone due to overgrazing and to the introduction of invasive cordgrass (*Spartina spp.*) from the eastern United States (Boyd

1995). Furthermore, as natural resources in the Skagit River delta become less available due to overgrazing, snow geese relied more heavily on anthropogenic resources, such as agricultural crops, and urban green spaces to sustain a larger NPS population, exacerbating depredation of these resources, and at times, causing friction between farmers, hunters, birders, and managers (J. Everson, personal communication, November 1, 2016). WDFW has established a sanctuary on Fir Island (the 200 ha Hayton Reserve) and planted it with winter cover crops favored by snow geese, which (as of 1996) has mitigated friction between farmers and geese damaging their agricultural crops (Pacific Flyway Council 2006).

The rapid reproductive success of the NPS population has also altered its composition to include a larger component of younger birds than is typical in flocks prior to the 1970s (Pacific Flyway Council 2006). The consequences of such reproductive success remains unknown, but increased population growth can be expected as larger cohorts of younger snow geese reproduce. However, the mechanisms of reproductive success are well understood. They are linked to low predation rates on Wrangel Island, early snow melts, and mild weather conditions on Wrangel Island, which allows snow geese to produce larger clutches of eggs with lower mortality rates than in harsher weather conditions (Hupp et al. 2001; Baranyuk 2005; Pacific Flyway Council 2006).

Migration and Timing

Wrangel Island snow geese undertake some of the longest migrations of any goose population in North America with some individuals observed migrating 14,000 km annually (Armstrong et al. 1999; Baldassarre 2014). However, the average distance for the WISG population traveling to their furthest southern reaches of their breeding grounds is 11,000 km (Armstrong et al. 1999). Much of what researchers currently know about the migration patterns and behaviors of WISG relies heavily on various banding studies (e.g., neck bands and leg bands), with the exception of a few studies using the same satellite data from Takekawa et al. (1994). This section will review the available literature and highlight some of the research gaps this study will address starting with the fall migration from WISG.

Wrangel Island snow geese depart for their fall migration in late August and follow one of two routes (Figure 4) to reach the wintering or staging grounds in the Fraser-Skagit region or the Central Valley in California. The first birds start to arrive in late September and continue to grow in numbers through October and early November (Baldassarre 2014). Ninety percent of the WISG population follows the coastal routes to reach the Fraser-Skagit staging region before 60% of the WISG take off again to head further south to the Central Valley (Bellrose 1980; Armstrong et al. 1999; Hines et al. 1999; Boyd and Cooke 2000). These "coastal routes" are vaguely described in the literature mainly due to the remoteness of the geographical areas WISG fly over, limiting the amount of access researchers have to this population. For example, Bellrose (1985) describes the primary fall migration route of WISG as, "across the Gulf of Alaska to make landfall near the mouth of the Columbia River and on to Summer Lake, Oregon, and the Klamath Basin".

Syroechkovsky and Litvin (1986) used neck band data from the 1970s to hypothesize that WISG did not use offshore migration routes and geese wintering in the Central Valley migrated there via the Canadian prairies through Alberta and

Saskatchewan. Syroechkovsky and Litvin's hypothesis was also vague on how geese migrate from an island to the mainland without crossing any major bodies of water (Syroechkovsky and Litvin 1986; Hines et al. 1999). Hines et al. (1999) and Armstrong et al. (1999) using neck band and leg band data were able to describe that 10% of the WISG population migrated from Wrangel Island through the Canadian prairies and then south to the Central Valley of California, validating some of Syroechkovsky and Litvin's (1986) hypothesis. However, Hines et al. (1999) and Armstrong et al.'s (1999) hypothesis still lacked specifics on coastal routes used by WISG to get to the Fraser-Skagit region. This lack of specificity for fall migration routes is mainly due to the remoteness and inaccessibility of the migration routes in northern Canada, AK, and northeastern Siberia prohibiting any observer networks from reporting the locations of neck or leg banded geese during their migrations through these areas (Armstrong et al. 1999). New methods were required to gather more detailed information on WISG migration patterns to help policy makers and managers make more informed decisions. In the early 1990s satellite transmitter technology had advanced far enough to allow installation of satellite transmitters on larger birds such as geese without interfering with their flight characteristics. This allowed researchers to collect real time data in remote and inaccessible areas such as the wilderness areas of Canada and AK.

Takekawa et al. (1994) and Baranyuk and Takekawa (1998) were the first to use GPS satellite tags to track the fall migration of WISG. Their results characterized the fall migration from Wrangel Island as a combination of long stopovers and rapid distance flights between stops (Table 1 and Figure 3). The first major stopovers are on the Chukotka (also known as Chukchi) Peninsula on the Siberian mainland (in the Cape

Billings and Koluthin Bay area). From there, the geese cross the Bering Sea to St. Lawrence Island and then to the Seward Peninsula to stage within the Yukon-Kushokwin River delta and the northern portions of the Alaskan Panhandle, which has large staging areas at the mouth of the Yukon River and the southern coast of Norton Sound (Baranyuk and Takekawa 1998; Pacific Flyway Council 2006; Baldassarre 2014). After leaving the Yukon-Kushokwin River delta region, some flocks fly down to the Fraser-Skagit region following the Alaskan and BC coastlines with some migrants making a final stop at the mouth of the Stikine River near Wrangell, AK before heading on to their wintering areas in the Fraser-Skagit deltas (Pacific Flyway Council 2006). Baranyuk and Takekawa (1998) go on to describe that half of the satellite tagged coastal migrants headed toward the Fraser-Skagit region along the coast turned east when they came near the Canadian Queen Charlotte Islands (now known as the Haida Gwaii Islands) and crossed the Rocky Mountains to the staging areas near Edmonton, Alberta in Canada (Konrad 1993). These results contradict leg and neck bands studies by Armstrong et al. (1999), Hines et al. (1999), and observations made by the Pacific Flyway Council (2009), which conclude that 10% of the WISG population not using the coastal route migrate from Wrangel Island and fly an inland route through the Northern Territories in AK, Alberta and Saskatchewan, Montana, and eastern Oregon to the Klamath Basin and California (Figure 4). This thesis will contribute to their work by providing additional satellite tag data to create a more accurate and precise picture of how WISG migrate to and from the Fraser-Skagit region.

The NPS population of snow geese over winter from late September to late January, with geese departing for the spring migration in February and March (Pacific

Flyway Council 2006; Baldassarre 2014). The spring migrations are generally hypothesized to follow the fall migrations in reverse order with some exceptions from the Central Valley (Armstrong et al. 1999; Hines et al. 1999; Pacific Flyway Council 2006; Baldassarre 2014). Researchers from the Pacific Flyway Council (2006) have documented the NPS population of snow geese as having major staging areas in AK on the Stikine River delta and the upper Cook Inlet with geese starting to arrive in late April. In early May, the lower reaches of the Yukon River become available for staging areas and become more populated with snow geese as food availability increases due to melting snow and ice in the region (Armstrong et al. 1999; Hupp et al. 2001). After feeding in staging areas in AK, the flocks travel to mainland Siberia and then on to Wrangel Island to start breeding in late May with most of the various populations from California, Oregon, and the Fraser-Skagit region arriving by June (Pacific Flyway Council 2006; Baldassarre 2014). For the Central Valley, 74% of the WISG population (other populations of snow geese also use these wintering grounds, e.g., Midcontinent snow geese) wintering there follow an inland route starting in mid-April, with staging areas on Freezeout Lake in Montana and in the Canadian prairies (Pacific Flyway Council 2006; Baldassarre 2014). The rest of the WISG populations wintering in the Central Valley follow a coastal route. Once any snow geese enter NW Canada, AK, and Siberia the amount of available data decreases as the remoteness and inaccessibility for humans increases, with the exception of satellite data (Armstrong et al. 1999; Pacific Flyway Council 2006).

The timing of the Fraser-Skagit region snow geese has not been extensively or specifically described in the literature. Temporal data has often been collected in conjunction with other metrics for a snow goose study. However, general trends have been noted from this surplus data collection on WISG populations and noted previously in this literature review. Most snow geese follow the northward progression of snow melt and use stopover areas shortly after open water and bare ground first becomes available during spring migrations; suggesting that migration can be correlated to weather events (Ryder 1967; Cooper 1978; Lincoln 1979; Raveling 1979; Wege and Raveling 1983; Hupp et al. 2001). Specifically, for the WISG population, Armstrong et al. (1999) was able to show seasonal variability for arriving times of wintering snow geese in the Fraser-Skagit region and the Columbia River with a leg and neck band data set from 1987 to 1992. The cause of this variability remained unexplored, but could be due to weather events (e.g. maximum or minimum temperatures). More specific temporal mechanisms and layover information during migration remain to be explored for the NPS.

Management of Northern Puget Sound Lesser Snow Geese

The management of the WISG population of snow geese is a complicated, international multiagency affair because WISG migrate through three different countries within at least two disjunctive regions of the Pacific Flyway (Syroechkovsky and Litvin 1986; Ely et al. 1993). Starting in Russia and traveling south, the WISG breeding grounds are managed by the Russian Federation under the ministry of Natural Resources and Ecology. Since 1976, access to the island has been restricted to protect the unique natural systems by the Soviet Union when it became a State Natural Reserve (Bousfield and Syroechkovsky 1985). Prior to 1976, the island contained at least two human settlements, a military radar installation, and a large herd of introduced reindeer that were destroying large areas of snow goose nesting areas. Post 1976, almost all human settlements were abolished and the reindeer herd was reduced to 1,000 managed animals to protect the snow geese nesting areas. In 1997, the reserve expanded to include 12 nautical miles of the surrounding water and was extended to 24 miles in 1999. Hunting is currently not allowed on the island, except for subsistence hunting for the local population and a rotating staff of researchers visiting the island to conduct the annual snow geese ground nest survey during the breeding season (Bousfield amd Syroechkovsky, 1985).

The Canadian Wildlife Service handles all matters of wildlife that belong to the Canadian government, including the protection and management of all migratory birds and associated habitats (Hines et al. 1999; Kerbes et al. 1999). The Canadian Wildlife Service has conducted the bulk of the various snow geese banding studies used in this literature review. In the United States, migratory bird management falls under the federal jurisdiction of U.S. Fish and Wildlife Service, with individual states co-managing their local waterfowl species and populations (U.S. Fish and Wildlife Service 2016).

In addition to state, federal and provincial management agencies, several international administrative councils provide guidance for migratory bird populations (Barlow 2016). These councils are divided up by flyway (Atlantic, Mississippi, Central, and Pacific) and are composed of the director or an appointee from the public wildlife agency in each state and or province in the western U.S., Canada, and Mexico (Barlow 2016). The Wrangel Island breeding population and the NPS population wintering in the Fraser-Skagit region fall into two biological and administrative flyways due to their migration routes and habitats, but in practice are placed in the Pacific Flyway with additional representation from the Russian Federation, including representatives from the

Russian Academy of Sciences and the curator of the Wrangel Island Nature Preserve (Barlow 2016; Pacific Flyway Council 2006). The intent of the council is to provide general recommendations to the agencies for cooperative management plans, identify common goals to foster continued collaborations for data collection and analysis, and emphasize research needs (Barlow 2016). These management plans are non-binding recommendations and do not require agencies to commit to specific goals or actions; but are highly encouraged to do so (Barlow 2016). As a result, WDFW works in concert with the U.S. Fish and Wildlife Service and the Pacific Flyway Council to manage its migratory bird resources.

Management topics that are of increasing concern to managers of snow geese on Wrangel Island and the Fraser-Skagit region include: overpopulation, shifting wintering areas, overgrazing of marshlands, setting appropriate harvest rates, and population dynamics (J. Everson, personal communication, October 1, 2016). For example, as the population of WISG grows, managers have increasingly observed the overgrazing of marshland habits, which over time will have deleterious effects on the aquatic and terrestrial species using these ecological niches. In Washington, this could mean negative impacts on endangered salmon populations using these wetlands as nurseries on their way out to sea.

Furthermore, there is mounting evidence that the Canadian Arctic tundra is being adversely affected around geese breeding areas from overgrazing. The large colonies of geese forage by grubbing and pulling up the vegetative biomass, degrading soil quality and increasing the rate of erosion (Abraham and Jefferies 1996; Abraham et al. 2005; Abraham et al. 2012; Baldassarre 2014). Since snow geese exhibit a high degree of fidelity towards their breeding areas, the problem of overgrazing will continue as geese nest in the same Arctic locations for the foreseeable future (Willams et al. 2008; Baldassarre 2014). Studies related specifically to the WISG population and overgrazing have yet to be conducted, but inferences can be made about its effects from the Canadian Arctic tundra studies and applied to the management regime for WISG and NPS population to try to avoid a similar situation.

When populations of snow geese are considered too high by managers, various methods of harvesting (e.g., sport and subsistence hunting and egg collecting by native peoples) are initiated to control the population. The Pacific Flyway Council (2016) recommends harvesting activities will be designed to meet the management plan objective level of 120,000 geese per year for the entire population of WISG. Individual agencies need to come up with harvesting regulations in their areas of jurisdiction. For the Fraser-Skagit region, the council recommends the WISG population be maintained between 50,000 and 70,000 geese (Pacific Flyway Council 2016). If the total WISG population falls below 60,000, the council recommends all harvesting activities cease. For the Fraser-Skagit region, the council recommends no harvesting activities if the WISG population falls below 30,000. Other more extreme methods besides hunting are available to regulate WISG populations levels, such as trapping geese on the breeding grounds (birds are molting during this period and cannot fly). There is an emphasis on increasing harvesting rates using hunting as the most desirable solution for reducing overabundant populations (Johnson and Ankney 2003; Alisauskas et al. 2011).

WDFW has managed the growing NPS population of snow geese by increasing harvest opportunities, while also facilitating a growing number of non-hunters seeking to view the snow geese (J. Everson, personal communications, October 15, 2016). However, increased harvest rates of the NPS population has not extinguished agricultural depredation issues or decreased overgrazing of marsh vegetation communities (J. Everson, personal communications, October 15, 2016). WDFW continues to invest significant management resources to address these and other management concerns such as the following (J. Everson, personal communications, October 15, 2016):

- Establishing a snow goose reserve on Fir Island to mitigate damage to private agricultural lands.
- Developing a lease and cover crop program to provide winter forage for snow geese to mitigate damage to private agricultural lands.
- Implementing a special snow goose quality hunting program to increase hunter harvest opportunity and maximize harvest rates.
- Manipulating annual hunting regulations to maximize harvest rates while balancing landowners' concerns.
- Facilitating a working group composed of landowners, hunters, and non-consumptive users on Fir Island to address these issues and provide recommendations to the Fish and Wildlife Commission.
- Investigating whether the NPS population is a discrete population to avoid overharvesting of non-NPS population snow geese.
- Investigating migration routes, phenology, staging areas, stop-over locations, and timing of migrations throughout the flyway(s).

The end goal of these management efforts is to avoid reactive management and move forward with proactive and adaptive management strategies for Snow geese and other species in a sustainable manner (J. Everson, personal communications, October 15, 2016).

Research Needs

After reviewing the literature, a number of research needs, gaps, and access to the literature were identified. First, the Russians have conducted over three decades of research on the WISG population; but most of the articles are published in Russian peer-reviewed articles in Cyrillic, making it inaccessible for many English speakers to access the primary literature sources. Only a few articles (e.g., Bousfield and Syroechkovsky, 1985) have been translated into English and are available to researchers outside of Russia. However, I was able to access various conference notes that many of the Russian researchers attended in English speaking countries summarizing their work.

Second, when the population of snow geese on Wrangel Island reached an all-time low in the mid-1970s, a concentrated effort was made over the next 30 years by the Russians and Canadians to understand population dynamics using leg and neck banding data. All of the research done by Armstrong et al. (1999), Hines et al. (1999), and Kerbes et al. (1999a and 1999b) included various banding methods. For studying migration routes in the remote and inaccessible areas in Canada, AK, and the Bering Sea, these methods have limitations. For example, banding relies on a network of observers to report the location of banded birds. In remote areas such as the Canadian and Alaskan wilderness with large geographical regions inaccessible to humans, gathering enough data points to create an accurate migration route is difficult. Furthermore, leg and neck band data can be of limited use for migration research because assumptions need to be made on how birds fly from point A to point B. This is often assumed to be a straight line, and therefore the shortest route between data points (Armstrong et al. 1999). However, this is not always the case do to geographical interferences, such as mountains, which birds may choose to fly around instead of over. As a result, as the distance increases between relocations, it becomes more difficult to account for local changes in behavior to weather (e.g., wind), topography (e.g., mountain ranges), and anthropogenic impacts (e.g., hunting pressure). Lastly, distances for all birds need to be measured in curved lines rather than straight lines, similar to airline miles due to the curvature of the earth.

A more efficient method of tracking snow goose migration includes using radio (VHS transmitters), radar tracking, or satellite tracking. These methods have been used to study other populations of snow geese in the Central, Mississippi, and Atlantic flyways, but rarely for the Pacific Flyway populations (Blokpoel 1974; Blokpoel and Gauthier 1975; Ely et al. 1993; Baranyuk and Takekawa 1998). Again, the remoteness and inaccessibility of the Canadian, Alaskan, and Siberian wilderness makes it difficult to apply the radio and radar tracking methods. Radio tracking requires personnel to either set up remote radio listing posts or be near the radio tag (within line of sight), which is difficult to do in areas with no roads or trails (Denny 2016). Radar tracking of snow geese has also been done using ground based radar at airports, but in the vast wilderness areas of the Pacific Flyway, provides little infrastructure for the use of other radar resources such as weather radars, aircraft radar, and portable radars (Blokpoel 1974;

Denny 2016). However, radio transmitters can be useful to study local movements and are currently in use by WFDW to study the NPS population (J. Everson, personal communications, October 15, 2016 & unpublished data).

Satellite data collection for WISG was been conducted twice by Dr. John Takekawa, who was with U.S. Fish and Wildlife at the time in 1991 (Konrad 1993). His data set was collected in 1991 (30 tagged geese on Wrangel Island) and again in 1992 (24 tagged geese on Wrangel Island) using transmitters mounted on geese using back packs. Most of his data set remains unpublished with the exception of two. One is published only in Russian (Baranyuk and Takekawa 1998) and the other is a combined study using satellite tags and VHS radio tags to study the movement patterns of snow geese in the Yukon-Kuskokwin delta in AK (Ely et al. 1993). These studies were referenced in the Pacific Flyway Counsil 2006 report to describe the migratory path of the WISG population. Since then, no other studies have been done using satellite tags to study WISG or NPS snow geese populations using satellite telemetry.

Current satellite technology has advanced considerably since the 1990s. For example, satellite transmitters are now small enough to be implanted in geese to avoid damaging the transmitter (e.g., geese biting of the antennas) with little harm on the bird's flight characteristics. In addition, battery life has increased, which allows tags to transmit for longer periods, resulting in better data collection coverage. Given that only one set of data has been collected using satellite tags to study the migration patterns of WISG (only for fall migration), the sample size is small (n=54) in comparison to the total current population of 300,000 geese currently breeding on Wrangel Island. Further studies are needed to add to this data set in order to complete a more accurate picture of the migration patterns of these geese.

Conclusion

The WISG geese population is recovering, but as their population increases, additional biological, migratory, and population data is needed to make informed management decisions. Past studies using banding and ground surveys have provided enough data to make accurate population estimates, but not enough data to accurately hypothesize the migration routes and stopovers of the WISG population. Accurately documenting stopovers and migration routes of WISG populations will help managers know where to maximize the conservation efforts when setting aside reserves, refuges, and nature preserves. In addition, predicting the timing of the migration routes and stopovers would allow managers to regulate hunting seasons more precisely, so hunting pressure would not interfere with key migration times and staging areas. Satellite data, since it does not require observers on the ground, will help to create a more accurate picture of WISG migration and timing.

Preliminary satellite studies done by Takekawa et al. (1994) and Baranyuk and Takekawa (1998) were the first studies conducted using satellite telemetry to more accurately document the migration routes of the WISG population. Their findings contradicted previous banding hypothesis on WISG migration, which suggests further replication of these satellite studies are needed. This study aims to contribute to the WISG satellite data set to create a more accurate and precise picture of their migration patterns and stopovers by increasing the sample size of tagged geese in the literature.

Researchers and managers will be able to strategically band geese in newly discovered stopovers and staging areas, which allows these stakeholders to answer questions about populations intermixing between flyways, local movement pattern studies (e.g., feeding patterns, inter and intra species behaviors, etc.), and population shifts and mortality assessment. Furthermore, researchers can place their observer networks strategically in these newly discovered (and accessible) WISG areas to report snow goose locations and reduce the amount of human effort and research money it would take to study WISG population dynamics and migration. For example, technologies that are currently on the market, such as Radio-frequency identification (RFID) tags, will enable collection of local movement data remotely: once an RFID tag (the size of a grain of rice) is injected into an individual goose, the data can be transmitted from the field, up to a satellite, and down to a researcher's desktop. The next step is to initially gather enough data to locate these remote staging and stopover areas to further study the WISG population patterns.

CHAPTER THREE: MANUSCRIPT

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Migration Routes and Stopovers of North Puget Sound Snow Geese

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ABSTRACT Snow geese have been extensively studied in the North America, but data on migration routes, stopover sites, and staging areas remains incomplete for many snow geese populations due to the remoteness of the regions they migrate over and the limited access available for observer networks to report snow goose locations using traditional banding methods. Advancements in satellite tracking methods have allowed researchers to study snow geese migration patterns in detail in these remote and inaccessible regions. Seven lesser snow geese (*Chen caerulescens caerulescens*) were captured in North Puget Sound (NPS) Washington, USA, fitted with PTT model satellite tags, and tracked from 27 February 2013 to 5 October 2014. Study geese were tracked using two different migratory routes from their wintering grounds in the Fraser-Skagit region along the border of Washington State and British Columbia (BC), Canada to their wintering ground on Wrangel Island (WI), Russia. Five of the study geese used a Pacific coastal route to fly from the Fraser-Skagit region to the upper Cook Inlet in Alaska (AK), USA before cutting across the SW corner of the AK, crossing the Bering Sea, and migrating along the northern coast of the Chukchi Peninsula in Eastern Siberia to WI. The second group used an inland route and headed east towards Alberta, Canada prior to heading NW across the Northern and Yukon Territories in Canada, across AK, the Bering Sea, along the coast of Eastern Siberia and to WI. Study geese were tracked to staging regions, areas where geese were on the ground for 7 or more days, in the Fraser River delta in BC and the Stikine River delta, AK. Stopovers regions, areas where geese were on the ground for 2 to 7 days, were located in the Stikine, Knik, Serpentine, and Bering River deltas in AK and the Fraser and Klinakline Rivers in BC Continuous satellite telemetry provided original data for managers and researchers for spring migrations in the remote regions of BC and AK and confirmed that Midcontinent and NPS snow geese migration routes overlap. Further research is needed to determine if Midcontinent lesser snow geese are using the same wintering grounds as NPS lesser snow geese, while current stopover and staging data will help managers in their conservation efforts for the NPS population of lesser snow geese.

KEY WORDS *Anser caerulescens caerulescens*, *Chen caerulescens caerulescens*, lesser snow goose, migration routes, North Puget Sound, satellite telemetry, stopover, Wrangel Island.

Wrangel Island, Russia, lesser snow geese (*Chen caerulescens caerulesnes*) undertake some of the longest migrations of any goose population in North America with some individuals migrating 14,000 km annually (Armstrong et al. 1999; Baldassarre 2014). However, the average distance for a Wrangel Island (WI) lesser snow goose (hereafter referred to as WISG) migrating to their furthest southern reaches of their wintering grounds in the southern U.S. is 11,000 km (Armstrong et al. 1999). During their long migrations to and from their breeding grounds on WI to North America, WISG make extensive use of stopovers and staging areas between long distance destinations to feed, rest, and take shelter (Baranyuk and Syroechkovsky 1994; Boyd 1995; Boyd and Cooke 2000; Lok et al. 2011). However, the largely remote and inaccessible areas of the Alaska (AK), USA and western Canadian wilderness areas that WISG migrate over make it difficult to gather data on migration, stopovers, and staging areas for managers, researchers and policy makers (Kerbes et al. 1999).

The WISG population is composed of 2 subpopulations breeding in one mixed colony, but winter in geographically separate areas in North America (Bousfield and Syroechkovsky 1985; Willams et al. 2008). In late August both subpopulations depart for their fall migrations and follow one of two routes (Figure 4) to reach their wintering or staging grounds in the Fraser-Skagit region along the BC and Washington boarder (48°38'40"N, 122°32'33"W) or the Central Valley in California (Armstrong et al. 1999). The first snow geese start to arrive in the Fraser-Skagit region in late September and continue to grow in numbers through October and early November (Baldassarre 2014). Ninety percent of the total WISG population migrates down the Pacific coast to reach the Fraser-Skagit region to either winter there or use it as a staging area to continue further south to the Central Valley (Bellrose 1980; Armstrong et al. 1999; Hines et al. 1999; Boyd and Cooke 2000). Sixty percent of the WISG population that lands in the Fraser-Skagit region will use the area as a staging area before continuing south by various routes to reach their wintering grounds in the Central Valley (40°12'N, 122°12'W) and form the second of the two WISG subpopulations. Forty percent of the WISG population that migrated down the Pacific coast will overwinter in the Fraser-Skagit region and form the first WISG subpopulation we refer to as the North Puget Sound (NPS) population (Armstrong et al. 1999; Hines et al. 1999; Kerbes et al. 1999). The remaining 10% of the WISG population that does not migrate down the Pacific coast crosses the Bering Sea to AK down through the Canadian prairies and then south to the Central Valley (Syroechkovsky and Litvin 1986; Armstrong et al. 1999).

The NPS population of snow geese ovoverwinterfrom late September to late January, with geese departing for the spring migration in February and March (Pacific Flyway Council 2006; Baldassarre 2014). The spring migrations are generally hypothesized to follow the fall migrations in reverse order with some exceptions from the Central Valley (Armstrong et al. 1999; Hines et al. 1999; Pacific Flyway Council 2006; Baldassarre 2014). Researchers from the Pacific Flyway Council (2006) have documented the NPS population of snow geese as having major staging areas (Figure 3) in AK on the Stikine River delta (56°33'28"N, 132°24'35"W) and the upper Cook Inlet (61° 3'17"N, 150° 7'45"W) with geese starting to arrive in late April. In early May, the lower reaches of the Yukon River (62°36'29"N, 164°53'3"W) become available for staging areas and become more populated with snow geese as food availability increases due to melting snow and ice in the region (Armstrong et al. 1999; Hupp et al. 2001). After feeding in staging areas in AK, the flocks travel to mainland Siberia and then on to WI (71°13'46"N, 179°25'39"W) to start breeding in late May with most of the various populations from California and the Fraser-Skagit region arriving by June (Pacific Flyway Council 2006; Baldassarre 2014).

The WISG population represents the last major snow goose population breeding in Asia and the primary Russian goose population that winters in North America, making WISG a high priority for international cooperative management and conservation effects (Kerbes and Meeres 1999; Pacific Flyway Council 2006; Baldassarre 2014). The WISG population became an ecological concern in the early 1970s when the population dropped by over 50% from 150,000 geese to fewer than 60,000 with no signs of recovery (Bayanyuk 1992; Kerbes and Meeres 1999). This lead to an extensive international effort by Canada, Russia, and the U.S. to improve and update information needed to conserve and manage the species in the 1980s. Neck and leg band data was used to address WISG population size (Kerbes et al. 1999); distribution (Hines et al. 1999); mortality (Hines et al. 1999); and routes and timing of migration (Armstrong et al. 1999). However, observer networks for these banding studies had a difficult time gathering specific information on WISG migration routes and stopovers due to the inaccessibility and remoteness of the Canadian and AK wilderness areas WISG fly over. A new method was needed to gather more specific migration data on routes, stopover locations, and staging areas for managers to make more informed decisions about the WISG population.

Takekawa et al. (1994) and Baranyuk and Takekawa (1998) used GPS satellite tags to track the fall migration of WISG and gather more specific migration data than banding studies would have collected (Kerbes et al. 1999). Their results characterized the fall migration from WI as a combination of long stopovers and rapid distance flights between stops (Konrad 1993). The first major stopovers for the WISG are on the Chukotka (also known as Chukchi) Peninsula on the Siberian mainland (Cape Billings [69°51'0"N, 176°8'0"E]; (Figure 3). From there, WISG cross the Bering Sea to St. Lawrence Island (63°24′0″ N, 170°10′0″W) and then to the Seward Peninsula, AK to stage within the Yukon-Kushokwin River delta (60°20'25"N, 163°44'25"W) and the northern portions of the AK Panhandle. The Yukon-Kushokwin River delta and the northern AK Panhandle have large staging areas at the mouth of the Yukon River (62°39'35"N, 165°5'14"E) and the southern coast of Norton Sound ([63°34'43"N, 162°31'13"E] Konrad 1993; Baranyuk and Takekaw 1998; Pacific Flyway Council 2006; Baldassarre 2014). After leaving the Yukon-Kushokwin River delta region, some WISG flocks fly down to the Fraser-Skagit region following the AK and BC coastlines with some migrants making a final stop at the mouth of the Stikine River near Wrangell, AK before heading on to their wintering areas in the Fraser-Skagit deltas (Pacific Flyway Council 2006). Baranyuk and Takekawa (1998) described that half of the satellite tagged WI coastal migrants (N>25 snow geese) headed toward the Fraser-Skagit region along the coast and turned east when the flock was near the Canadian Queen Charlotte Islands (Haida Gwaii [53°21'43"N, 132°15'22"W]) and crossed the Rocky Mountains to the staging areas near Edmonton, Alberta in Canada (Konrad 1993). These results contradict leg and neck bands studies by Armstrong et al. (1999), Hines et al. (1999), and observations made by the Pacific Flyway Council (2009) researchers; which concluded that 10% of the WISG population not using the Pacific coastal route migrate from WI and fly an inland route through the Northern Territories in AK, Alberta and Saskatchewan, Montana, and eastern Oregon to the Klamath Basin and winter in the Central Valley of California.

An understanding of WISG stopovers and migration is critical for WISG conservation and management. For example, spring stopover sites often provide the energy and nutrients required for reproduction in migratory waterfowl on route to their nesting grounds (Reed at al. 2004; Schmutz et al. 2006; Lok et al. 2011). Specifically, for the WISG population locating stopovers and staging areas with high quality forage is important to their survival during their exceptional long migrations and for WISG management. For the NPS population many of these sites remain unknown due to the remoteness of their migration route(s) and therefore make it necessary to use satellite tagging methods to locate stopover sites and migration routes (Armstrong et al. 1999).

Previous works using satellite data have primarily focused on southbound migrations of the WISG migration and not the NPS population migrating northward (Baranyuk and Takekawa 1998; Takekawa et al. 1994). Thus, making original baseline satellite telemetry provided from this study important for NPS snow geese managers. Data on new NPS population stopovers and migration routes could be used for conservation purposes, such as the setting aside of refuges in critical foraging areas or heavily used stopovers or staging areas. Furthermore, regulators could use this data to update polices for harvesting opportunities. For example, hunting seasons and locations could be changed so harvest pressure does not alter the behavior of NPS geese to interfere with important migration routes, stopover sites, and staging areas that would further increase NPS mortality during migration. Managers could use the satellite data to define snow geese populations more clearly by studying migration routes and looking for any overlap in flyway use. This is especially important to prevent overharvesting of specific populations such as the WISG wintering in the Fraser-Skagit region, where snow geese from multiple populations and different flyways use local foraging resources (Kerbes et al. 1999).

Satellite telemetry provides an unbiased and valuable tool for describing migration routes and locating stopover areas in the remote regions of the Pacific coast, western Canada, AK, and Eastern Siberia. The specific objectives of this research were to 1) identify stopover sites used by the NPS population for both spring and fall migrations, 2) locate any additional wintering areas used by the NPS population outside of the Fraser-Skagit region, 3) intensify typical NPS migration routes for both spring and fall migration, and 4) ascertain if the NPS population uses other flyways other than the Pacific flyway during migrations.

STUDY AREA

We considered all territory in the Pacific Northwest, western Canada, AK, the Bering Sea and Eastern Siberia as the study areas and examined stopover sites and migration routes within these regions. The Pacific coastal regions of the Pacific Northwest, western Canada, and AK are composed of large, complex archipelagos adjacent to a mountainous mainland. These landforms create an extensive network of protected waterways and complex nearshore habitats for a wide variety of bird species in the Pacific Flyway (Lok et al. 2011). The interior region of the study area in western Canada is composed mainly of boreal forests, arctic tundra, and prairie lands, while much of our study area in AK is arctic tundra and boreal forests. The Bering Sea and Eastern Siberia region contains various islands devoid of trees, which formed through the subduction of tectonics plates and volcanism in the region, including WI on which the main colonies of the WISG population breed.

METHODS

Capturing and Tracking

We captured 7 female snow geese on their wintering grounds in Washington between February and March, 2013; using a general-purpose net gun after the conclusion of the goose hunting season (Mehlmin and Shaiffer 1980). Individual geese were captured in three wintering locations in Skagit (48°19'22"N, 122°21'49"W), Snohomish (48°12'36"N, 122°21'12"W), and Island Counties (48°13'28"N, 122°26'31"W) using a human spotter on the ground to locate and identify lesser snow goose flocks and to guide the capture crew into position to use the net gun. We tagged only females, as this study was part of a larger study on female breeding, nesting habits and chick raising. When multiple geese were captured in a single net only one female was selected at random to avoid tagging multiple members of the same family group. Individuals selected for tagging were sexed, weighted leg banded and implanted with satellite platform terminal (PTT) transmitters (Model IMPTAV-2640, 42g, Telonics, Inc.) in the abdomen by a veterinarian following established surgical protocols (Korschgen et al. 1996; Table 2). Marked birds were released after a recovery period of less than 2 hours. We programmed PTTs with duty cycles to be more frequent (4 hours on and 27 hours off) during the spring and fall migrations and less frequent (2 hours on and 77 hours off) for non-migratory periods in the winter and summer (Table 4). This study was part of larger study on female breeding, nesting habits and chick raising and as a result, our sample of geese were required to be female as part of these efforts.

The Argos location and data collection system was used to monitor snow geese movements. Argos estimates PTT locations from the Doppler shift in transmitter frequency received by National Oceanic and Atmospheric Administration (NOAA) weather satellites as WISG approach and then move away from an individual PTT (Argos Inc. 1996). The accuracy of each location is then classified based on the satellite-to-PTT geometry during each satellite pass; the number of transmissions (messages) received per satellite pass and the stability of the PTT transmission frequency (Argos Inc. 1996; Miller et al. 2005). The Location Classes (LC) 3, 2, 1, and 0, are rated by the Argos data system as <150, 150-350, 350-1000, and > 1,000 m, respectively. Accuracy was not provided for LC A (3 messages received), LC B (2 messages), and LC Z (latitude and longitude often provided if >1 message received). Location data usually included at >1 usable location per bird in a transmission day. One Selected Location was chosen for each bird per transmission day according to the nine criteria described in Miller et al. (2005), which favors locations for LC 3, 2, and 1 (Lok et al. 2011). The Selected Location method by Miller et al. (2005) was chosen to account for multiple locations per bird per transmission day not being independent as well as Argos expression of accuracy as the probability that 67% of the locations will fall within stated limits; which therefore might make some high-quality locations inaccurate and some poor-quality locations very accurate (Britten et al. 1999; Hatch et al. 2000; Hays et al. 2001).

Data Analysis

We used Movebank (www.movebank.org), a free online infrastructure available to all researchers for storage, managing, sharing and analyzing animal movement data, to spatially and temporally filter PTT marked snow geese data from the Argos data system to select only stopover and migration locations in our study area (Kranstauber et al. 2011; Douglas et al. 2012). Data was further filtered using Movebank and Argos sorting and filtering algorithms to look for and omit outliers in the PTT data. Outliers would include incorrect locations caused by equipment or data processing problems, locations for which the error is too large to properly analyze, or LC data that should not be considered part of an animals track (e.g., negative altimeter reading for a migrating goose; Argos Inc. 1996). Data was then transferred to ArcGIs 10.4 via a shapefile to process location data with the Selected Location method to determine migration stopovers, staging areas, and migration routes. We further defined our Selection Location method for staging and stopover sites to favor LC 3, 2, 1 data as defined in Miller et al. (2005) and added the additional criteria of including only LC data with a recorded zero m altitude reading. We defined a stopover event as the act of an individual stopping at a site for a rest or foraging during migration (Lok et al. 2011). Spatially, we defined stopover events as a series of ≥2 consecutive Selected Locations within 10 km of each other. For temporal use of sites, we classified stopover events as a short stopover if the site was used for 2-7 days, and as a staging stopover if the site was used for >7 days (Warnock and Bishop 1998; Lok et al. 2011). Given the limited number of tagged individuals, we considered use by 2 individuals (n=7) adequate to represent selection and use of a stopover or staging site. We increased our Selection Location criteria for the migration analysis to also favor LC 0 data, including any records of zero m in altitude meeting the 9 criteria set forth in Miller et al. (2005), due to limited sample size and the very large geographical area covered in this study. Locations for migration data was sorted by migration season (e.g., spring = northward movements and fall = southward movements) and mapped.

Results

Satellite location data quality

PTT tag performance

PTT tag performance varied by goose during this study (Table 3), but none of the 7 PTT tags were able to transmit for the intended 3 years of the PTT program (Table 4). Goose 127447 was able to transmit the longest from 27 February 2013 to 17 September 2014 for 330 days of satellite tracking (Table 3). Goose 127452 transmitted for the least amount of time from 28 February 2013 to 30 April 2013 or 108 days of satellite tracking (Table 3). Goose 127449 had fewer satellite tracking days (80), but transmitted longer temporally by calendar year (88 verses 62 calendar days; Table 3) then Goose 127452. The largest date set of combined Location Class's (LC 3, 2 ,1,0, A, B and Z) came from goose

127447 (n=1924; Table 3). Reasons for termination of PTT signals are unknown (e.g., mortality, damaged PTT tag, negative effects of PTT tag on goose or PTT battery life) with the exception of goose 12752, which was reported deceased to WDFW. Cause of death was unreported.

Migration routes and chronology of migration

Characteristics of NPS migration routes and chronology

All 7 of the tagged geese survived the tagging process, over wintered in the Fraser-Skagit region (Figure 3), and were able to start their migration back to the WI breeding grounds (Figure 1). Geese 127446, 127448, 127449, and 127454 migrated up the Pacific coast from the Fraser-Skagit region to upper Cook Inlet, AK before cutting across the southwestern (SW) quadrant of the AK mainland to the Yukon River delta or Norton Sound. PTT transmissions from goose 127449 ended at the Yukon River delta (Figure 11) after 26 May 2013 (Table 3), during the spring migration of season 2 of the PTT program (Table 4). Goose 127448 (Figure 9) migrated past the Seaward Peninsula of AK, across the Bering Sea to the Kolyuchinskaya Bay region of Russia, through northeastern Siberia to the Cape Billing region, and then crossed the Eastern Siberian Sea to the breeding grounds on WI. PTT signal was lost after 5 October 2013 (Table 3) during the fall migration (Table 4). The Kolyuchinskaya Bay region was a common waypoint used by 5 of the study geese. Goose 127446, after reaching the Norton Sound region, flew over the Seward Peninsula of AK and across the Bering Sea straight to WI (Figure 5). After the breeding season on WI, goose 127446 migrated south, for the fall migration of 2013 (Table 4), to Cape Billings, along the Eastern Siberian coast past Kolyuchinskay Bay, across the Bering Sea, through SW AK, across the Gulf of Alaska, over Haida Gwaii, and then followed the Pacific coast back to the wintering grounds in the Fraser-Skagit region for the second time. Goose 127446, along with geese 127450, 127447, and 12754, crossed the Gulf of Alaska during fall migrations, but not during the spring migration, while using a more western Pacific coastal route then on the northbound (fall) migrations (Figures 5, 7, 13, and 17). Goose 127446 accumulated the most days of satellite tracking (342; Table 3), with the last signal received on 24 May 2014 near Upper Cook Inlet, near Anchorage, AK during its second spring migration (Table 4). Goose 127454 was tracked overwintering twice in the Fraser-Skagit region before the signal was lost after 7 June 2014 (Table 3) after Goose 127454's second spring migration back to WI (Table 4). Goose 127454 followed a coastal route to upper Cook Inlet, similar to geese 127449, 127448, and 127446, during the first spring migration (Table 4) and was the only goose to have a large aggregation of LC data points (n=41) along the northwestern shoreline of the Seward Peninsula before crossing the Bering Sea to Kolyuchinskaya Bay, Russia (Figure 17). The migration plot suggests that goose 127454 crossed the Gulf of Alaska twice, once during the second spring migration and once during the first fall migration, but there are no data points between the Stikine River delta and landfall south of the upper Cook Inlet to support the second spring Gulf of Alaska crossing (Figure 17).

Goose 127447 used a combination of inland and coastal routes. Goose 127477 used a Pacific coastal route similar to 127446, 127448, 127449, and 127454 during the second spring migration (Table 4), but followed a more inland migration on the first spring migration on the east side of the Canadian coastal mountain range (Figure 7). This goose took an unusual migration path compared to the rest of the study group during the first spring migration by flying west towards Norton Sound and then switching direction northward and flying over Kotzebue Sound, AK and then crossing the Bering Strait to Kolyuchinskaya Bay. The signal was lost on 17 October 2014 after tracking this goose for 4 migratory seasons (Table 4) near Cape Billings, Russia, and after two breeding seasons on WI and two wintering seasons in the Fraser-Skagit region.

Goose 127450 was the only goose to migrate to the Canadian prairies near Alberta before proceeding to the Northwest and Yukon Territories and onward to WI (Figure 13). This migration route would suggest there is some intermixing of the NPS snow goose and the Midcontinent populations along the Pacific and Midcontinent flyways, and at the wintering grounds in the Fraser-Skagit region. However, the second spring migration track from the Fraser-Skagit region would suggest the migration route towards Alberta during spring is not an annual occurrence, since the last data point on the migration track would indicate a more coastal route then the previous spring migration.

Goose 12752 had the shortest migration track, using an inland Pacific coastal route before heading east (Figure 15), when the signal terminated during the spring migration of 2013 (Table 4). The last few data points for this goose would have had it heading towards Alberta and the Canadian prairies, possible indicating further mixing of the Pacific and Midcontinent flyway populations.

Stopover and Staging areas

Sites used as stopovers

Seven sites were identified as stopover sites (2-7-day usage) using the Selective Location method with LC's 1, 2, 3 data at an elevation of zero meters (n=1008). All of these locations were located along the coastline of North America. Commonly used stopover sites were the Fraser River delta, Bering River delta, and upper Cook Inlet (Figure 19).

Geese that used the upper Cook Inlet (127446, 127447, 127448, and 127454) congregated in or near the Knik River delta. Less common sites were the Stikine and Klinaklini River deltas in BC, and the Artic Lagoon and Serpentine River delta on the Seward Peninsula in AK (Table 5). Geese that used a combination of both common and less common stopover sites were 127447 (Figure 8), 127448 (Figure 10), and 127454 (Figure 18), over the course of the study period. Single stopover site users were geese 127449 (Figure 12), 127450 (Figure 14), and 127452 (Figure 16). The only goose that used two stopovers was Goose 127446 (Figure 6).

Another stopover analysis was run using the Selective Location method with LC's 1, 2, 3 data at an elevation of zero meters and changing the temporal setting to include all data, i.e., not selecting data that only fell into the 2-7 or >7 days categories. This increased the available stopover and staging area data by 61.5% (n=1639 instead of n=1008), but represents 24.5% of the total LC data collected (n=6690); an increase of 9.5% in the amount of data used from the entire LC data set (Table 3) from the previous analysis. The results show an increased use of the coastal regions and offshore areas, such as the Chukchi Sea, the Bering Sea, and the Gulf of Alaska (Figure 20). Common stopovers sites such as the Stikine River delta, the Bering River delta, and the upper Cook Inlet show increased use, but for less time (>2 days), than the previous analysis. Other less common sites along the coasts of the Seward Peninsula (i.e., Shishmaref Inlet, Kotzebue Sound and Port Clarence) are short term stopover sites (>2 days) for geese. New areas of use include the Kolyuchinskaya Bay, the coastal regions of Eastern Siberia up to Cape Billings, and the offshore regions of Yakutat, AK (Figure 20). No inland stopover or staging areas were documented using either of the two analyses.

Staging and wintering areas

The geese in this study used two staging areas: the Fraser River delta in BC and the Stikine River delta (Figure 19). The Fraser River delta was used during both the fall (September through October 2013) and spring (April 2013) migrations by geese 12746, 12748, and 127454 (Table 5). The Stikine River delta was used only during the spring migration (April through May 2013, mainly around Dry and Farm Islands, near the town of Wrangell, AK, by geese 12749 and 127454 (Table 5; Figure 19). Staging areas were at times also used as wintering locations, which is the case with the Fraser River delta (Table 5).

Wintering locations for the NPS population varied, but all geese except 127447 and 127449 split their time between the Fraser River delta and the Skagit River region (Figure 21). The other five study geese (12746, 12748, 12750. 12752, and 127454) overwintered in Washington in Skagit, Snohomish, and Island counties, primarily on agricultural lands, intercostal waterways or tidelands. In Snohomish County, study geese were tracked mainly around Fir Island and Skagit Bay. In Skagit County study geese mainly overwintered in Port Susan Bay and at the mouth of the Stillaguamish River delta. Island County contained the fewest LC data points, mainly out in the middle of Port Susan Bay followed by the intertidal area near the city of Stanwood located at the intersection of the Skagit and Island Counties at the south end of Skagit Bay.

DISCUSSION

Previous studies on WIGS migration patterns indicated that two migration routes were used to migrate from the Fraser-Skagit region to WI (Baranyuk and Takekawa 1998;

Armstrong et al. 1999; Hines et al. 1999). Our results, based on continuous satellite telemetry during migration seasons, also showed two primary migration routes were used during the spring migration for the NPS population. Seventy-one percent (n=5) followed a Pacific coastal route from the Fraser-Skagit region to upper Cook Inlet, AK before cutting across the SW corner of AK and across the Bering Sea into Eastern Siberia to WI. A second route through western Canada was used by 29% (n=2) of the snow geese during the spring. However, we lost telemetry on goose 12752 before it completed its full migration through BC, Canada. Taking a Pacific coastal route would provide several advantages over taking the western Canadian route. First, a Pacific coastal route is more direct and would be shorter than an interior route through the western providences of Alberta, the Northern territories, and the Yukon territory of Canada. In general, shorter distances would require less energy, if environmental stochastic events such as precipitation, temperature, and headwinds had no effect on goose energy reserves. Second, there would be more foraging opportunities along a Pacific coastal route then the western Canadian route. The BC and AK coastlines provide abundant foraging opportunities at ubiquitous river deltas formed by summer snow melt and receding glaciers from the coastal mountain range. Different species of sedges such as Lyngbyaei (*Carex lyngbyeai*) and Ramenski's (*Carex ramenskii*) reside in these waterways and are known to be part of the NPS snow geese's main diet (Boyd 1995; Baranyuk et al. 1999; Pacific Flyway Council 2006). NPS snow geese taking an inlet route through BC and into central Alberta would find it more difficult to find forage sites because much of the interior of BC is composed of forested landscapes and mountainous topography with less access to primary food sources such as sedges or agricultural produces until you reach the prairies of central Alberta. Our stopover data supports this observation because we observed no stopover or staging area data along the interior migration route.

Fall migration results showed NPS snow geese did not follow the same migratory route in reverse order of the spring migration route, which is different than previous works (Baranyuk and Takekawa 1998; Armstrong et al. 1999; Pacific Flyway Council 2006). Fall migration routes would instead follow the northern coastline of Eastern Siberia to Kolyuchinskaya Bay, Russia, cross the Bering sea then cross overland the SW corner of AK and cross the Gulf of Alaska to make landfall near the Queen Charlotte (Haida Gwaii) Islands, Canada before proceeding south via the Pacific coast to the wintering grounds in the Fraser-Skagit region. This route was consistent for all the geese we had multiple seasons of telemetry data for (n=4). Distances between data points crossing the Gulf of Alaska (in some cases <2,000 km; goose 127450) would suggest that our PTT duty cycles were not programmed to the optimal temporal period to maximize migration data collection (i.e., PTT duty cycle was programmed to collect data too soon or too late in the migration season) or this region has poor satellite coverage. However, there was enough satellite coverage to record 3 out of the 4 snow geese (127446, 127450, and 127454) stopping in the middle of the Bering Sea, suggesting that it could be possible for NPS snow geese to complete extremely long segments of migration in excess of 2,000 km at a time. Completing such long flights would further suggest these geese have built up enough energy reserves (i.e., lipids) in the breeding colonies to either not require as many foraging stopovers as the spring migration or that their departure from WI required them to expedite their migration to their wintering grounds and take the shortest route possible to get there. Since, all the study geese were female an expedited departure due to a late departure from the breeding grounds could explain why there is a difference between fall and spring migration routes. Breeding female snow geese leave WI later in the year because they have to raise their chick(s) until they are strong enough to migrate (Baldassarre 2014). Nonbreeding snow geese don't have to wait until so late into the year to start their migration and tend to leave earlier then the breeding snow geese and thus could take a different migratory route (Baldassarre 2014). Given our limited sample size of 7 female snow geese and that we were unable to determine if any of the study geese produced chicks on WI, further studies into WISG migration would benefit from increased sample sizes, an increased duty cycle rate on PTT tags, and tagging both breeding and nonbreeding snow geese of both sexes.

Stopovers were generally in the vicinity of river deltas or protected bays, suggesting stopovers were selected for their forage availability. River deltas and protected bays are typical environments for plant species such as Lyngbyaei (*Carex lyngbyeai*) and Ramenski's (*Carex ramenskii*) sedges to grow, which are known to be part of WISG's diet (Boyd 1995; Pacific Flyway Council 2006). If sites were selected for other reasons such as fatigue or the need for shelter to avoid adverse weather conditions our telemetry data would likely show a higher density of location data in areas such as the middle of the Gulf of Alaska or the Chukchi Sea like some of the data from geese 127446, 127450, and 127454 did. However, stopover sites such as Shishmaref Inlet, Port Clarence, and upper Cook Inlet have both topographical features to provide shelter and habitat for foraging. Further investigation into environment stochasticity events such as weather, tides, and temperature correlated with location data from a larger sample size would benefit future studies of NPS stopovers.

MANAGEMENT IMPLICATIONS

The PTT data provided a wealth of original information about movement patterns of WISG and NPS snow geese populations among flyway use areas. Previous studies using banding techniques have been less effective in collecting migration data in the remote and inaccessible regions of the western interior of Canada and AK, especially for spring migration (Armstrong et al. 1999; Pacific Flyway Council 2006). The data showed a small percentage (15%) of the snow geese overwintering in the Fraser-Skagit region use an interior route through western Canada and AK to reach their nesting grounds at WI during the spring migration. These geese were tracked to the prairies in central Alberta, Canada, suggesting that snow goose populations from the Pacific (NPS and WISG populations) and Midcontinent flyways could be intermingling during the spring migration in this region (U.S. Fish and Wildlife Service 2016). For management purposes, the mixing of different populations would require changes to existing harvest strategies for the smaller WISG and NPS snow geese populations and increased harvest monitoring of the larger Midcontinent populations to prevent overharvesting of WISG and NPS snow geese.

Locating, monitoring, and documenting snow geese stopover and staging areas is important for management to conduct due to the effects of anthropogenic influences, such as climate change on snow goose habitat. For example, rising sea levels could permanently flood existing salt marshes NPS snow geese depend on for forage such as Lyngbyaei (*Carex lyngbyeai*) and Ramenski's (*Carex ramenskii*) sedges in the Stikine River delta staging area and upper Cook Inlet stopover (Pacific Flyway Council 2006). Furthermore, changing precipitation patterns, such as reduced snow melt, could shrink existing marshlands and river delta foraging sites causing snow geese to seek different stopover and staging sites. These changing environmental conditions are part of a shifting baseline of environmental changes due to climate change, and will require constant monitoring to observe effects on NPS snow geese populations for future conservation and management efforts (Pauly 1995).

The sample size (n=7) is too small to make any long-term predictions. However, our stopover data would be useful for managers and researchers for future studies of WISG. For example, using popular stopover regions, such as Kolyuchinskaya Bay, Russia and Shishmaref Inlet, AK, to conduct habitat and local movement studies would be an efficient use of a researcher or managers' resources, while at the same time increasing the probability of having a large enough sample size to make accurate assessments and predictions. Furthermore, heavily used stopover or staging locations would be ideal locations to test new methods of snow goose tracking technologies, such as radio-frequency identification (RFID), to collect local movement data remotely.

CHAPTER FOUR: DISCUSSION AND CONCLUSIONS

Discussion

Spring Migration

Snow geese tagged from the NPS population (n=7) in Washington, USA generally took two different migration routes from their wintering areas in the Fraser-Skagit region to their nesting grounds on Wrangel Island, Russia. The main route used by most of the snow geese during the spring (71%, n=5) followed a Pacific route coastline from the Fraser-Skagit region into the upper reaches of Cook Inlet in Alaska (AK) before crossing the SW corner of AK towards the Seward Peninsula. From the Seward Peninsula, snow geese crossed the Being Sea to the Chukchi Peninsula, Russia, and followed the northern coastline of Eastern Siberian to Wrangel Island. The second route used by 29% (n=2) of the snow geese during the spring migration used an inland route through western Canada from the Fraser-Skagit region to Wrangel Island. From the Fraser-Skagit, snow geese flew in BC before heading east towards the prairie lands of Alberta, Canada. One goose, 12752, lost signal in BC for reason unknown and was reported deceased to Washington Department of State Fish and Wildlife (WDFW). Goose 127450 continued to migrate northward from Alberta into the Northern Territories and then west over the Yukon Territories of Canada into AK (Figure 13). Goose 127450 continued over the northern regions of AK across Kotzebue Sound, in the Bering Sea, over Kolyuchinskaya Bay, Russia and along the East Siberian coastline to Wrangel Island. These findings support the Pacific coastal route hypothesized by Armstrong et al. (1999) and Hines et al. (1999) using leg and neck banding studies, but were unable to confirm due to the remoteness of this region of BC and AK (Figure 4). These findings also confirmed some of the findings by Baranyuk and Takekawa (1998), using early satellite tracking technology from the early 1990's.

Taking the Pacific Coastal route would offer snow geese some advantages over taking an inland route through western Canada. First, the Coastal route in general is shorter than the western Canadian route. Reducing the amount of distance traveled during migration would be advantageous to snow geese because flying over shorter distances will use less energy and saving energy increases a snow gooses' fitness at the breeding grounds at the end of the migration. Thereby, increasing the chances of successful reproduction and reducing mortality of the population of snow geese on route to their breeding grounds due to increased fitness. However, this scenario does not take into account the effects of environmental stochasticity, such as weather and forage availability. But if a straight line is drawn from Wrangel Island to the Fraser-Skagit region, representing the shortest distance between these two points, the North Puget Population (NPS) of snow geese follow a very similar route, which would suggest distance is a strong influence on migration route regardless of any environmental stochasticity.

A second advantage to using the Coastal route could be the availability of forage. The temperate climate along the BC and southern AK coast often results in less accumulation of snowfall due to the warming effects of the Pacific Ocean on atmospheric temperatures in this region compared to the interior regions of BC and AK. Less snow accumulation permits easier and earlier access to foraging sites during spring migrations. Furthermore, the topography of the North American coastline from the Fraser-Skagit region to the upper Cook Inlet in AK has far more river deltas containing intertidal marsh plants, such as the bulrush (*Scirpus americanus*), typically consumed by NPS snow geese, then the interior regions of BC, which consists mostly of temperate coniferous and boreal forests and would be forage limited for snow geese (Boyd 1995). Stopover and staging area data supports this hypothesis because there was no data for a western Canadian migration route (Figures 19 and 21). All the stopover and staging area data was along the Pacific coastal route. The migratory path of goose 127450 also supports the hypothesis that the forested areas along the Pacific coastal route are resource limited. The limited resources are due to goose 127450's spring migratory route from the Fraser-Skagit region over the BC coniferous and boreal forests into the Canadian prairie lands in Alberta, Canada, where other food sources, such as agricultural forage and grasses are more readily available (Figure 13).

Weather and topography could both be influential on whether to take an inland western Canadian spring migratory route or a Pacific coastal route. The ubiquitous islands along the Pacific costal route from the Fraser-Skagit region to upper Cook Inlet could provide some protection from the Bering Sea weather during the spring migration, as would flying on the east side of the coastal mountains, such as goose 12447 did (Figure 7). However, this study did not focus on the influences of migratory routes, but rather the routes themselves. Weather data (e.g., snow accumulation, barometric pressure, wind) is available for this data set on the movebank.org website from reputable national weather resources, such as NOAA. The movebank.org website has the ability to cross reference LC data points with the closed recorded weather phenomena and provide it for analysis. Weather effects on migration would be a good topic for future research of NPS migration.

Fall Migration

We collected fall migration data from 4 Platform Terminal Transmitters (PTT) from geese 127446, 12447, 127450, and 127454. Each of these geese transmitted one season of fall migration data before the PTT's failed. The results from these 4 geese showed a similar pattern of migration from Wrangel Island, Russia to the Fraser-Skagit region. The geese started their fall migration from Wrangel Island and headed to the mainland at Cape Billings on the northern Shores of Eastern Siberia. From Cape Billings, the geese fallowed the coast west towards the Chukchi Peninsula to Kolyuchinskaya Bay, before crossing the Bering Sea to the Seward Peninsula in AK and south across Norton Sound and the SW portion of the state and cutting across the Gulf of Alaska and making landfall near or at Queen Charlotte (Haida Gwaii) islands, Canada. After this point, the geese followed a Pacific Coastal route to their wintering grounds in the Fraser-Skagit region.

A major difference between spring and fall migration routes was the Bering Sea crossing during the fall migration. None of the spring migrates attempted to follow this route. Furthermore, fall migratory data showed that geese made more use of the Eastern Siberian coastline from Cape Billing to Kolyuchinskaya Bay during the fall then the spring and all stops in this region were > 2 days in duration with no staging areas existing in the region. The Eastern Siberian coastline was historically used for nesting and feeding by WISG prior to their population being overhunted in the 19th century (Kerbes, Meeres and Hines 1999). Its current continued use by WISG would suggest that this habitat is still capable of supporting a recovering population of WISG. As the population of WISG continues to grow at a decadal growth rate of 8%, the nesting colonies on Wrangel Island could spread back into their historical breeding grounds as the population recovers.

Stopover and Staging Areas

Using the Select Locations method (Miller et al. 2005) and choosing only LC 1, 2 and 3 data at zero altitude reduced the number of available LC data points by 85% (n=1008) for identifying stopover and staging areas along the migratory routes. Adding the step of using only LC data with an elevation of zero meters was important because it was the only way to confirm that a goose was on the ground, which would imply that the goose was not flying and the assumption can be made that the goose was in a resting stage of the migratory process. However, this resting assumption does not take into account the effects of weather and other environmental stochasticity events that could force a goose to seek shelter without the need to have to feed. Further data analysis using the Environmental Data Automated Track Annotation System (Env-Data System) tool within Movebank could be used to account for environmental stochasticity using weather data and existing Argos LC data.

The results of the stopover data showed 62.5% of the stopovers were >2 days in duration and generally located in the vicinity of river deltas or protected bays for all geese (Figure 20). The most heavily used regions in AK were along the coast of Yakutat, the Bering river delta, upper Cook Inlet, Port Clarence, and Shishmaref Inlet. In Russia, the most heavily used regions were on the Chukchi Peninsula at Kolyuchinskaya Bay and the coastal region at Cape Billings. I have no habitat data from these regions, but I would hypothesis their close proximity to river deltas and protected bays would make these areas ideal locations for the various marsh plants that make up the primary diet of a snow goose. Furthermore, the Kolyuchinskaya Bay, Port Clarence and Shishmaref Inlet located on either side of the Bering Sea, which is the longest leg of the spring migration route, where forage would not be available, making it necessary to build up energy reserves to complete this portion of the migration. My literature review sources as of June 2017 did not describe snow geese using Kolyuchinskaya Bay, Port Clarence, Shishmaref Inlet, the Bering River delta, or the coastal regions near Yakitat as stopovers, suggesting these locations could be new information for either researchers or managers. However, this information could be common knowledge to the Native Peoples or current residents living in these regions and it has simply not been published or passed on to researchers and managers due to the remoteness of these regions or language barriers (e.g., Russian science literature that has not been translated to English).

Stopover data that fell into the ≤2 and ≥7 day criteria included the Arctic Lagoon (Goose 127454; Figure 18), Bering River delta (Geese 127447; Figure 8), Klinaklini River delta (127447), and the Serpentine River delta (Goose 127447; Table 4). These 4 locations were not described in any of the literature I reviewed, suggesting these locations could also be new information for either researchers or managers. The only previously described stopover location that was used by 3 of the study geese was upper Cook Inlet located near Anchorage. Geese 127446 (Figure 6), 127448 (Figure 10), and 127454 (Figure 18) were tracked more specifically to the Knik River delta in the headwaters of Cook Inlet during the spring migration (Table 4). Cook Inlet was not used as a stopover or staging area during the fall.

The results of the staging areas data confirmed that WISG population in general and the NPS population specifically used the Stikine River delta in AK as a staging area only during the spring migration (geese 127454 and 12749). Geese crossing the Bering Sea during the fall migration bypassed the Stikine River staging area and made landfall near the Queen Charlotte (Haida Gwaii) Islands instead. After making landfall, these geese preferred to make short (>2 days) stopovers, heading south along the Pacific coast instead of stopping for longer periods of time at a staging area until they reached the wintering grounds in the Fraser-Skagit region. The only exception of this observation was goose 12746 (Figure 6), who used the Fraser River delta as a staging area prior to heading further south into Washington to the Skagit River delta region to overwinter. Future studies would benefit from a habitat and foraging analysis at staging and stopover sites to further investigate why snow geese are using these sites.

Conclusions

This study has provided the first set of satellite telemetry data for NPS migration routes, stopovers, and staging areas. The key findings from the data showed the following results: 1) two migratory paths, the Pacific coastal route or the interior western Canadian route, during the spring migration (north bound) and a single route during the fall migration (south bound) over the Bering Sea and down the Pacific coast from the Queen Charlotte (Haida Gwaii) Islands to the Fraser-Skagit region, 2) Midcontinent and NPS snow geese populations could be intermingling during the spring migration over the prairies in Alberta, Canada, suggesting managers should adjust their harvesting strategies accordingly to avoid overharvesting of the NPS population, 3) most stopovers (62.5%) were less than 2 days in duration and were located primarily at river deltas and protected bays along the coastlines of Russia, Canada, and the U.S., 4) stopovers between 2 and 5 days were less common (37.5%) then rest stops that were less than 2 days, 5) new stopover sites included the Arctic Lagoon, Serpentine River delta and Bering River delta in AK and the Klinakline River delta in B.C., and 6) we confirmed previous finding that WIGS use the Stikine River delta in B.C. as a staging area and specifically that the NPS population uses this site as well. The results from these movement patterns will help managers and researchers form a more successful conservation and management strategy for NPS snow geese going forward.

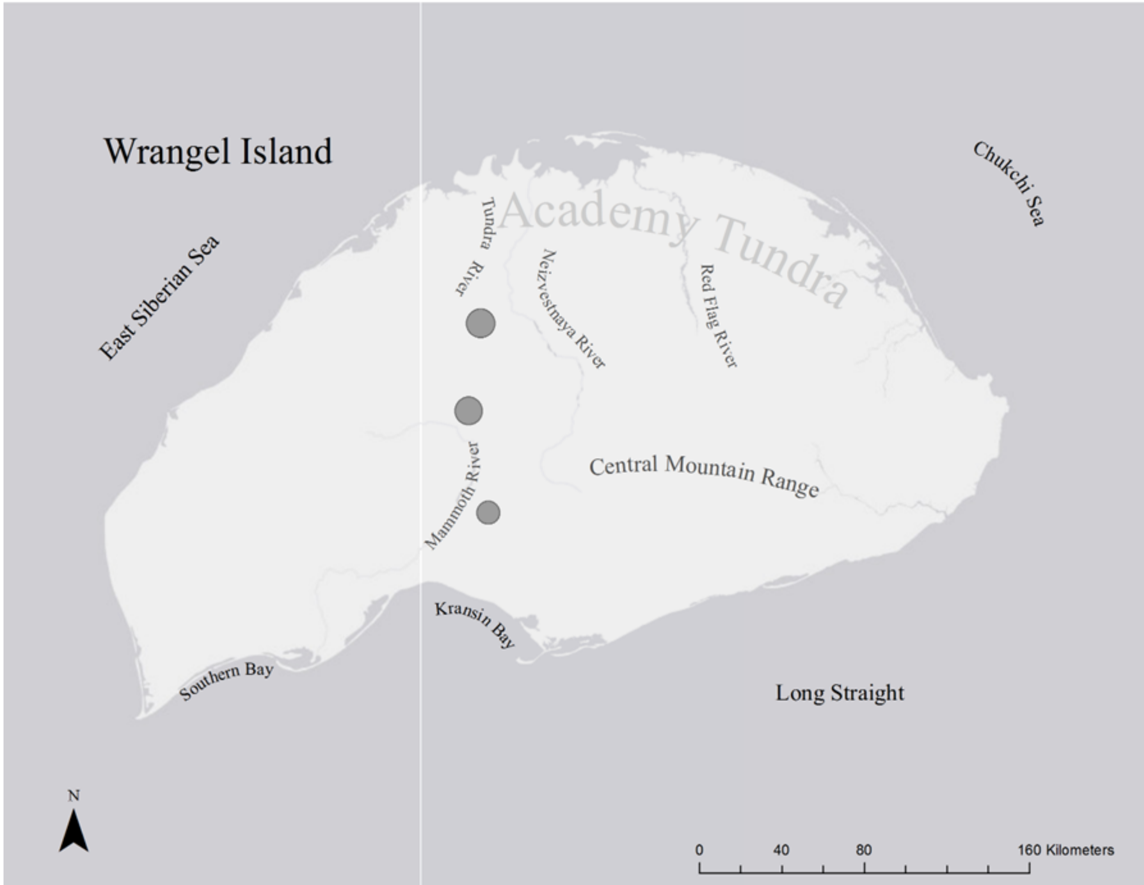

Figure 1. Wrangel Island, Russia, the main breeding site of the Wrangel Island lesser snow goose (*Chen caerulescens caerulescens*) population. The grey circles represent colony sites regularly occupied during the breeding season from May to August (Baranyuk 1999; Pacific Flyway Council 2006).

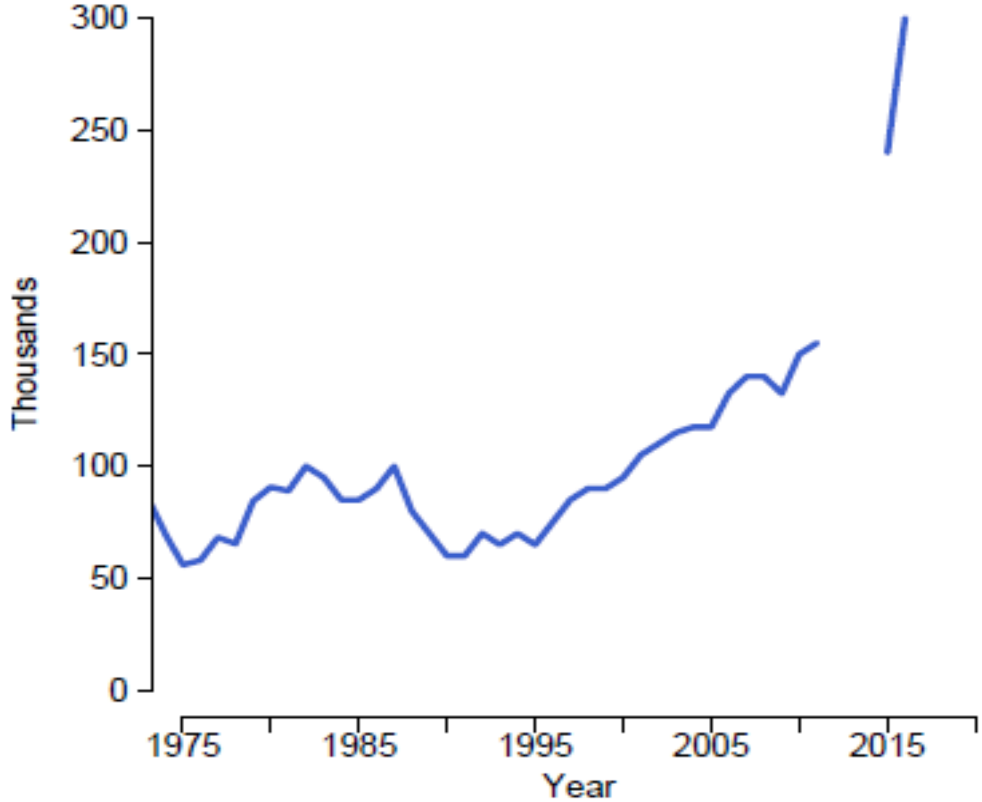

Figure 2. Wrangel Island, Russia lesser snow goose (*Chen caerulescens caerulescens*) population trends from 1975 to 2016 (U.S. Fish and Wildlife Service 2016). No data was collected in 2015, representing the gap in the trend line.

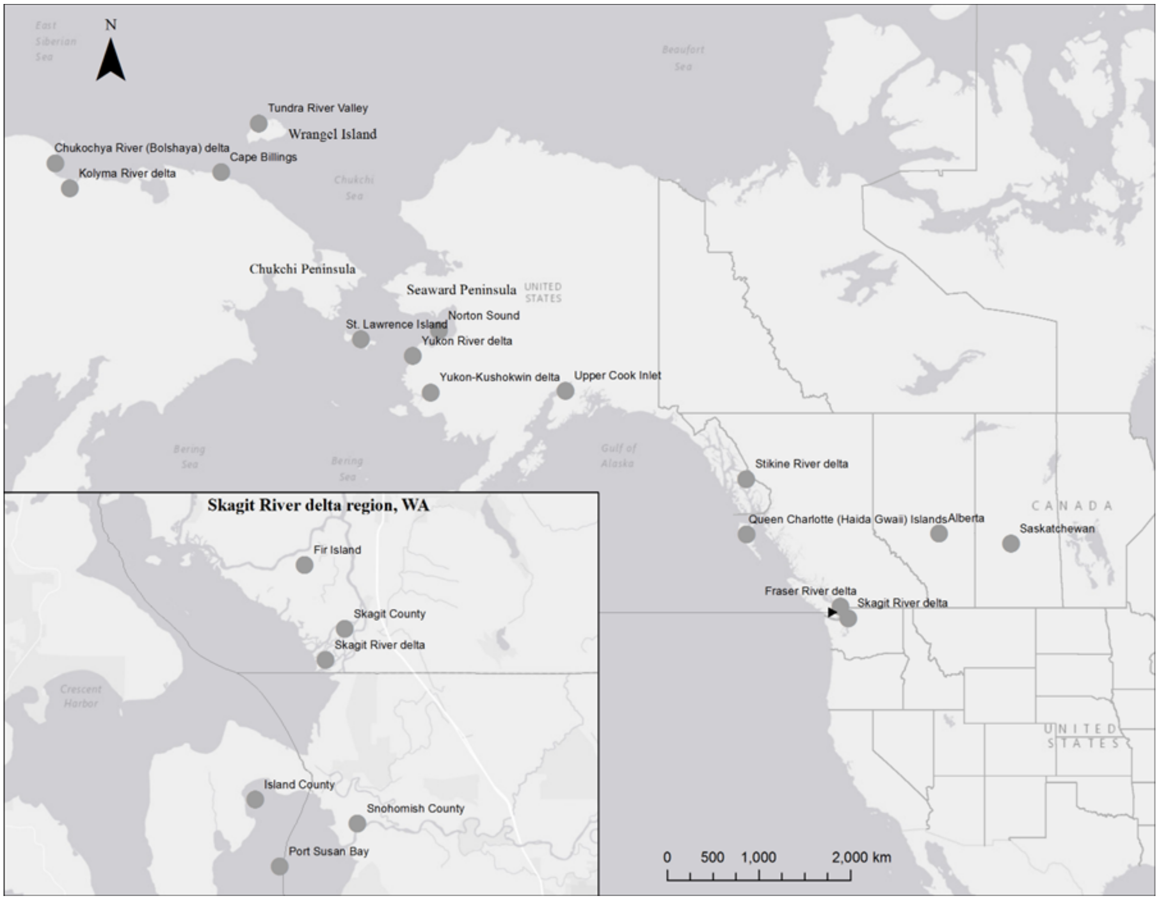

Figure 3. Known migration stopovers of North Puget Sound lesser snow geese (*Chen caerulescens caerulescens*) and winter ranger in the Skagit River delta region (Kerbes et al. 1999).

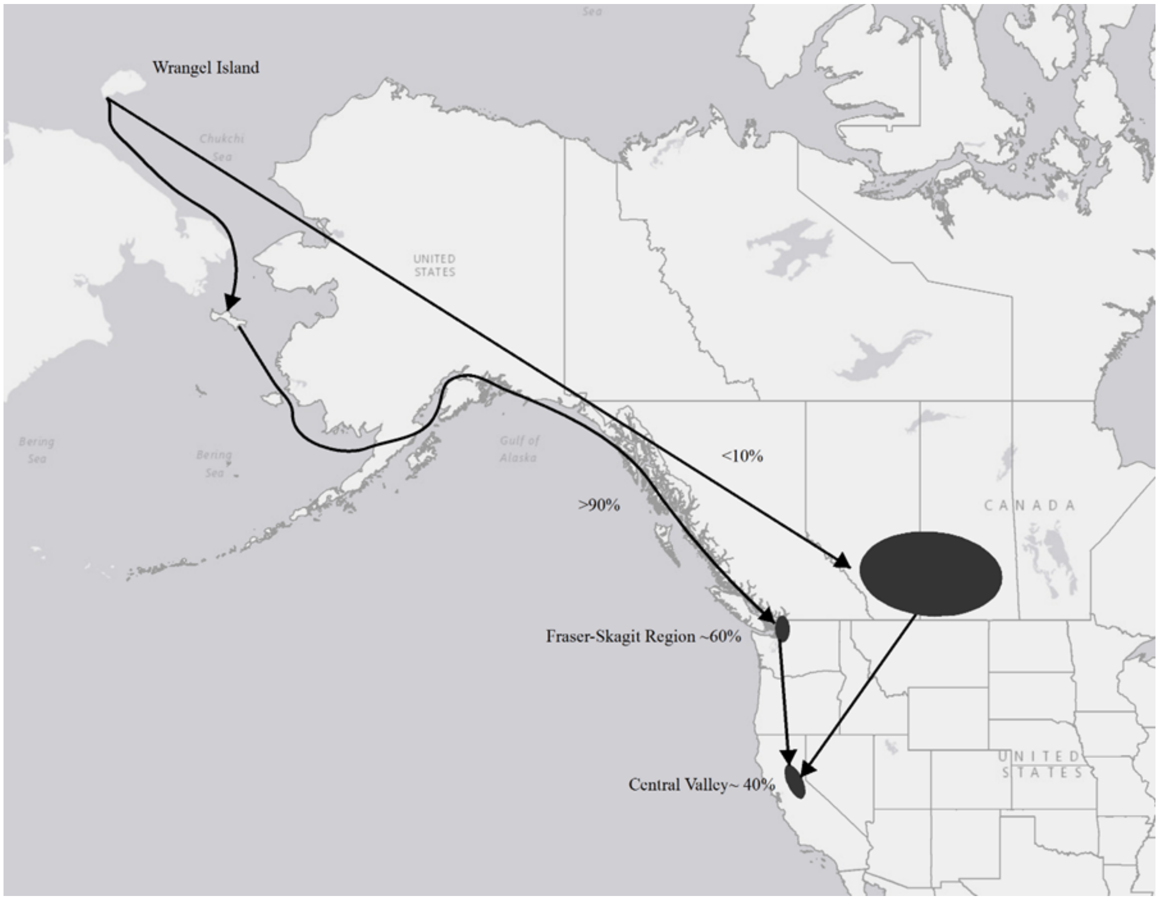

Figure 4. Wrangel Island, Russia lesser snow goose (*Chen caerulescens caerulescens*) fall migration routes. Less than 10% of the Wrangel Island snow geese (WISG) population migrate over the Chukchi Sea over Alaska, USA into the Canadian prairie lands of Alberta and Saskatchewan before heading to their wintering grounds in Central Valley, California, USA. More than 90% of the Wrangel Island population migrate down the Pacific coast and use the Fraser-Skagit region as a staging area. Sixty percent of the lesser snow geese using the Fraser-Skagit region will migrate further south to the Central Valley to overwinter with the remaining 40% of the population staying within the Fraser-Skagit region for the winter (Armstrong et al. 1999; Hines et al. 1999; Pacific Flyway Council 2006).

Table 1. Table of geographical locations with coordinates.

Stopover site	Coordinates
Alberta, Canada	54.316°N, 144.677°E
Cape Billings, Russia	69.850°N, 176.133°E
Central Valley, California	40.200°N, 122.240°W
Chukochya River (Bolshaya) delta, Russia	48.350 N, 122.394 E
Fir Island, Washington	70.1 N, 159.7667 E
Fraser River delta, BC, (Canada)	49.058°N, 123.177°W
Fraser-Skagit region, Washington and BC	48.644°N, 122.543°W
Freezeout Lake, Montana	47.661°N, 112.051°W
Island County, Washington	48.224°N, 122.442°W
Japan	36.17°N, 138.237°W
Kolyma River delta, Russia	69.30°N, 161.30°W
Lena River delta, Russia	72.476°N, 126.633°W
Lower Columbia River, Washignton and Oregon	46.225°N, 123.624°W
Lower Yukon River, Alaska	62.608°N, 164.884°W
Norton Sound, Alaska	48.180°N, 122.425°W
Port Susan Bay, Washington	53.362°N, 132.256°W
Queen Charlotte Islands (Haida Gwaii) , BC, Canada	63.579°N. 162.520°E
Saskatchewan, Canada	52.940°N, 106.451°E
Skagit County, Washington	48.323°N, 122.364°W
Skagit River delta, Washington	48.305°N, 122.381°W
Snohomish County, Washington	48.210°N, 122.353°W
St. Lawrence Island, Canada	63.4°N, 170.167°W
Stikine River delta, Alaska	56.579°N, 132.41°W
Summer Lake, Oregon	42.748°N, 120.489°W
Tundra River Valley, Wrange Island, Russia	71.433°N, 179.805°W
Upper Cook Inlet, Canada	61.054°N, 150.129°W
Wrangel Island, Russia	71.229°N, 179.428°W
Yukon River mouth (delta), Alaska	62.660°N, 165.087°W
Yukon-Kushokwin River delta, Alaska	60.969°N, 163.346°W

Table 2. Captured North Puget Sound lesser snow geese (*Chen caerulescens caerulescens*) by individual satellite tag identifier, sex, mass, U.S. Fish & Wildlife Service neckband number, and release site from 2013 to 2014.

Individuals	Sex	Mass (g)	USFWSBAND #	Release location
127446	Female	2068	1727-55979	48.341°N, -122.386°W
127447	Female	1972	2097-09240	48.330°N, -122.382°W
127448	Female	1928	2097-09252	48.341°N, -122.386°W
127449	Female	2042	2097-09245	NA
127450	Female	1826	2097-09256	48.341°N, -122.414°W
127452	Female	1978	127452	48.545°N, -122.428°W
127454	Female	2006	2097-09451	48.361°N, -122.417°W

Table 3. Information on North Puget Sound lesser snow geese (*Chen caerulescens caerulescens*) implanted with Platform Transmitting Terminals from 2013 to 2014.

	Deployment date			
Individuals	start (yyyy.mm.dd)	end (yyyy.mm.dd)	location data points (n)	Days of satellite tracking
127446	2013.02.27	2014.05.24	1016	342
127447	2013.02.26	2014.09.17	1924	330
127448	2013.02.27	2013.10.05	478	98
127449	2013.02.28	2013.05.26	374	80
127450	2013.02.28	2014.03.22	1007	201
127452	2013.02.28	2013.04.30	221	108
127454	2013.03.01	2014.06.07	1670	292
Total			6690	1451

Table 4. Platform Transmitting Terminal program used for captured North Puget Sound lesser snow geese (*Chen caerulescens caerulescens*) fitted with satellite tags from 2013 to 2014.

Season	Year	Transmit start date	Transmit end date	Non-migratory	Migratory	Migratory season	Duty cycle (On/Off)
1	1	Feb-13	15-Mar-13	X			2/77
2	1	15-Mar-13	31-May-13		X	Spring	4/27
3	1	31-May-13	9-Aug-13	X			2/77
4	1	9-Aug-13	15-Oct-13		X	Fall	4/27
5	2	15-Oct-13	15-Mar-14	X			2/77
6	2	15-Mar-14	31-May-14		X	Spring	4/27
7	2	31-May-14	9-Aug-14	X			2/77
8	2	9-Aug-14	15-Oct-14		X	Fall	4/27
9	3	15-Oct-14	15-Mar-15	X			2/77
10	3	15-Mar-15	31-May-15		X	Spring	4/27
11	3	31-May-15	9-Aug-15	X			2/77
12	3	End transmission due to low battery					

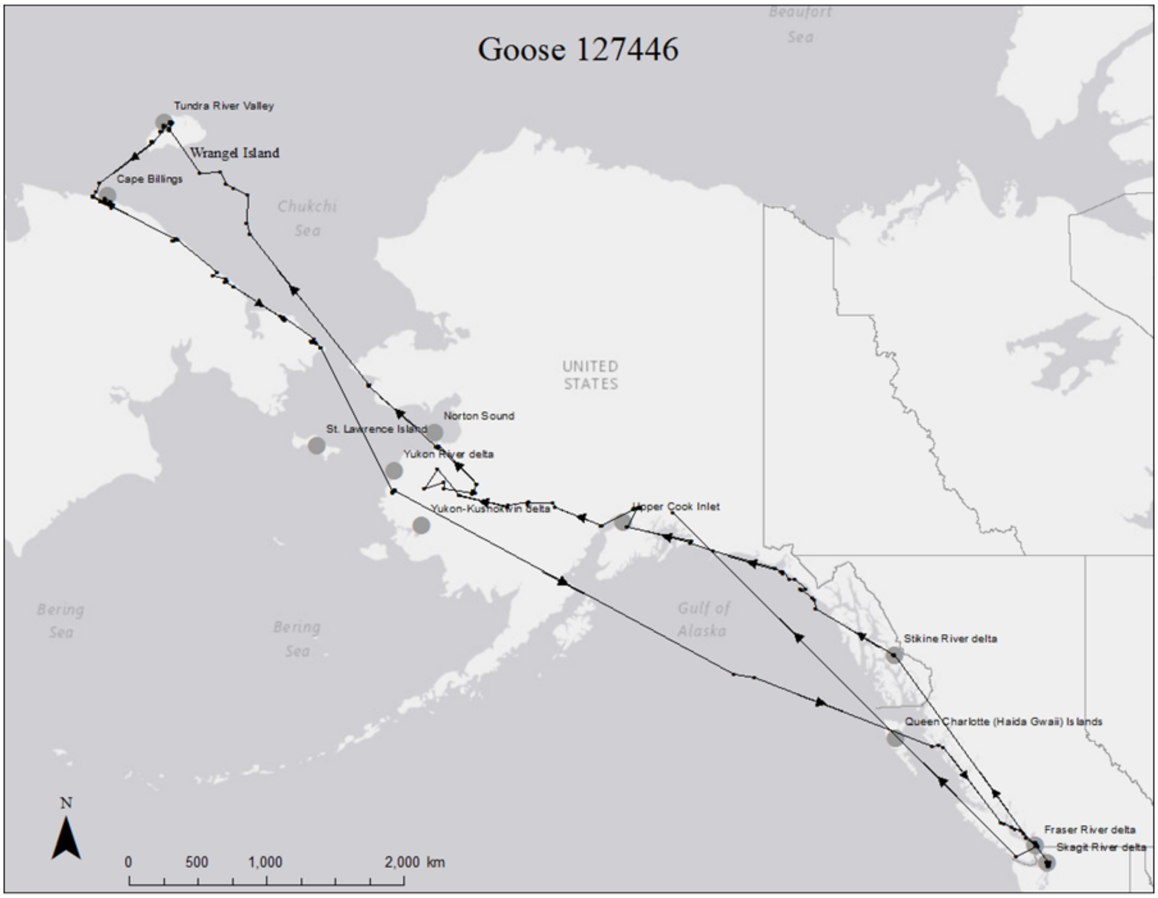

Figure 5. Migration route of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127446 captured and tagged in the Skagit River delta on 27 February 2013 and tracked to 24 May 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa, 1998; Kerbes et al. 1999).

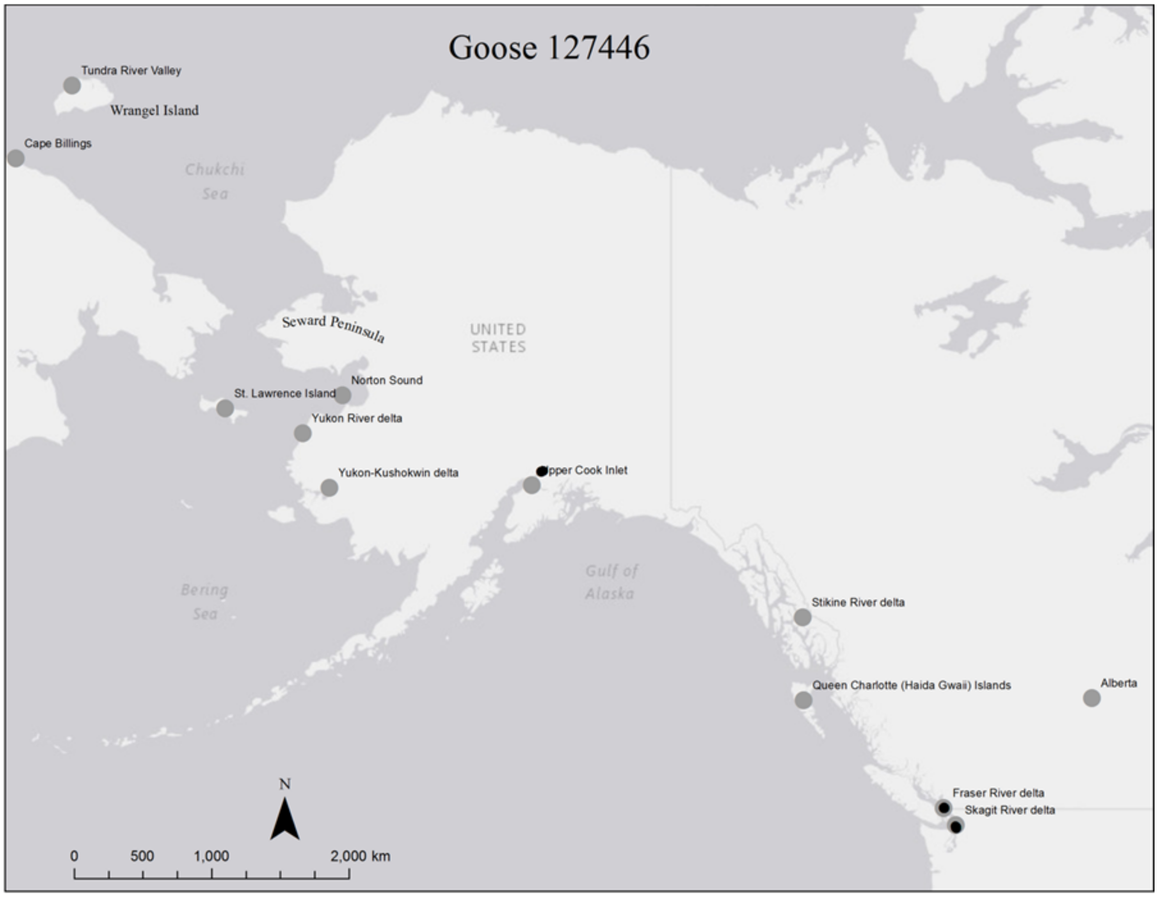

Figure 6. Stopover and staging sites (black dots) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127446 captured and tagged in the Skagit River delta on 27 February 2013 and tracked to 24 May 2014. Grey circles indicate previously documented stopover sites and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

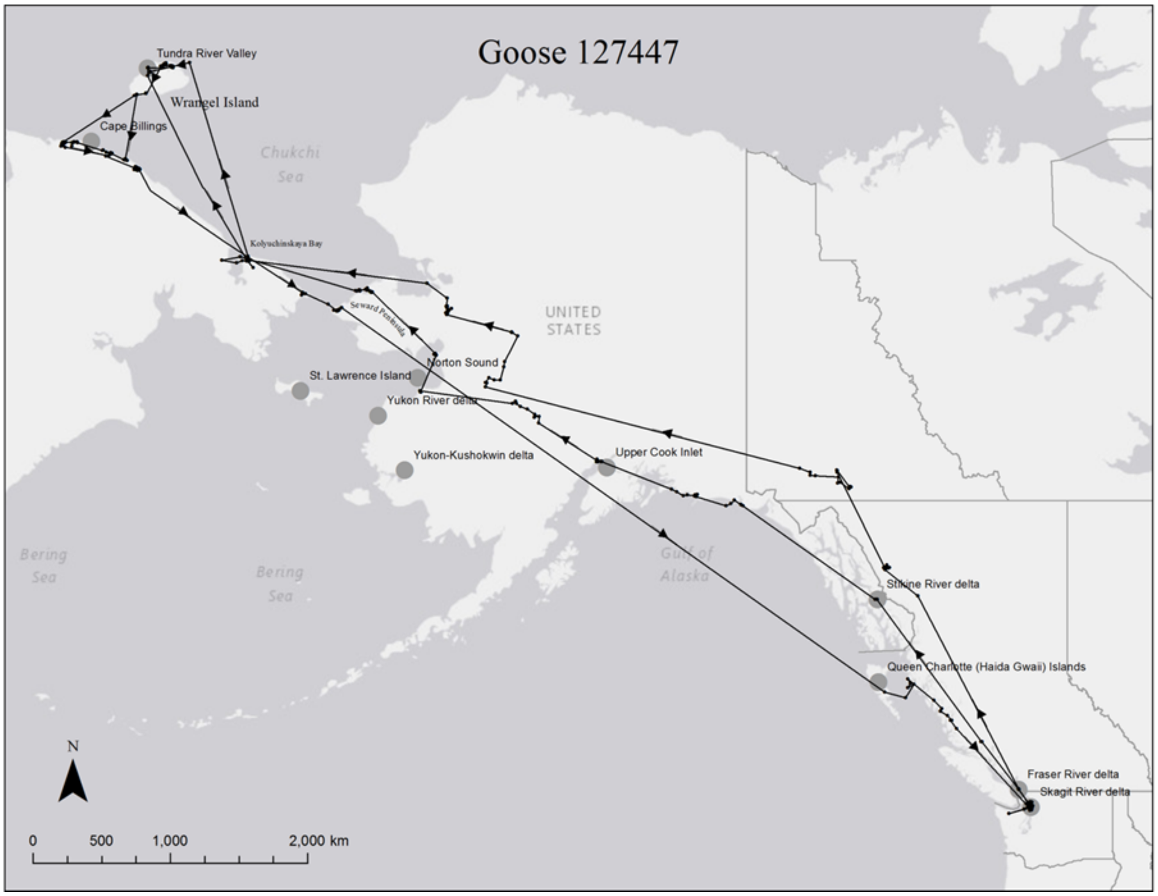

Figure 7. Migration route of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127447 captured and tagged in the Skagit River delta on 26 February 2013 and tracked to 17 September 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

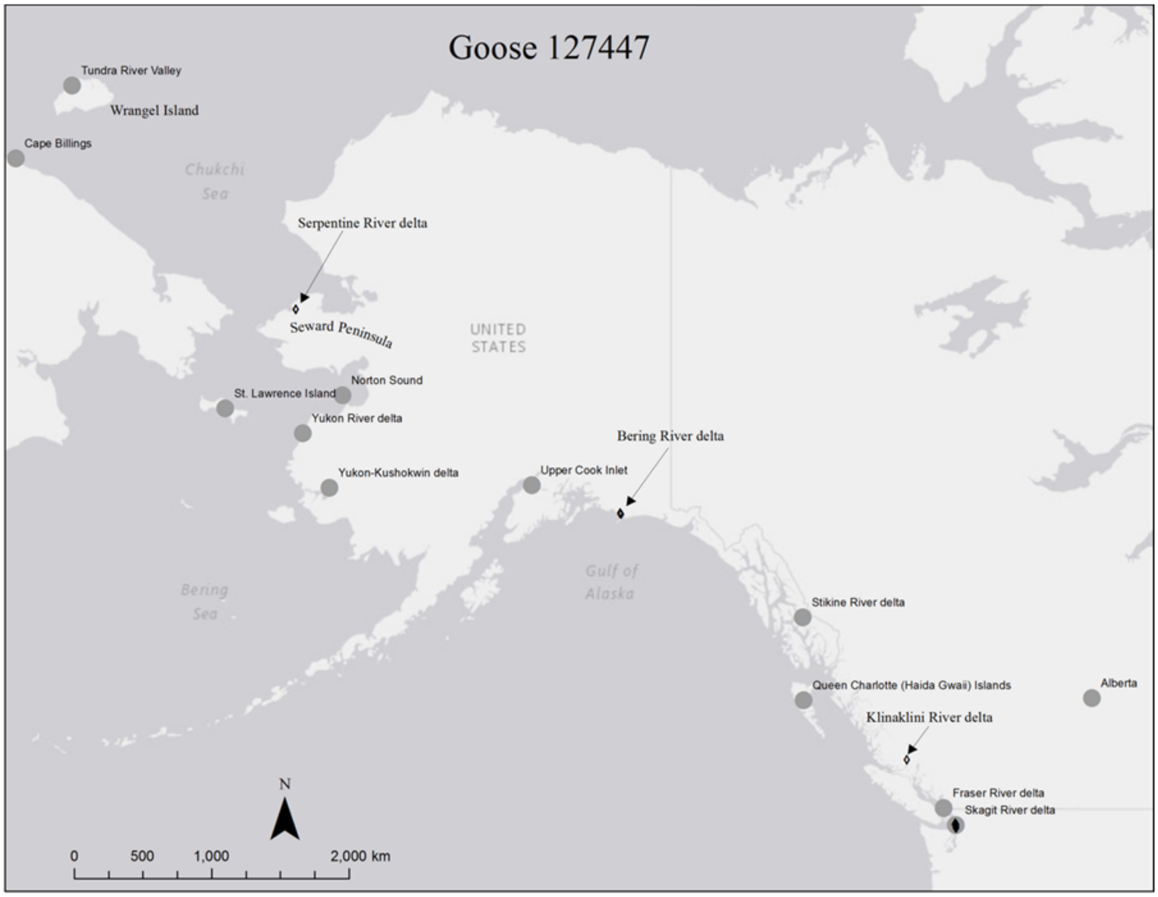

Figure 8. Stopover and staging sites (black diamonds) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127447 captured and tagged in the Skagit River delta on 26 February 2013 and tracked to 17 September 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

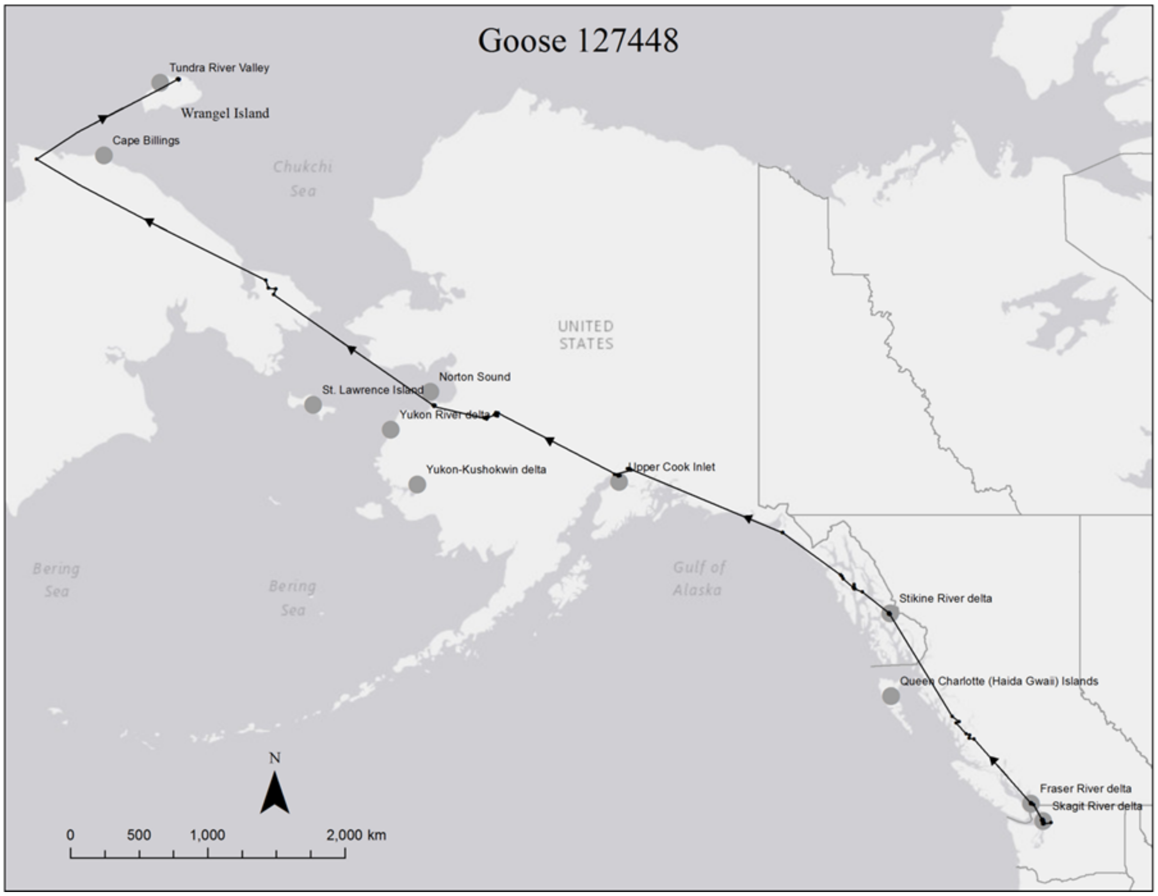

Figure 9. Migration route of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127448 captured and tagged in the Skagit River delta on 27 February 2013 and tracked to 05 October 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

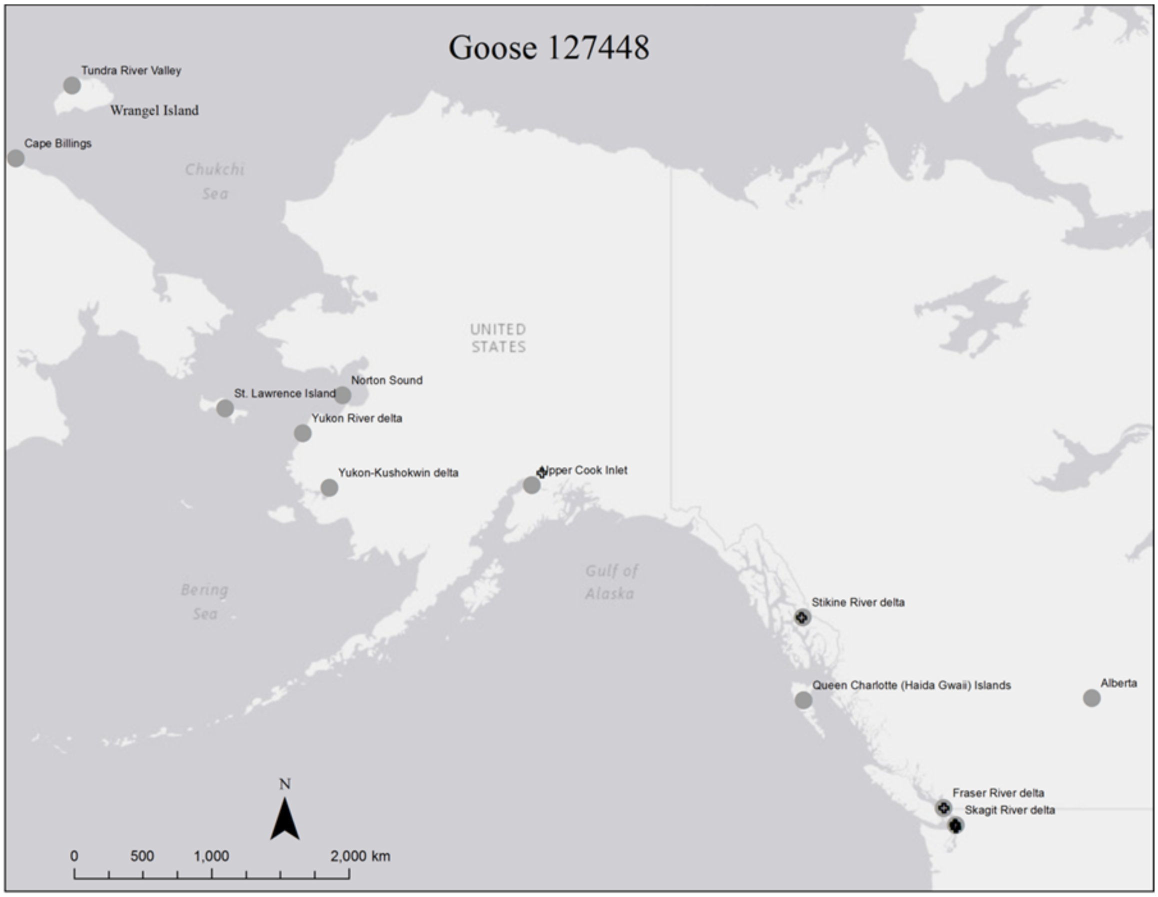

Figure 10. Stopover and staging sites (black crosses) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127448 captured and tagged in the Skagit River delta on 27 February 2013 and tracked to 05 October 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

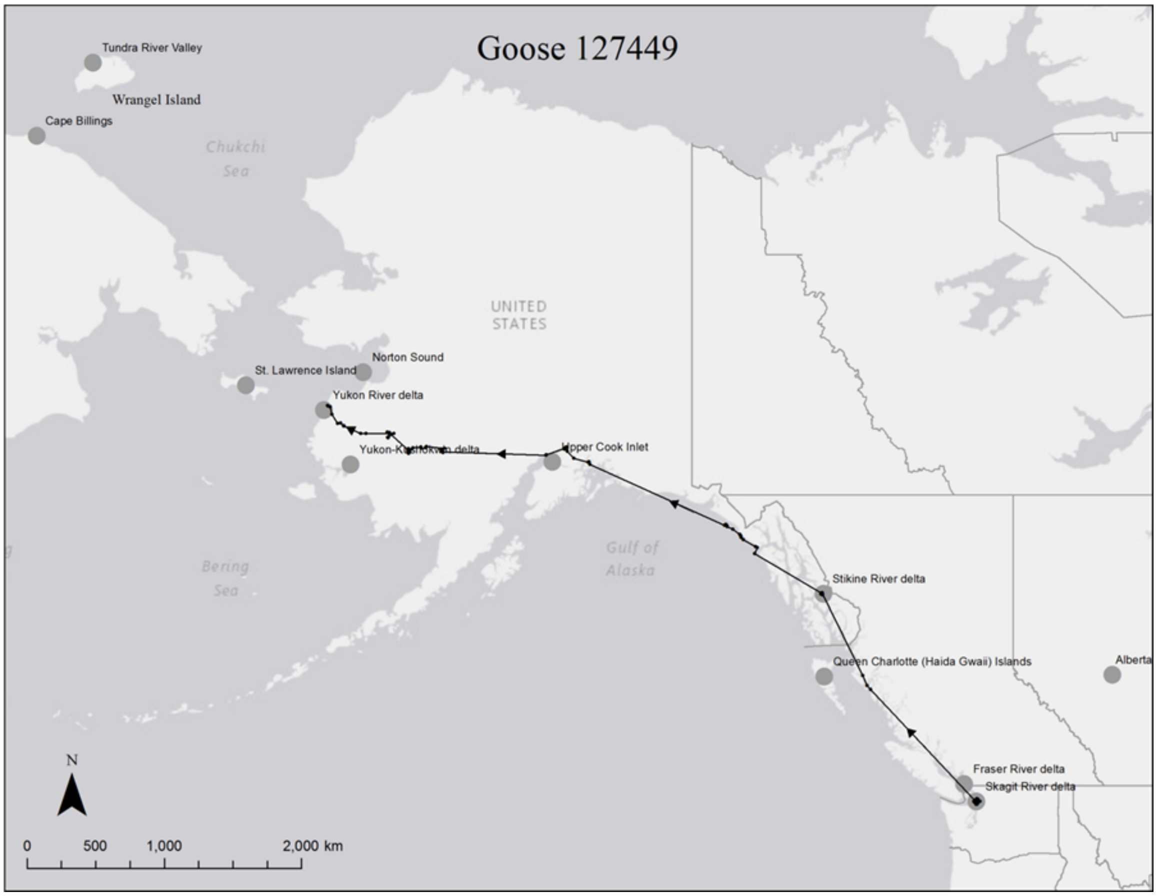

Figure 11. Migration route of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127449 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 26 May 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

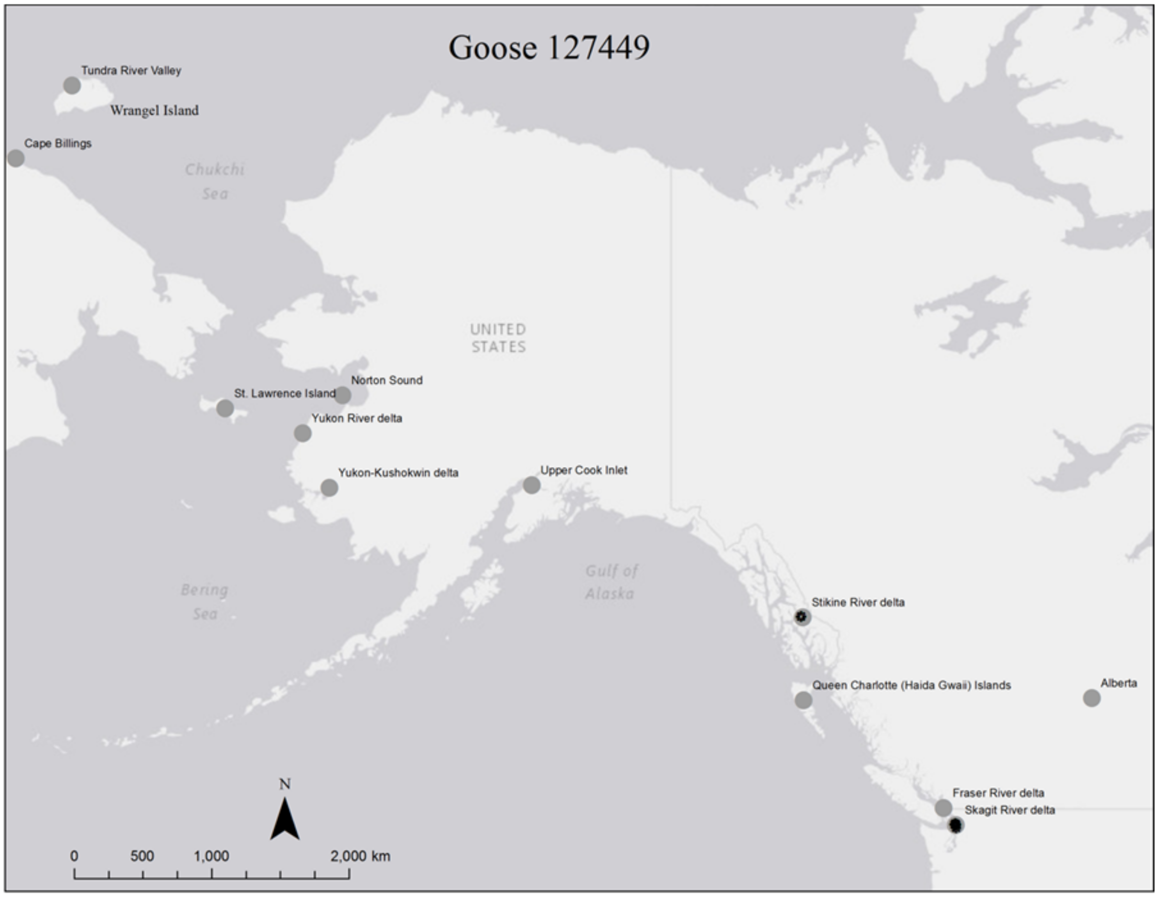

Figure 12. Stopover and staging sites (black asterisks) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127449 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 26 May 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

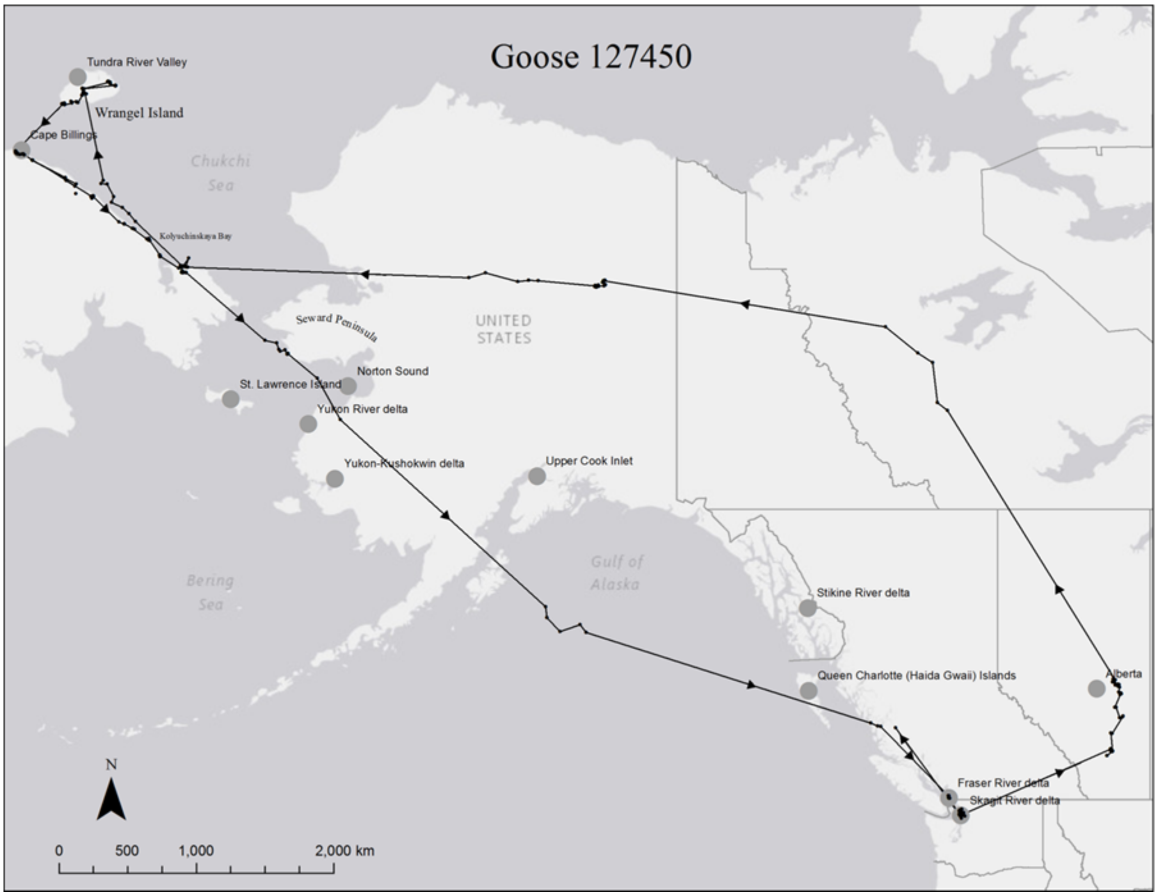

Figure 13. Migration route of a female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127450 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 22 March 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al.1999).

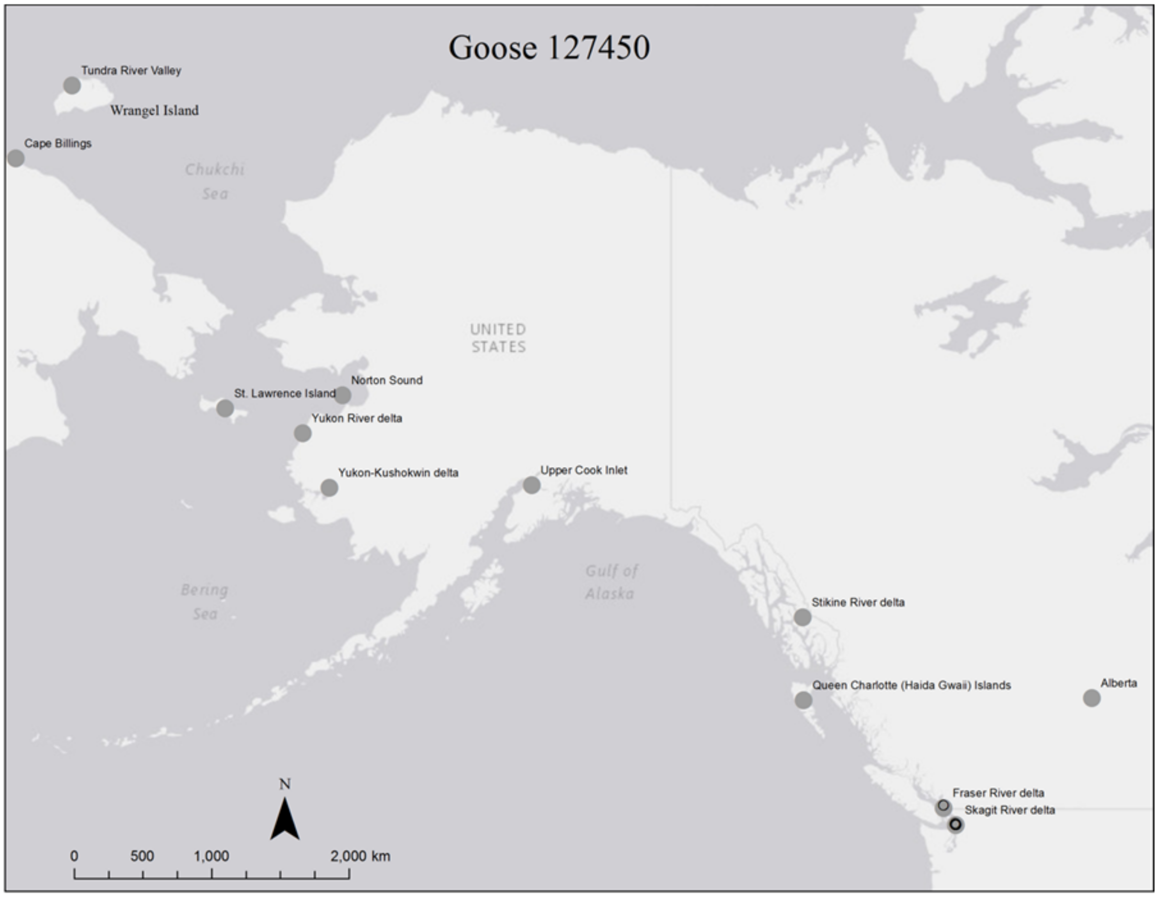

Figure 14. Stopover and staging sites (black circles) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127452 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 30 April 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

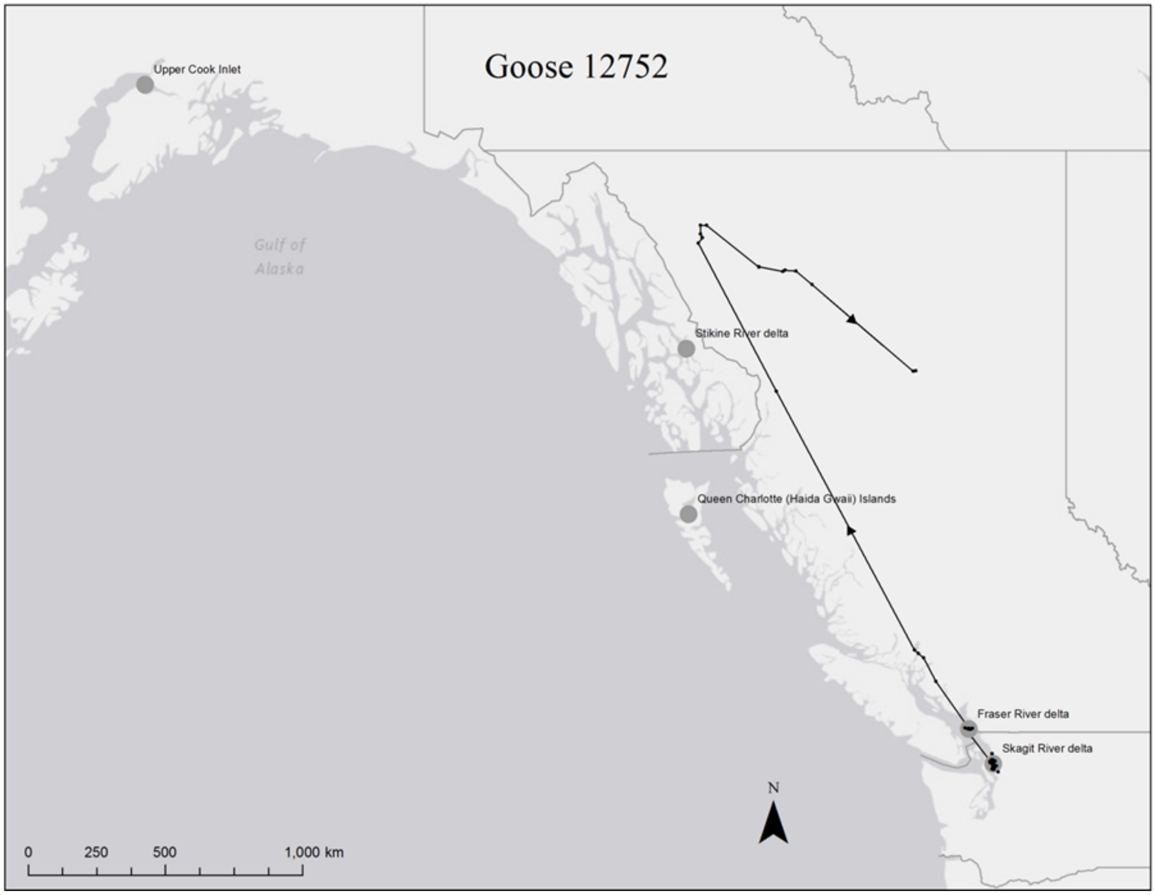

Figure 15. Migration route of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127452 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 30 April 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

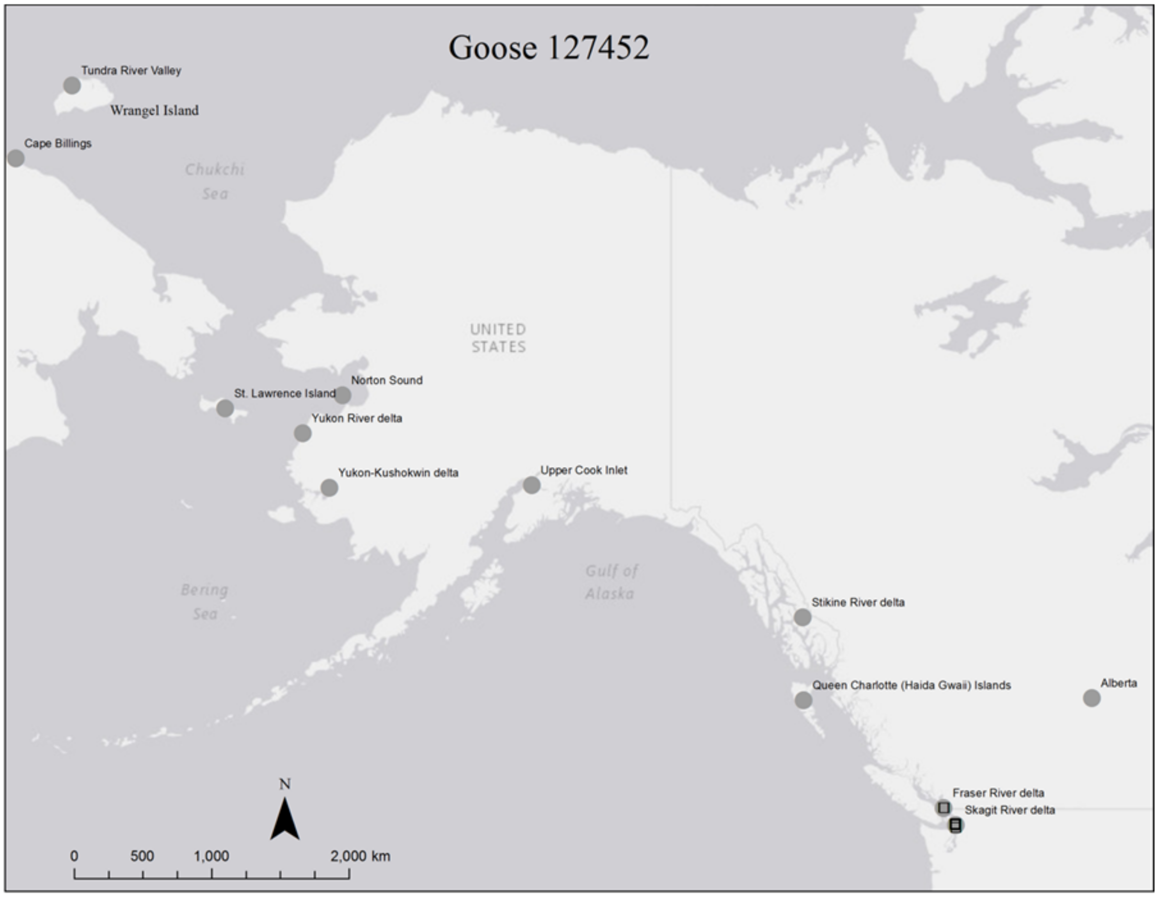

Figure 16. Stopover and staging sites (black squares) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127452 captured and tagged in the Skagit River delta on 28 February 2013 and tracked to 30 April 2013. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

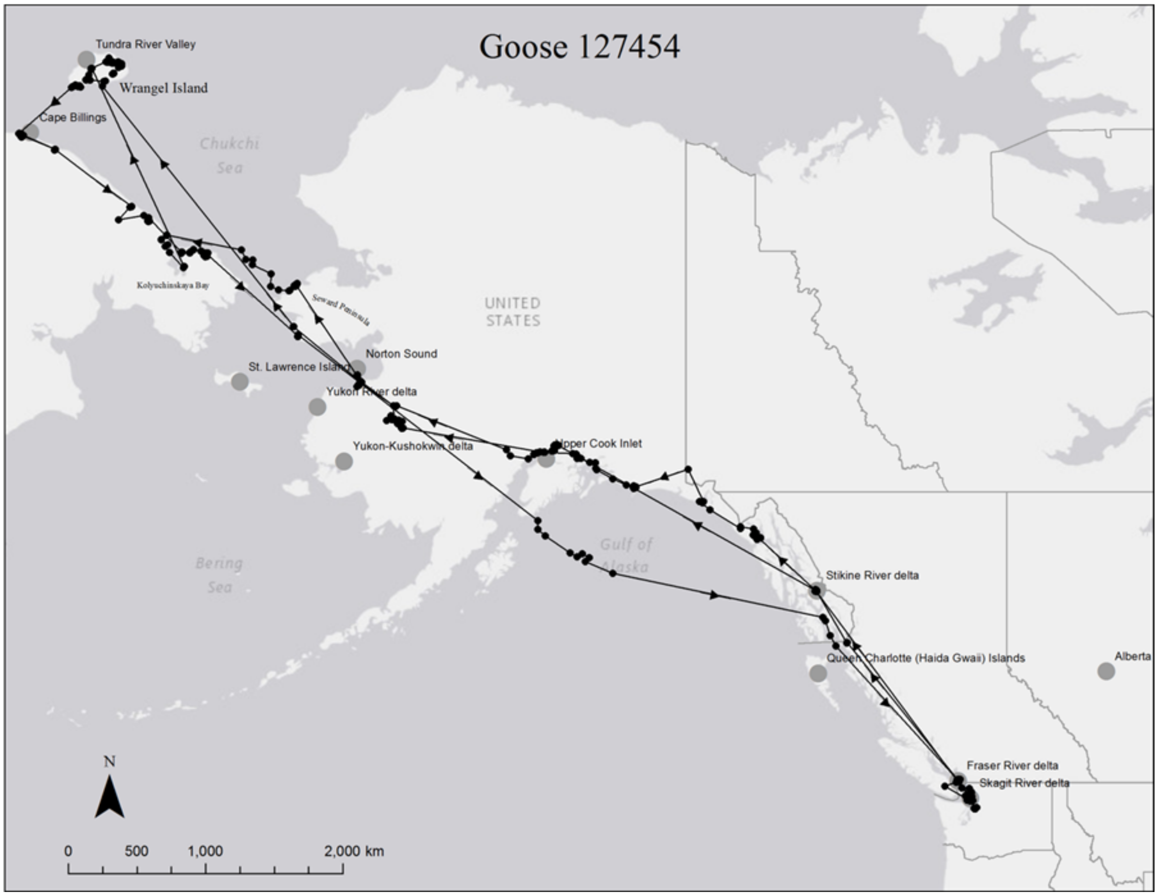

Figure 17. Migration route of a female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127454 captured and tagged in the Skagit River delta on 1 March 2013 and tracked to 07 June 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

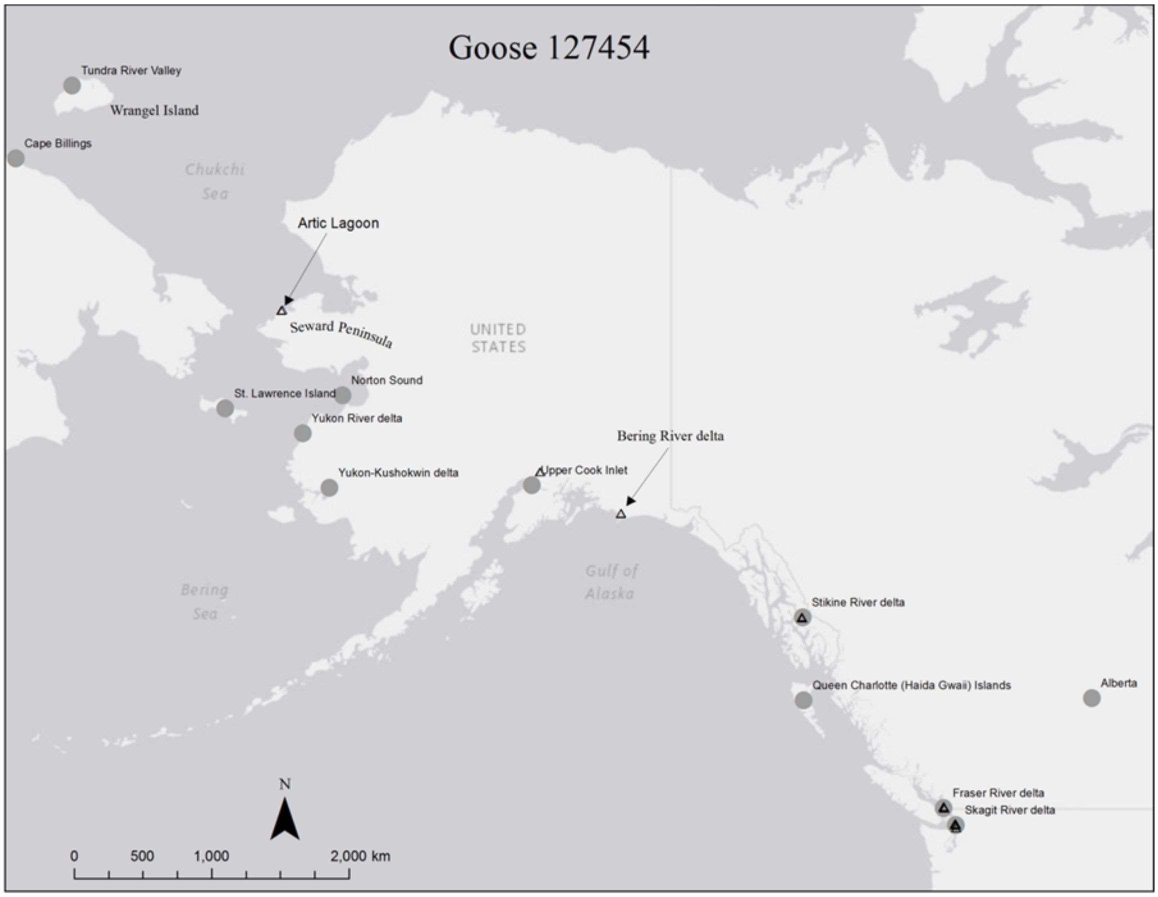

Figure 18. Stopover and staging sites (black trianges) of female PTT-tagged lesser snow goose (*Chen caerulescens caerulescens)* 127454 captured and tagged in the Skagit River delta on 1 March 2013 and tracked to 07 June 2014. Grey circles indicate previously documented rest and staging areas (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

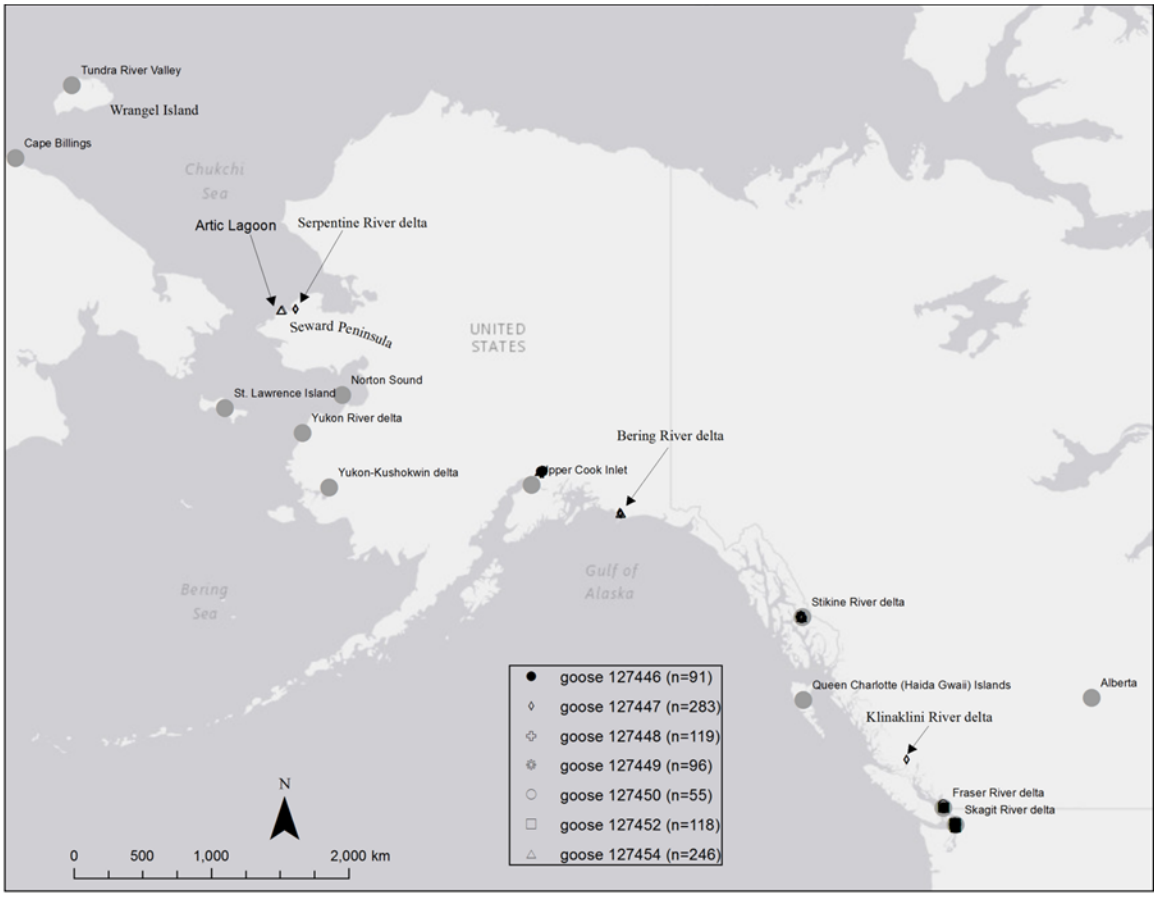

Figure 19. Stopovers and staging sites (black dots) of all lesser snow geese (*Chen caerulescens caerulescens*) tagged and released from the North Puget Sound population in the Skagit River delta region in Washington State, USA Geese were tracked from 26 February 2013 to 5 October 2014. Grey circles represent previously documented staging and stopover sites (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

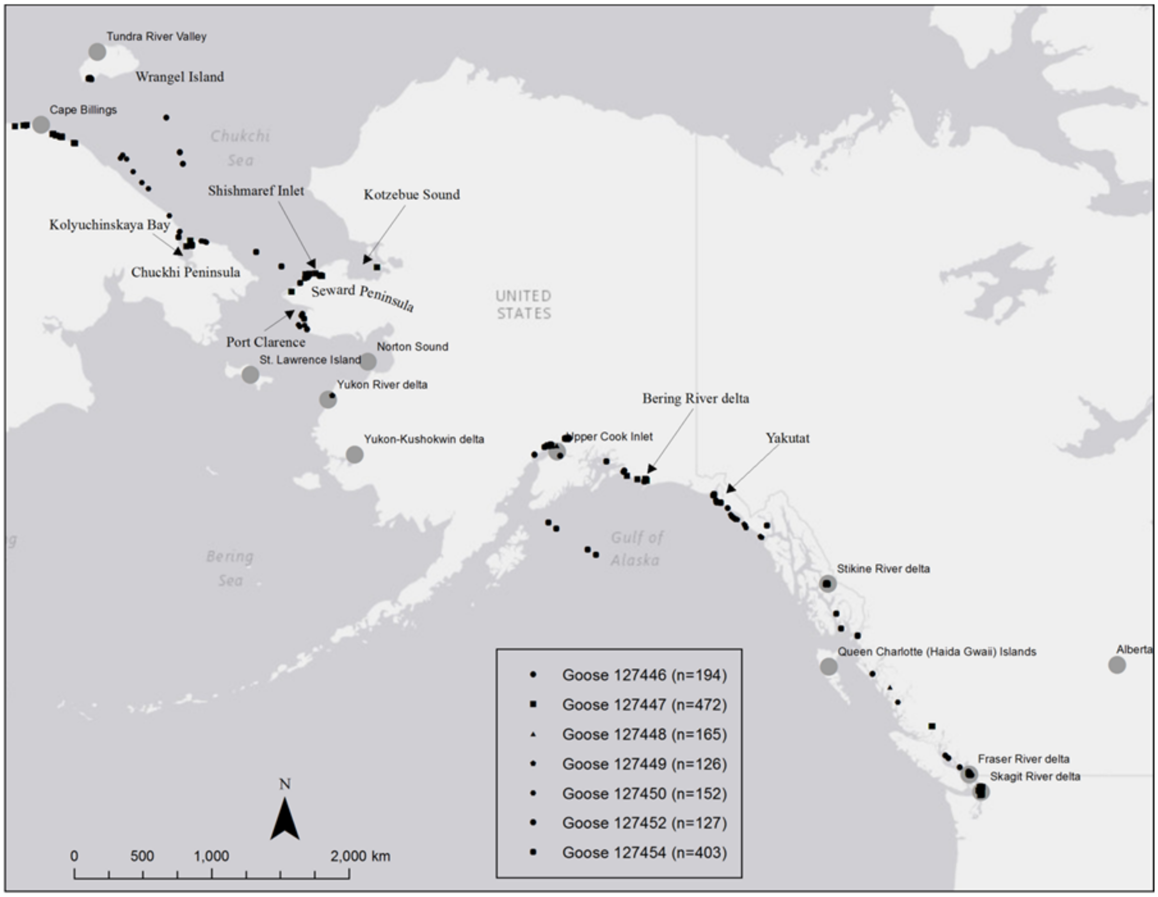

Figure 20. Stopovers and staging sites (black dots) of all lesser snow geese (*Chen caerulescens caerulescens*) tagged and released from the North Puget Sound population in the Skagit River delta region in Washington State, USA Geese were tracked from 26 February 2013 to 5 October 2014. Grey circles represent previously documented staging and stopover sites (Baranyuk and Takekawa 1998; Kerbes et al. 1999).

Figure 21. North Puget Sound wintering area of all 7 lesser snow geese (*Chen caerulescens caerulescens*) tagged and released from the North Puget Sound population in the Skagit River delta region in Washington State, USA Geese were tracked from 26 February 2013 to 5 October 2014.

Table 5. Locations of North Puget Sound stopover and staging sites by year and PTT tag number.

Region	Coordinates	Individuals by PPT tag number							Date	Staging	Stop-
		12746	12747	12748	12749	127450	127452	127454	(month/yy)	area	over
British Columbia, Canada											
Fraser River delta	123.134°W, 49.050°N	X							Oct-13	X	
Fraser River delta	123.206°W, 49.167°N					X			Oct-13		X
Fraser River delta	123.167°W, 49.087°N							X	Mar-14		X
Fraser River delta	123.167°W, 49.087°N							X	Sept-Oct-2013	X	
Fraser River delta	123.167°W, 49.087°N							X	Apr-14		X
Fraser River delta	123.134°W, 49.050°N			X					Apr-13	X	
Fraser River delta	123.151°W, 49.071°N						X		Apr-13		X
Klinaklini River delta	125.092°W, 51.092°N		X						Apr-14		X
Stikine River delta	132.463°W, 56.583°N			X					Apr-May-2013		X
Stikine River delta	132.463°W, 56.583°N				X				Apr-May-2013	X	
Stikine River delta	132.463°W, 56.583°N							X	Apr-13	X	
Alaska, U.S.A.											
Upper Cook Inlet	149.588°W, 61.483°N							X	Apr-14		X
Knik River delta	149.515°W, 61.48°N	X							Apr-May-2013		X
Knik River delta	149.444°W, 61.444°N			X					May-13		X
Serpentine River delta	165.553°W, 66.162°N		X						May-14		X
Arctic Lagoon	166.492°W, 66.138°N							X	May-14		X
Bering River delta	144.353°W, 60.125°N		X						Apr-14		X
Bering River delta	144.284°W, 60.167°N							X	May-13		X

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