HOME RANGE, HABITAT SELECTION, AND MIGRATORY PATHWAYS OF CANADA GEESE WINTERING AT THE SANTEE NATIONAL WILDLIFE REFUGE

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Wildlife and Fisheries Biology

---

by
Molly Marie Giles
December 2010

Accepted by:
Dr. Patrick Jodice, Committee Chair
Dr. Robert Baldwin
Dr. Patrick Gerard
Mr. John Stanton

ABSTRACT

Information on local and flyway-scale space use is lacking for the cohort of migrant geese (*Branta canadensis interior*) that winter in and adjacent to the Santee National Wildlife Refuge in Summerton, South Carolina. I examined home range and habitat selection of Canada geese in this region. I deployed transmitters on 17 geese (9 VHF and 8 PTT) on wintering grounds at Santee NWR during the winter of 2009-2010. Estimates of fixed kernel home range size ranged from 214.2 to 263.6 ha for VHF-marked geese and 1190.2 to 1915.6 ha for PTT-marked geese. Home ranges of all birds were compact and mainly contained within the Bluff Unit of Santee NWR, although geese did make occasional forays to private agricultural fields within ca. 3 km of the refuge. Habitat selection analyses of VHF-marked geese showed that birds selected for corn, millet, and moist soil habitat during the winter of 2009-2010. Selection of habitat by geese varied by time of day, as well as throughout the wintering period.

Geese departed Santee NWR between 5 and 7 March 2010 and arrived on the Atlantic Population (AP) breeding grounds on the eastern shore of the Hudson Bay by either 24 May 2010 or 9 June 2010 via two migration routes. Six PTT-marked geese followed an eastern route, stopping in northeastern North Carolina and western New York, with three of those birds completing a spring migration to AP breeding grounds. Geese following the eastern route had a mean distance between stopover sites of 417.3±76.0 km, and a mean total migration distance of 2837.9±345.6 km. Two geese followed a more western route, stopping in northeastern Ohio after departing Santee NWR. Bird F11 had a mean distance between stopover sites of 402.0 km and a total

migration distance of 4020.4 km, while bird F12 had a mean distance between stopover sites of 365.1 km and a total migration distance of 3650.5 km.

A better understanding of local wintering space use and habitat selection of geese will inform land management on refuge lands, and aid in the conservation and management of goose populations in South Carolina. Information on flyway-scale movements and migration stopovers used by geese is beneficial to the understanding of migratory habitats, and better informs the timing of sport harvest seasons of Atlantic flyway goose populations.

ACKNOWLEDGMENTS

I would first and foremost like to thank my advisor, Dr. Patrick Jodice, for giving me the opportunity to conduct research on the Santee National Wildlife Refuge. Moreover, I thank Dr. Jodice for his guidance and support throughout this project. I thank my committee members, Dr. Robert Baldwin, Dr. Patrick Gerard, and Mr. John Stanton for their expert advice and contributions to this project. I would also like to thank the South Carolina Department of Natural Resources and Santee National Wildlife Refuge for their funding and support. In particular, I would like to acknowledge Dean Harrigal, Marc Epstein, Haven Barnhill, and Buddy Baker.

I would like to acknowledge the USGS South Carolina Cooperative Fish and Wildlife Research Unit, in particular Carolyn Wakefield, who provided support in all forms. I would like to thank and acknowledge Santee National Wildlife Refuge staff and volunteers for their assistance with winter field work, and South Carolina Department of Natural Resources staff for their assistance with summer goose banding. I would also like to thank the Florida Fish and Wildlife Conservation Commission, Delta Waterfowl, SC Ducks, South Carolina Waterfowl Association, local hunters and landowners, and the many private contributors to this project. Last, but certainly not least, I would like to thank my father, mother, and all of my family and friends for their love, support, and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Waterfowl managers currently recognize 20 populations of 11 subspecies of Canada geese (*Branta canadensis*) in North America (Moser and Caswell 2004). Management of each Canada goose population is vital to the conservation of the species at large, as well as to the continuation of hunting traditions in the U.S. and Canada. In the Atlantic Flyway, four populations of Canada geese occur; the Atlantic Population (AP) and Southern James Bay Population (SJBP) are of the subspecies *Branta canadensis interior*, the North Atlantic Population (NAP) is of the subspecies *B. c. canadensis*, and the Atlantic Flyway Resident Population (AFRP) is of the subspecies *B.c. maxima* (Hindman et al. 2004).

During the 1960's, goose distributions in the Atlantic flyway shifted, with increased use of more northern wintering grounds and use of private farmland in the mid-Atlantic and Chesapeake states (Hankla and Rudolph 1967; Hestbeck and Malecki 1989; Hestbeck et al. 1991). The northward shift in wintering goose distributions was likely due to changes in agricultural land use, including an increase in the mean size of farms and the acreage in corn which subsequently lead to changes in goose food habits away from native wetland and upland plants to corn and other waste grains (Harvey et al. 1988; Maleki et al. 1988). The increased use of agricultural lands by geese does not imply that state and federal refuges have become unimportant to wintering survival. Although changes in agricultural land use have substantially coincided with shifts in wintering distribution, the establishment of state and federal refuges during the 1940's and 1950's has also influenced distributions by creating migratory and wintering habitats for geese in the Atlantic flyway (Hankla and Rudolf 1967). Although some populations of geese in the Atlantic flyway show less dependence on state and federal lands (Addy and Heyland 1968; Harvey 1987), there are some cohorts that rely heavily on refuges, especially those wintering in the southeastern United States (Orr et al. 1998; Combs et al. 2001).

One such cohort that relies heavily on refuge lands are the migrant geese that winter in the coastal plain region of South Carolina at the Santee National Wildlife Refuge. Geese from the Southern James Bay Population are historically associated with this refuge. During the 1960's, greater than 40,000 geese wintered at Santee NWR, however only 1,000 birds are estimated to winter at Santee NWR currently. The refuge continues to plant crops such as corn and winter wheat for wintering geese, and this area is currently closed to goose harvest, yet it appears that these measures have not halted the decline in wintering goose numbers.

Much like other Atlantic flyway goose populations, the distribution of SJBP geese has shifted to more northern states over the last several decades. Possible factors linked to this shift in distribution include changes in climate, changes in agricultural and urban land use throughout the flyway, the creation of public and private waterfowl refuges in northern states, increases in resident or temperate-nesting geese in the Atlantic flyway (Abraham et al. 2008), and the differential survival of southern cohort geese (Davies and Hindman 2008). Although SJBP geese are historically linked to Santee NWR, changes in the distribution of geese in the flyway, as well as wintering conditions during a given year, may result in other populations using the refuge during the winter. In addition to these flyway-scale issues, there has been recent interest in opening a portion of Clarendon County to allow for the harvest of resident geese. As in much of the Atlantic flyway, resident geese have become abundant. This is also the case in South Carolina, especially in Clarendon, Orangeburg, and Berkeley counties, where goose harvest is currently restricted. Little is known about the local space use patterns of migrant geese, and how the opening of a goose season may affect wintering populations of migratory geese.

I examined the wintering ecology of Canada geese (*Branta canadensis interior*) at the Santee National Wildlife Refuge during the winter of 2009-2010. I examined data from radio and satellite-marked geese at both the local and flyway scale. At the local scale I examined factors associated with space use and habitat selection, while at the flyway-scale I examined the spring migratory pathways and migration chronology of geese.

Chapter two of this thesis, "Home range and habitat selection of Canada geese in and adjacent to the Santee National Wildlife Refuge", examines home range size and use of habitat in and adjacent to Santee NWR. Within this chapter I also assessed habitat types available and habitats selected by geese throughout the wintering season, and suggested reasons for the selection of habitats. Chapter three of this thesis, "Spring migratory pathways and migration chronology of Canada geese wintering at the Santee National Wildlife Refuge", identifies migratory pathways used by PTT-marked geese after their departure from the wintering grounds. This chapter measures migration distances, identifies stopover and staging areas, and determines the timing of spring migration.

Determining home range size and extent, as well as measuring habitat use within the Bluff Unit study site is important to the understanding of how geese utilize public and private lands while on the wintering grounds. Migratory movements of geese wintering in South Carolina have not been previously studied through the use of satellite transmitters. Information gained by using these devices is valuable to waterfowl managers in that it will identify stopover and staging areas, determine the chronology of migration, and determine breeding ground affiliation of geese wintering in South Carolina.

REFERENCES CITED

Abraham, K.F., W.A. Phelps, and J.C. Davies. (Eds). 2008. A management plan for the Southern James Bay Population of Canada geese. Mississippi and Atlantic Flyway Council Technical Sections. 55pp.

Addy, C.E., and J.D. Heyland. 1968. Canada goose management in eastern Canada and the Atlantic flyway. Pages 10-23 in Hine, R.L., and C. Schoenfield (Eds). Canada goose management. Dembar Educ. Res. Serv. Madison, WI, USA.

Combs, D.L., K.L. Morgan, E.F. Bowers, and D.H. Orr. 2001. Migratory Canada goose population affiliation and interchange among four national wildlife refuges in Tennessee and Alabama. Proc. Annu. Conf. Southeastern Assoc. Fish and Wildlife Agencies. 55: 517-527.

Davies, J.C., and L. Hindman (Eds.). 2008. A management plan for the Atlantic population of Canada geese. Canada Goose Committee and Atlantic Flyway Technical Section. 52pp.

Hankla, D.J., and R.R, Rudolph. 1967. Changes in the migration habits of Canada geese in the lower portion of the Atlantic and Mississippi flyways – with special reference to national wildlife refuges. Proc. Annu. Conf. Southeast Assoc. Game and Fish Comm. 21: 133-144.

Harvey IV, W. F. 1987. Winter movements and resource use by Canada geese affiliated with Kent County, Maryland. M.S. Thesis, Cornell Univ., Ithaca, N.Y. 96pp.

Harvey IV, W.F., R. A. Malecki, and E. C. Soutiere. 1988. Habitat use by foraging Canada Geese in Kent County, Maryland. Trans. Northeast Sect. Wildl. Soc. 45:1-7.

Hestbeck, J.B., and R.A. Malecki. 1989. Estimated survival rates of Canada geese within the Atlantic flyway. The Journal of Wildlife Management. 53: 91-96.

Hestbeck, J.B., J.D. Nichols, and R.A. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. Ecology. 72: 523-533.

Hindman, L.J., K.M. Dickson, W.F. Harvey IV, and J.R. Serie. 2004. Atlantic flyway Canada geese: new perspectives in goose management. Pages 12-21 in Moser, T.J., R.D. Lien, K.C. VerCauteren, K.F. Abraham, D.E. Andersen, J.G. Bruggink, J.M. Coluccy, D.A. Graber, J.O. Leafloor, D.R. Luukkonen, and R.E. Trost (Eds.). Proc. Int. Canada Goose Symposium. Madison, WI, USA.

Malecki R.A., S.E. Sheaffer, J.W. Enck. 1988. Influence of agricultural land use changes on wintering Canada geese in the Atlantic flyway. Trans. Northeast Sect. Wildl. Soc. 45: 8-17.

Moser, T.J., and F.D. Caswell. 2004. Long-term indices of Canada goose status and management. Pages 123-129 in Moser, T.J., R.D. Lien, K.C. VerCauteren, K.F. Abraham, D.E. Andersen, J.G. Bruggink, J.M. Coluccy, D.A. Graber, J.O. Leafloor, D.R. Luukkonen, and R.E. Trost (Eds.). Proc. Int. Canada Goose Symposium. Madison, WI, USA.

Orr, D.H., E.F. Bowers, and O.J. Florschutz. 1998. Canada geese population trends, distributions, and management strategies in the southeastern United States. Pages 239-248 in Rusch, D.H. M.D. Samuel, D.D. Humburg, and B.D. Sullivan (Eds.). Biology and management of Canada geese. Proc. Int. Canada Goose Symposium. Milwaukee, WI, USA.

CHAPTER TWO

HOME RANGE AND HABITAT SELECTION OF MIGRANT CANADA GEESE IN AND ADJACENT TO THE SANTEE NATIONAL WILDLIFE REFUGE

INTRODUCTION

Migrant Canada geese (*Branta canadensis*) in the southeastern United States have historically been associated with public lands, most often national wildlife refuges (Orr et al. 1998, Combs et al. 2001). A series of national wildlife refuges occur throughout the southeastern U.S. and provide important stopover and wintering habitat for migratory geese. While these refuges were designed to function as a complex of protected lands for species such as migratory waterfowl, each is also managed individually to fit within the local-scale needs for wildlife. This often requires managers to consider state regulations with respect to harvest and local trends with respect to habitat loss or land development.

The Santee National Wildlife Refuge (NWR), located in the South Carolina coastal plain, is an important wintering area for migrant geese. During the 1960’s, wintering geese numbered over 40,000 annually at this refuge, but currently there are an estimated 1,000 geese using this area as a wintering grounds. This decline is due in part to northward shifts in goose distribution in the Atlantic Flyway during the last two decades (Abraham et al. 2008), and has also been linked to the differential survival of southern cohort geese (Davies and Hindman 2008). Although migrant geese have a long history at Santee NWR, there is little information on the home range and habitat use of these birds while on South Carolina wintering grounds. For example, migrant geese here exhibit strong wintering site fidelity to the refuge, specifically to the Bluff Unit, but have also been observed feeding and loafing on private agricultural lands adjacent to the refuge. However, the magnitude of use of these adjacent private lands is unknown and it appears that many of these lands are targeted for development. Therefore, information pertaining to home range and habitat use of these birds is needed in order to determine the degree of susceptibility to land use changes.

The conservation and management of goose populations in South Carolina has varied over the years with many changes to the harvest season length, no-harvest zones, and bag limits during the 1980's and 1990's. These changes resulted in the designation of a no-harvest zone that currently surrounds Clarendon County and parts of Orangeburg and Berkeley Counties (i.e., areas adjacent to Santee NWR). This zone was established to protect the declining numbers of wintering migrant geese in the area. Although this zone has provided a protected and undisturbed area for migrant geese, it has also protected resident geese, resulting in what appears to be an overabundance of birds in these counties. There has been recent interest in opening hunting in a portion of the current no-harvest zone to allow for the harvest of resident geese. However, information on the wintering space use and habitat selection of migrant geese is needed to assess the possible threats that birds may face if areas of the no-harvest zone are opened to goose hunting.

Due to the lack of spatial data pertaining to migrant geese wintering in South Carolina, the objectives of this chapter are to 1) determine home range size of wintering geese at Santee NWR, and determine if those home ranges include areas outside refuge boundaries, 2) determine the habitat selection of geese wintering at the Santee NWR, and

3) measure changes in home ranges and habitat selection throughout the wintering period. These data will be discussed in the context of current management issues within the state of South Carolina, particularly in relation to land use change at the local scale and hunting regulations within the state.

METHODS

Study Site

Santee National Wildlife Refuge is located in Clarendon County, approximately 12.5 km southwest of Summerton, South Carolina (Fig. 2.1). The refuge includes 5,082 ha of mixed hardwoods, mixed pine-hardwoods, pine plantations, marsh, croplands, old fields, ponds, impoundments, and open water (USFWS 2008; Barnhill, personal communication). The refuge is located on the shores of Lake Marion, a 45,000-ha reservoir created by the South Carolina Public Service Authority between 1939 and 1942 as a hydroelectric project on the Santee River. Shortly after the creation of Lake Marion in 1942, the USFWS recognized this area as highly beneficial to migratory birds, and established Santee NWR under the Migratory Bird Conservation Act and the Refuge Recreation Act (USFWS 2008). The refuge is the most significant inland area for migratory waterfowl in South Carolina (USFWS 2008), and is managed in part to support the last remaining migratory flock of SJBP geese in the southeastern Atlantic states. Migrant geese winter at Santee NWR from late November to early March. The refuge is also adjacent to private lands, predominantly agricultural fields planted with corn, wheat, and soybeans, as well as residential areas. There has been recent concern that some of these agricultural fields will experience residential development in the near future.

Research was conducted on the 862-ha Bluff Unit of Santee NWR (Fig. 2.2). A primary management goal of Santee NWR is to ensure wintering habitat for SJBP geese by supplying high-energy foods and green browse (USFWS 2008). Therefore, crops such as corn, winter wheat, and millet are planted annually on the Bluff Unit. During the winter of 2009-2010 there were approximately 22 ha of corn, 25 ha of winter wheat, and 16 ha of millet available to migrant geese in refuge agricultural fields and impoundments.

Field Procedures

Field work was conducted between November 2009 and March 2010. Geese were captured on the Bluff Unit of Santee NWR during December and January. I regularly set out and refreshed bait (corn) in agricultural fields within range of rocket nets which were camouflaged with vegetation and surrounded by decoys of Canada geese. I also used a digital game-caller (FoxPro, Lewistown, PA, USA) to attract flying flocks of geese to the trap area. Trapping occurred mainly in the early morning and evening, when geese foraged at the Bluff Unit. I measured the body mass (±100 g), culmen length (± 0.01 mm), tarsus length (± 0.01 mm), and wing cord (± 5 mm) for all captured geese. I used these measurements to distinguish subspecies (Bellrose 1980) and only fitted individuals deemed to be migratory *Branta canadensis interior* (Southern James Bay Population or Atlantic Population) or *B. c. canadensis* (North Atlantic Population) with radio transmitters. Resident geese (*B. c. maxima*) were not fitted with transmitters.

I fitted both after hatch year males and females with either a VHF or satellite (PTT) backpack-style transmitter. The transmitter was attached dorsally between the wings using a harness made of Teflon® ribbon (Bally Ribbon Mills, Bally, PA, USA). I attached VHF and PTT transmitters to both males and females; however females were favored for PTT deployment so only one male was fitted with a PTT. VHF transmitters (Telonics MOD-125, 53 grams) were set with a 10 hr on/14 hr off duty cycle which encompassed the hours between 0730 and 1730 (Telonics Inc., Mesa AZ, USA). Therefore, all analyses based on relocations of VHF-marked birds represent diurnal activities only. Satellite transmitters were either 45 grams (Microwave Telemetry Inc., Columbia, MD, USA) or 60 grams (TAV-2456 Telonics Inc., Mesa AZ, USA). Satellite transmitters were deployed with an initial three-day duty cycle from 30 September 2009 to 30 April 2010 in order to collect spatial information while birds were on the wintering grounds, as well as while birds were migrating north in spring. From 30 April 2010 to 30 September 2010 transmitters ran on a ten-day duty cycle in order to preserve battery life while birds were nesting on the breeding grounds. These three and ten-day duty cycles continue for the life of the transmitter.

Instrumented geese were fitted with a USGS aluminum leg band and a green leg band with white alphanumeric code (X01–X51), and were also dye-marked with a yellow stain on the cheek patch, undertail coverts, and flank. Dye-marking allowed for the resighting of geese during the wintering season, which was beneficial to assessment of home range and habitat use. The dye markings remained on the geese for the entire field season, however they faded as time progressed, and were nearly gone but still visible when birds departed from Santee NWR in March. Dye-marking was chosen over more conspicuous forms of marking, such as neck collaring, so that birds were less susceptible to harvest. Captured birds were held overnight (< 12 hours) to acclimate to transmitters. Geese were released at 0730 the morning after capture, at which time I checked the backpack again to make sure it was not impeding the bird's movement, and to reset the transmitter duty cycle. Trapping did not take place the morning of a goose release, but did resume later that evening. All trapping and handling procedures were approved by the Clemson University Institutional Animal Care and Use Committee.

VHF Telemetry Sampling Methods

I monitored instrumented geese until their spring departure from Santee NWR on either 6 or 7 March 2010 (see Results). I attempted to locate birds during three sampling periods each day: 0730-0900 (AM), 1200-1330 (Noon), and 1600-1730 (PM). Sampling periods were based on observations of goose movements to and from feeding and roost sites and were divided evenly throughout the available 10-hour duty cycle permitted by the VHF transmitter. Each bird was randomly assigned to one of the three temporal sampling periods each day. The first three birds were assigned to the AM sampling period, the next three to the Noon period, and the last three to the PM period, resulting in three groups of three birds. The three birds chosen for each sampling interval were referred to as the primary (1°) geese for that period, and were located first. If, after locating the primary birds, sufficient time remained in the sampling period I then attempted to locate all other birds. This sampling schedule resulted in 1-3 locations per sampling day for each bird by either visual observation or triangulation.

Most location data for transmittered birds was obtained through direct observations. The visual observation of each bird was obtained by first locating the target bird with the telemetry receiver, and obtaining an appropriate signal direction towards the flock. The flock was then scanned using binoculars or a spotting scope to resight any dye-marked birds. Locations of observed birds were recorded on printed maps of the Bluff Unit. These locations were later found on an orthophotograph of Santee NWR in ArcGIS 9.3 (ESRI, Redlands, California) to obtain approximate UTM coordinates. Data such as date, time, daily time period, flock size, weather information (i.e. temperature, wind speed and direction, barometric pressure, and cloud cover), as well as a description of the habitat type were also recorded when birds were sighted visually. When it was not possible to observe radio-marked geese, I triangulated on their location using a handheld telemetry receiver and three-element antenna. I obtained 3 bearings for each bird whenever possible. I attempted to obtain bearings within 15 minutes, although bearings obtained within 30 minutes were sometimes used to calculate estimated locations. Data such as date, time, daily time period, and weather information (i.e. temperature, wind speed and direction, barometric pressure, and cloud cover) were also recorded.

I entered triangulation data into Location of a Signal v.4.0.3.6 (LOAS; Ecological Software Solutions, Hegymagas, Hungary), a Windows-based program that calculates an estimated location from a group of bearings. Within LOAS, I used the Maximum

Likelihood Estimator (Lenth 1981a, Lenth 1981b) with default settings. All relocations obtained with 3 bearings and an error ellipse of ≤18 ha, the mean size of most habitat patches on the Bluff Unit of Santee NWR, were used in analyses. All locations obtained using 2 bearings were discarded, as well as those with error ellipses >18 ha. Mean error ellipse size was 4.1 ± 0.31ha.

Home Range Analyses Using Data from VHF Transmitters

Home range was calculated using the 100% minimum convex polygon method and the 95% fixed kernel estimator using Hawth's Tools (Beyer 2004) for ArcGIS 9.3. Core areas were calculated as 50% fixed kernel estimators. Kernel methods free the utilization distribution from parametric assumptions and provide a means of smoothing location data (Worton 1989). Kernel methods also have well understood consistent statistical properties and are widely used in both univariate and multivariate probability estimation (Worton 1989). I used Animal Space Use 1.3 (Horne and Garton 2009) to calculate both least squares cross validation (LSCV*h*) and likelihood cross-validation (CV*h*) smoothing parameters (*h*) for fixed kernel home ranges estimation. I selected CV*h* as the smoothing parameter because it generally produces home range estimates with better fit and less variability, and does not have a tendency to under smooth data as does LSCV*h* (Horne and Garton 2006). Likelihood cross-validation also performs better than LSCV*h* when using smaller sample sizes.

I obtained the mean CV*h* value for all nine transmittered geese, and then used this value to perform a sensitivity analysis of smoothing parameters and home range size. I used the mean CVh value calculated in Animal Space Use 1.3 (h = 185.162) as a starting point. Then I calculated 95% and 50% fixed kernel home ranges using smoothing parameter values between 50 and 225, each time increasing the value by 25. By varying the smoothing parameter I was able to compare home range models and determine which model best represented the spatial patterns of Canada geese. I repeated this process with fine scale smoothing parameter values ranging from 125 to 175, each time increasing the value by 5. A smoothing parameter value of 140 was ultimately chosen and used to calculate home ranges for individual geese.

Prior to analysis, I compared home ranges derived from all relocation data (1 to 3 locations per bird per day) with home ranges derived from only the primary location per bird per day. The mean 95% fixed kernel home range size did not differ (paired t-test; $t_8 = 2.3$, $P = 0.1$) when using multiple locations per day (233.8 ± 6.1) versus using only the primary location per day (250 ± 12.5). Multiple relocations per day were used in the subsequent estimation of goose home ranges. Since wintering geese utilized a relatively small area, the use of additional relocations within the localized area will help to better identify the space and habitats used.

I calculated the percentage of overlap in both 95% kernel home ranges and 50% core areas among all geese. I used ArcGIS 9.3 to overlay home ranges of geese and calculate the area (in hectares) of overlap between each pair of birds. Percentage of overlap was then calculated by dividing the area of overlap by the total area of the goose's home range or core area (Schrecengost et al. 2009).

I also assessed shifts in the home range area used throughout the wintering season. Location data were available for the time period of 22 December 2009 to 7 March 2010. This time period was broken into two-week intervals. Upon examination of the data, it was obvious that the number of points in early winter was not equal to the number of points in late winter. To account for the unequal samples sizes, I used a data set containing only the primary location per bird per day in order to perform this analysis. Therefore no data from late December were used, and period 1 included the dates between 3 January and 16 January, period 2 included dates between 17 January and 30 January, period 3 included dates between 31 January and 13 February, period 4 included dates between 14 February and 27 February, and period 5 included dates between 28 February and 6 or 7 March (when birds departed Santee NWR). Due to the high degree of overlap among individual goose home ranges (see Results) data for all nine geese were pooled for a population-level analysis of temporal home range shift. A new smoothing parameter value was chosen for this data set (h = 190) using the steps outlined above, and used to calculate home ranges. I then calculated percentage of overlap between time periods using the methods described above.

Habitat Selection Analyses Using Data from VHF Transmitters

After completion of home range analyses for both VHF and PTT-marked geese, it was evident that the birds wintering at Santee NWR were acting as a flock, and utilizing similar locations in and around the refuge (See Results). For this reason, relocation data from all geese were pooled for analysis of habitat selection. However, only relocations obtained through direct observations of geese were included in habitat use analyses as there was little opportunity for misclassification of habitat types associated with these locations. When observations of geese were obtained in the field, habitat type was recorded and this information was used to check the accuracy of the habitat type assignment to the relocations in the analysis. I used multiple relocations per bird per day in the subsequent estimation of goose habitat use.

The home range analyses also suggest that geese mainly utilize habitats on the refuge during daylight hours (the hours between 0730 and 1730), with very little use of private lands adjacent to the refuge (See Results). Therefore I defined the study area as the area within the Bluff Unit of the Santee NWR. I obtained spatial GIS data from Santee NWR (2010) which defined habitat types on the Bluff Unit. I then used Hawth's Tools (Beyer 2004) for ArcGIS 9.3 to determine the number of goose relocations within each habitat type within the study area.

Habitat selection ratios were calculated using an Excel-based resource selection calculator (Gerow 2007; available from www.statsalive.com). This analysis is based on the methods of Neu et al. (1974) and Byers et al. (1984). Results of tests using data where one or more habitat categories have low numbers of observations, usually five or less, may be suspect and may not be an accurate approximation of the sampling unit. Therefore resource selection was calculated with this tool using only the habitat types that contained ≥ 5 goose relocations. To determine habitat selection, a Pearson Chi-square statistic was calculated to test the null hypothesis of no selection, or that geese are utilizing habitats in proportion to their availability. The Pearson Chi-square and the loglikelihood Chi-square are both commonly used statistics to calculate habitat selection, however both tests have the same number of degrees of freedom and both have chi-squared distributions for large samples if the null hypothesis being tested is correct (Manly et al. 2002). Both statistics will also give similar results unless either the expected frequencies are very small, or the difference between the observed and expected frequencies is very large (Manly et al. 2002). Results of both chi-square tests were similar, and I chose to use the Pearson statistic, which had a larger p-value and therefore better guarded against false significance (Gerow 2007).

Once selection was demonstrated using the Chi-square test, I then used a selection ratio to determine which habitats were selected for by geese. The selection ratio is a measure of the proportion of habitat used in relation to the proportion of habitat available. If the ratio is greater than 1, then the habitat is selected for by geese in proportion to its availability. If the value is below 1 then the habitat was not selected for by geese in proportion to its availability, and if the value is equal to 1 then there is no selection by geese. I first calculated an overall analysis which contained all data from January 2010 to March 2010. Next I performed analyses using data from three daily sampling periods. These were the same periods used in home range analyses (AM, Noon, and PM). Lastly I conducted resource selection analyses using the same five two-week temporal periods used in the estimation of home range shifts (See above methods for definition of time periods), however temporal period 1 had a small sample size and was thus excluded from analyses. Within each of these tests, whether overall or the various tests based on temporal scales, I incorporated a Bonferroni- adjusted α value.

When performing multiple tests, such as the test on multiple habitat types in my analyses, the chance of incorrectly declaring significance (i.e. making a type I error) may be higher (Zar 1999). By using the Bonferroni correction, which divides an α of 0.05 by the number of habitat types used in the analysis, the chance of making a type I error is reduced.

Satellite Telemetry Sampling Methods

Satellite locations were obtained using the ARGOS data collection system (ARGOS 2008). ARGOS assigns a Location Class (LC) to each location, which is an estimate of accuracy. I used the criteria presented in Miller et al. (2005) to choose one location per bird per day to use in subsequent analyses. As in Miller et al. (2005) and Haukos et al. (2006) I favored Location Classes 3 (estimated error of <150 m), 2 (estimated error of 150 to 350 m), and 1 (350 to 1,000 m). If several locations with the same LC were available, I then favored the one with 1) the largest NOPC index (Number of Successful Plausibility Checks), and 2) the largest number of messages. If messages with the same LC, NOPC, and number of messages still remained, I then plotted the locations on an orthophotograph of Santee NWR in ArcGIS 9.3. If the plotted locations were within 1,000 m of each other (the highest possible error distance for LC's 3, 2, and 1) then I randomly chose one to represent that bird for that day. If the plotted locations were >1,000 m apart and also greater than one hour apart in time then it is possible that all locations could represent an area visited by the bird, so all locations were then used in analysis, although this rarely occurred (fewer than 10 times).

Home Ranges and Space Use of PTT-marked Canada Geese

Home range for PTT-marked birds was also calculated using the 95% and 50% fixed kernel estimator in Hawth's Tools (Beyer 2004). The smoothing parameter for home ranges was chosen using Animal Space Use 1.3 (Horne and Garton 2009) and a sensitivity analysis of home range maps. A smoothing parameter of 450 was chosen and used to calculate home ranges for all eight PTT-marked birds. Location data from PTTs was used to identify areas of use, particularly those areas not identified by VHF telemetry, and to assess refuge versus non refuge use.

Using the buffer tool in ArcGIS 9.3 I produced a map of the Santee NWR Bluff Unit with 1,000 m buffers outside and inside the refuge. I chose to use 1,000 m because this is the highest possible error distance for a location estimate with an LC of 3, 2, or 1. Given the error estimates and buffers, any location falling outside the outer 1,000 m buffer was considered off-refuge use, and any location falling inside the 1,000 m buffer was considered on-refuge use. Of those locations considered on-refuge, locations occurring between the refuge boundary and 1,000 m buffer were classified as possible refuge use, while those inside the boundary were classified as definite refuge use (Fig. 2.3). I then calculated the proportion of locations within each of these areas to assess the amount of use both on and off refuge.

RESULTS

A total of 38 trap days (205 trap hours) occurred between November 2009 and January 2010 on the Bluff Unit of Santee NWR, resulting in six geese captured on 15 December 2009, five captured on 18 December 2009, and seventeen captured on 11 January 2010. I deployed six satellite transmitters on 15 December 2009, three VHF and two satellite transmitters on 18 December 2009, and six VHF transmitters on 11 January 2010 (Table 2.1).

Home Ranges of VHF-marked Canada Geese

I obtained 924 relocations of radio-marked geese between January 2010 and March 2010 (Table 2.2). Of the 924 relocations, 81% were obtained through visual observations of geese and 19% through the use of triangulation (Table 2.3). The range of 100% MCP home ranges was 579.8 ha to 915.4 ha for all individuals (Table 2.4). Estimates of 95% fixed kernel home range size ranged from 214.2 ha to 263.6 ha for all individuals, with 50% core areas ranging in size from 46.0 ha to 55.5 ha (Table 2.4). Maps of fixed kernel and MCP home ranges for each individual appear in Appendix A. Mean size of 95% kernel home ranges was 231.8 ha for males and 235.3 ha for females (Table 2.4). Mean size of the 50% core use area was 49.4 ha for males and 51.1 ha for females. There was no significant difference in either the 95% kernel home ranges (unpaired t-test; $t_7 = 2.4$, $P = 0.8$) or 50% core areas (unpaired t-test; $t_7 = 2.4$, $P = 0.5$) between males and females.

Home range overlap between individual VHF-marked geese was high (Table 2.5). Within the 95% kernel home ranges, mean overlap between geese was 88 ± 1%, with a minimum overlap of 74% and a maximum overlap of 97%. Within the core areas, mean overlap between geese was 84 ± 1%, with a minimum overlap of 72% and a maximum overlap of 94%. Of the 641 visual observations of VHF-marked Canada geese where flock size was noted in the data, 82% occurred in a flock that contained at least 400 geese (Figure 2.4).

I examined the percentage of home range overlap for VHF-marked Canada geese among two-week time intervals (Table 2.6). Home range maps for geese during these time periods are presented in Appendix B. The mean overlap between time periods for 95% kernel home ranges was 57 ± 2%, with a minimum overlap of 40% and a maximum overlap of 76% (Figure 2.5). Within the core areas, mean overlap between time periods was 32 ± 5%, with a minimum overlap of 2%, and a maximum overlap of 81%. Temporal overlap between 95% kernel home ranges was rather consistent, whereas temporal overlap between 50% core areas was not (Fig. 2.5). The degree of overlap between consecutive and non-consecutive temporal periods within the 95% kernel home ranges remained consistent throughout the winter, with a mean overlap of about 50% (Table 2.7). However, the degree of overlap between consecutive and non-consecutive temporal time periods within 50% core use areas did not remain constant throughout the winter, ranging from 38% to 2% (Table 2.7). Temporal periods separated by 1 or 2 lag periods overlapped more than those separated by 3 or 4 lag periods, therefore core use areas in early winter were different that those in late winter.

Habitat Selection of VHF-marked Canada Geese

I obtained 716 visual relocations of radio-marked geese between January 2010 and March 2010. Goose relocations were overlaid onto a habitat map of the Santee NWR Bluff Unit in ArcGIS 9.3. The map contained twenty different habitat classifications totaling 862.8 ha (Table 2.8). When data were pooled among all individuals and time periods, geese selected for corn, millet, and moist soil areas on the Bluff Unit during the winter of 2009-2010 (Table 2.9). I then examined habitat selection during three daily time periods; AM (0730-0900), Noon (1200-1330), and PM (1600-1730). During the AM and noon periods, geese selected for corn and moist soil habitats (Table 2.10). During the PM period, geese selected for corn and millet habitat types (Table 2.10). I also determined the habitat selection during five two-week periods during the winter of 2009-2010. Temporal period 1 was not used in analyses due to small sample size. During temporal periods 2 and 4, geese selected only for corn (Table 2.11). During period 3, geese selected for corn and moist soil habitats. During period 5, geese selected for corn, millet, and moist soil areas.

PTT-marked Canada Geese

I obtained 217 relocations of satellite-marked geese between December 2009 and March 2010 (Table 2.12). Estimates of 95% fixed kernel home range size ranged from 1190.2 ha to 1915.6 ha, with core areas ranging in size from 264.3 ha to 515.2 ha (Table 2.13). Maps of fixed kernel home ranges for each individual PTT-marked goose are presented in Appendix C. Location data and 1,000 m buffers were used to assess and identify use of both refuge and non-refuge areas by Canada geese. Of the 217 locations obtained for all eight PTT-marked geese, no more than 34% were found to definitely occur off- refuge (Table 2.14). Of those locations occurring off-refuge, nearly 84% occurred within 2 km of the refuge boundary, with some locations ranging up to 8 km from the refuge. Of those locations found to occur on-refuge, 58% were possibly on-refuge, and 7% were definitely on-refuge.

DISCUSSION

Diurnal space use of wintering Canada geese on Santee NWR was compact and usually contained within the refuge boundary. There was a high degree of overlap in home ranges among individuals, and marked birds were commonly found together in a flock of 400 to 600. Home ranges of the nine VHF-marked birds were all similar in size and space use, with birds concentrated on refuge property including Cantey Bay, refuge fields, and refuge impoundments that were planted with agricultural crops. Each VHF-marked goose also made what appeared to be foraging flights to private agricultural fields about 3 km from the refuge boundary which were planted in either mowed corn/winter wheat or mowed soybean. However, out of a total of 924 relocations of VHF-marked geese, only thirty were on private lands. During the previous winter (2008-2009) geese were observed foraging in these private agricultural fields, however this may have been due to drought conditions during the summer of 2008 which caused a complete failure of the Bluff Until corn crop. Birds may have been utilizing private fields more often during winter 2008-2009 to supplement the lack of food resources on the refuge.

Geese marked with satellite transmitters showed similar patterns of use to those marked with VHF transmitters, with home ranges centered mainly within the refuge boundary. However, home ranges of PTT-marked geese were more extensive compared to those of VHF-marked geese. Most PTT relocations (i.e. 66%) occurred within the refuge boundary. Of those relocations occurring outside the refuge boundary, 84% occurred within 2 km of the refuge. The duty cycle of the satellite transmitters may be one factor linked to the more extensive home ranges associated with these tracking devices. Data from satellite transmitters was usually obtained between ca. 2200 hours and ca. 1200 hours the following day, and this time period only partially overlaps with that of the VHF transmitters which are functioning between 0730 and 1730. During the late night and early morning hours not accounted for by VHF transmitters, it is likely that geese are roosting, and may be roosting in areas not used during the day. This may account for relocations occurring in portions of Lake Marion rather than in the typical roosting area of Cantey Bay and would also expand the size of the home range.

Conversely, there are satellite relocations that occur within the same diurnal time period of the VHF duty cycle, and appear in areas not accounted for in the VHF data. These relocations may be the result of the error associated with this type of satellite transmitter. There is little error associated with relocations of VHF-marked birds that were visually observed, and there is a mean error ellipse of 4.0 ha associated with VHF-marked birds that were located using the triangulation method. However, out of 217 relocations of PTT-marked birds, only 15% were ranked as Location Class 3 (estimated error of <150 m), 49% were ranked as Location Class 2 (estimated error of 150-350 m), and 36% were ranked as Location Class 1 (estimated error of 350-1,000 m). The error associated with each Location Class may account for some of the difference in size between VHF and satellite-derived home ranges. For example, if an estimated relocation had an LC of 1, the true location of the bird may be nearly 1,000 m away, thus overestimating the bird's true home range size. The objective of using PTTs in my research was mainly to determine if space use of wintering geese occurred in close proximity to Santee NWR or if geese utilized habitats in other portions of Clarendon, Orangeburg, and Berkeley Counties. Despite the difference in home range size obtained using the two telemetry methods, it is clear that all marked birds are primarily utilizing refuge lands during the winter.

In contrast to most other North American populations, Canada geese in the Atlantic flyway have less dependence on public lands during the winter (Addy and Heyland 1968). However, many populations in the southeastern United States have shown high site fidelity to public lands (Orr et al. 1998; Combs et al. 2001). Canada geese in my study show strong dependence on public lands during the winter and this may have contributed to relatively compact home ranges. By contrast, home range size of Canada geese wintering on private lands in Kent County, Maryland averaged 76.9 km^2 and 225.3 km^2 during two consecutive years (Harvey 1987). Greater snow geese (*Chen caerulescens atlantica*) wintering on public and private lands near Bombay Hook National Wildlife Refuge in Delaware had mean movement distances between roost sites and feeding sites of 1.3 to 20.7 km during the winter of 1990-1991 (Hill and Frederick 1997). Migratory geese in Maryland and Delaware changed roosting and feeding sites throughout the winter, and thus traveled farther distances, resulting in larger home ranges than those maintained by birds at Santee NWR. Geese at Santee used mainly two roosting sites on the refuge (Cantey Bay and the south pond impoundment) and neither area was impacted by ice cover like some roost sites in Maryland. Wintering grounds in South Carolina also differ from those in Maryland and Delaware in that much of the area surrounding Santee NWR is closed to goose harvest, which greatly reduces disturbance and movement of geese. Additionally, food resources do not appear limited for birds wintering at Santee NWR, and daily requirements can be met without making long feeding flights.

Core use areas within goose home ranges are useful in identifying the primary habitats and food resources utilized at Santee NWR. Core use areas of geese are associated with Cantey Bay, refuge fields, and refuge impoundments that were planted with agricultural crops. There was a high degree of overlap between home ranges and core areas among all nine VHF-marked geese. There was also consistent overlap of 95% kernel home ranges among the two-week sampling periods. However, overlap between core use areas throughout the winter varied, suggesting that there is a difference in the core habitat used during the early winter and late winter periods. Analyses of the habitat types underlying these cores areas were useful in determining the wintering needs of Canada geese.

Geese selected for corn, millet, and moist soil habitat types in greater proportion compared to their availability. Conversely, wheat is also available in similar proportions to that of corn, millet, and moist soil, but it was not selected for by geese. Open water, which comprised approximately 85% of the habitat that was available for analysis of use, was used less frequently than predicted based on its availability (approximately 50% of locations occurred there). Open water was used primarily as roosting habitat, and use of open water habitat was primarily restricted to sheltered areas of Cantey Bay.

At Santee NWR, geese used corn fields in greater proportion to their availability throughout the entire winter, and use was substantial throughout all daily and bi-weekly time periods, suggesting that this habitat type is highly valuable to wintering geese. Similarly, corn was found to be a staple in the wintering diets of Giant Canada geese (*B. c. maxima*) in Minnesota (McLandress and Raveling 1981), Mississippi Valley Population (MVP) Canada geese in Wisconsin (Craven and Hunt 1984), and Canada geese in Kent County, Maryland (Harvey 1987).

Geese, more so than other species of waterfowl, have adapted their foraging behavior to the availability of cereal grains (Baldassarre and Bolen 2006). As with other cereal grains, corn is a source of high energy carbohydrates (McLandress and Raveling 1981) that is readily available to migratory geese on both public and private lands. Cereal grains are rich in carbohydrates, and are beneficial to geese in the fall to form lipid reserves for migration, and in winter to maintain homeostasis (Baldassarre and Bolen 2006). Crops planted at Santee NWR, such as corn and millet, provide geese with the fat-building carbohydrates needed during the wintering season, which may account for the selection of these two habitat areas. However, diets composed solely of agricultural grains are nutritionally incomplete (McLandress and Raveling 1981; Fredrickson and Taylor 1982; Baldassarre and Bolen 1984) and carbohydrates may not be fully assimilated by waterfowl with a diet restricted to corn (McLandress and Raveling 1981). Green browse such as winter wheat and native wetland plants can provide geese with protein and essential amino acids needed for maintenance of body condition. Protein-rich foods also provide birds with valuable endogenous reserves that may be used during spring migration and egg formation on the breeding grounds. Although wheat was not selected for by geese in my study, protein-rich foods may have been obtained by feeding in moist soil areas, which may account for the selection of this habitat type. Studies on the use of moist soil foods by Canada geese have shown that combinations of moist soil seeds and agricultural crops are often needed to meet protein and essential amino acid requirements (Austin 1988; Buckley 1989; Austin et al. 1998).

Crops such as corn and millet, as well as moist soil areas were utilized by geese at Santee NWR, and temporal habitat selection analyses of these habitats further explain their significance for wintering birds. Corn was selected for in all three daily time periods, however selection was highest during the AM period. Corn fields were commonly utilized by geese as a morning feeding area, and birds sometimes stayed in fields foraging and loafing into the afternoon. Geese usually went to a roost site in the afternoon, and then made feeding flights back to the corn field in the evening. In late winter, geese were observed feeding in corn fields all day, unless flushed by refuge activities or predators, and selection of corn fields was higher during temporal periods 4 (14 February to 27 February) and 5 (28 February and 6 or 7 March). Geese may have been spending more of the day in corn fields during late winter to acquire the resources needed for migration.

Millet was significantly selected for during the PM period. The area planted in millet (mainly the south pond impoundment) was used throughout the wintering season as a roosting and feeding site. However, according to the habitat selection analysis, it was only used during the PM period and during temporal period 5 (28 February to 6 or 7 March). Birds were often seen moving from this area to feeding locations in the morning, however the VHF transmitters were usually still off at this time, and birds were not detected until about ten to fifteen minutes later when they had already moved to a different location. This may account for a lack of detection of birds in millet during the AM period and Noon periods. The Bluff Unit and Cantey Bay are closed to the public during the winter to reduce disturbance to ducks and geese, however on 1 March these areas are reopened, so period 5 is the only temporal period during which the Bluff Unit is open to the public.

During this late winter period there is a change in the distribution of goose relocations within the study site. The proportion of use in Cantey Bay (i.e. open water) decreases significantly after 1 March due apparently to disturbance from fishermen and boat traffic. Geese were often flushed from Cantey Bay in the morning and moved to alternate roosting areas on the western side of the Bluff Unit in Lake Marion, presumably to areas near Persanti Island. In the evenings, geese would fly from the lake to an evening roost in the south pond (planted in millet), which would account for the high use of the area in the PM period. Additionally, when birds moved to areas on Lake Marion, they were not detectable through visual observation, and were rarely detectable even through triangulation, so I was only able to detect them as they flew into the evening roost during the last few moments of the transmitter duty cycle period.

Moist soil areas, which are seasonally flooded to promote the growth of wetland plants, were also selected for by geese at Santee NWR. Resource selection analyses show a greater selection of moist soil habitats in the AM period, as well as during temporal periods 3 (31 January to 13 February) and 5 (28 February and 6 or 7 March). One of the large moist soil areas on the Bluff Unit is adjacent to the main cornfield used by migrant geese. Birds often stayed in this area all day, moving between corn stubble and flooded areas. The area was often used as both a feeding and loafing site throughout the day, and use of the area appeared to increase in later winter. During time period 5, the resource selection ratio for moist soil was higher than that of corn, although both were significant. The ratios for both habitats were likely significant due to the overlapping of these two habitats when water levels in the banding pond increased and corn fields flooded.

Late winter (i.e. period 5) is dramatically different than the other four periods. In late winter the proportion of locations becomes more evenly distributed among habitats. The selection ratio for millet is higher than that of corn for this time period. As stated earlier, this is likely due to disturbance caused by the 1 March opening of the Bluff Unit and Cantey Bay. However, in late winter and early spring, Canada geese are known to diversify their diets, and consume greater amounts of protein-rich green browse to accumulate the body reserves needed for reproduction (McLandress and Raveling 1981). Many studies show that geese change feeding habits before migration (McLandress and

Raveling 1981, Austin 1988, Hill and Frederick 1997). Although my results demonstrate a change in the selection of habitats just before migration, it is unclear if this change was due to disturbance factors or if birds were preparing for migratory flight.

The energy needs of Canada geese wintering at Santee NWR were addressed by Stanton (2010, personal communication) using energy estimates of Canada goose foods (Petrie et al. 1998) and daily energy requirements of SJBP geese (based on Prince 1979). It was determined that an average adult SJBP goose (*B.c. interior*) on Santee NWR wintering grounds would require 950 kcal/day. A flock of 1,000 geese spending 110 days on the wintering grounds would require 104,500,000 kcal during the wintering period. Therefore geese require approximately 8 hectares of corn throughout the winter. During the winter of 2009-2010, there were 22 ha of corn planted on the Bluff Unit; which suggests that there is more than enough to support a flock of 400 to 600 geese. These data suggest that food resources were likely not limiting for geese during the study period. Waterfowl management, in the form of planting agricultural crops and manipulating water levels in refuge impoundments, is clearly effective in supporting the wintering population of Canada geese.

Management Implications

Radio and satellite telemetry show that wintering Canada geese at Santee NWR had small home ranges and exhibited localized space use patterns compared to wintering geese in other studies. Migratory geese had a strong wintering site affinity to the refuge which provides feeding, loafing, and roosting habitat that is generally free of disturbance.

Wintering geese relied heavily on agricultural fields on the refuge during the winter of 2009-2010, however observations of geese in 2008-2009 suggest that birds may utilize private agricultural fields in years when food resources are scarce on the refuge. Therefore, in years when crops such as corn are not abundant on the Bluff Unit, the matrix of agricultural lands adjacent to the refuge may become more important.

Precaution should be taken when considering the results of this study, as it occurred during only one wintering period, and most results were based on data collected between the hours of 0730 and 1730 (i.e., when transmitters were duty-cycled on). Although the information gained from diurnal data was valuable, it may not include important morning roost information and evening feeding and roosting information, especially during late winter when day length changed. The goal of this local-scale home range and habitat selection chapter was to document the home range area traversed by these geese during the non-breeding season, and identify any off-refuge use by wintering Canada geese. During the winter of 2009-2010, when food resources appeared to be abundant in refuge agricultural fields, my study shows minimal utilization of private lands. However these areas should be considered if changes are made to the harvest regulations in Clarendon, Orangeburg, and Berkeley Counties.

REFERENCES CITED

Abraham, K.F., W.A. Phelps, and J.C. Davies. (Eds). 2008. A management plan for the Southern James Bay Population of Canada geese. Mississippi and Atlantic Flyway Council Technical Sections. 55pp.

Addy, C.E., and J.D. Heyland. 1968. Canada goose management in eastern Canada and the Atlantic flyway. Pages 10-23 in Hine, R.L., and C. Schoenfield (Eds). Canada goose management. Dembar Educ. Res. Serv. Madison, WI, USA.

Argos Inc. 2008. User's manual. Landover, Maryland, USA. Retrieved from http://www.argos-system.org/manual.

Austin, J.E. 1988. Wintering ecology of Canada geese in northcentral Missouri. Ph.D. Dissertation. University of Missouri, Columbia. 285pp.

Austin J.E., D.L. Humburg, and L.H. Fredrickson. 1998. Habitat management for migrating and wintering Canada geese: a moist-soil alternative. Pages 291-297 in Rusch, D.H, M.D. Samuel, D.D. Humburg, and B.D. Sullivan (Eds.). Biology and management of Canada geese. Proc. Int. Canada Goose Symposium. Milwaukee, WI, USA.

Baldassarre, G.A., and E.G. Bolen. 1984. Field-feeding ecology of waterfowl wintering on the southern high plains of Texas. The Journal of Wildlife Management. 48: 63-71.

Baldassarre, G.A., and E.G. Bolen. 2006. Waterfowl ecology and management. Second edition. Krieger Publishing Company, Malabar, Florida, USA.

Bellrose, F.C. 1980. Ducks, geese and swans of North America. Third edition. Stackpole Books, Harrisburg, PA, USA.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Retrieved from http://www.spatialecology.com/htools.

Buckley, C.E. 1989. The nutritional quality of selected rowcrop and moist-soil seeds for Canada geese. M.S. Thesis. University of Missouri, Columbia. 69pp.

Byers, C.R., R.K. Steinhorst, and P.R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. The Journal of Wildlife Management. 48: 1050-1053.

Combs, D.L., K.L. Morgan, E.F. Bowers, and D.H. Orr. 2001. Migratory Canada goose population affiliation and interchange among four national wildlife refuges in Tennessee and Alabama. Proc. Annu. Conf. Southeastern Assoc. Fish and Wildlife Agencies. 55: 517-527.

Craven, S.R., and R.A. Hunt. 1984. Fall food habits of Canada geese in Wisconsin. The Journal of Wildlife Management. 48: 169-173.

Davies, J.C., and L. Hindman (Eds.). 2008. A management plan for the Atlantic population of Canada geese. Canada Goose Committee and Atlantic Flyway Technical Section. 52pp.

Ecological Software Solutions LLC. 2004. Location of a signal version 4.0. Hegymagas, Hungary. Retrieved from http://www.ecostats.com/software/loas/loas.htm.

Fredrickson, L.H, and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Dept. Int., Fish and Wildlife Service. Resource Publication 148. 29pp.

Gerow, K. 2007. Stats Alive. Retrieved from http://www.statsalive.com/.

Harvey IV, W. F. 1987. Winter movements and resource use by Canada geese affiliated with Kent County, Maryland. M.S. Thesis, Cornell Univ., Ithaca, N.Y. 96pp.

Haukos, D.A., M.R. Miller, D.L. Orthmeyer, J.Y. Takekawa, J.P. Fleskes, M.L. Casazza, W.M. Perry, and J.A. Moon. 2006. Spring migration of northern pintails from Texas and New Mexico, USA. Waterbirds. 29: 127-136.

Hill, M.R.J., and R.B. Frederick. 1997. Winter movements and habitat use by greater snow geese. Journal of Wildlife Management. 61: 1213-1221.

Horne, J.S., and E.O. Garton. 2006. Likelihood cross-validation versus least squares cross-validation for choosing the smoothing parameter in kernel home-range analysis. Journal of Wildlife Management. 70: 641-648.

Horne, J.S., and E.O. Garton. 2009. Animal Space Use 1.3. Retrieved from http://www.cnr.uidaho.edu/population_ecology/animal_space_use.htm.

Lenth, R.V. 1981a. Robust measures of location for directional data. Technometrics. 23: 77-81.

Lenth, R.V. 1981b. On finding the source of a signal. Technometrics. 23: 149-154.

Manly, B.F. J., L.L. McDonald, D. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwer Academic Publishers, Dordrecht, The Netherlands.

McLandress, M.R., and D.G. Raveling. 1981. Changes in diet and body composition of Canada geese before spring migration. The Auk. 98: 65-79.

Miller, M.R., J.Y. Takekawa, J.P. Fleskes, D.L. Orthmeyer, M.L. Casazza, and W.M. Perry. 2005. Spring migration of northern pintails from California's central valley wintering area tracked with satellite telemetry: routes, timing, and destinations. Canadian Journal of Zoology. 83: 1314-1332.

Neu, C.W., C.R. Byers, and J.M.Peek. 1974. A technique for analysis of utilization-availability data. The Journal of Wildlife Management. 38: 541-545.

Orr, D.H., E.F. Bowers, and O.J. Florschutz. 1998. Canada geese population trends, distributions, and management strategies in the southeastern United States. Pages 239-248 in Rusch, D.H. M.D. Samuel, D.D. Humburg, and B.D. Sullivan (Eds.). Biology and management of Canada geese. Proc. Int. Canada Goose Symposium. Milwaukee, WI, USA.

Petrie, M.J., R.D. Drobney, and D.A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. The Journal of Wildlife Management. 62: 1147-1152.

Prince, H.H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 103-117 in Bookout, T.A (Ed.). Waterfowland wetlands – an integrated review. Northcentral Sect. Wildl. Soc. Madison, WI, USA.

Santee National Wildlife Refuge. 2010. Santee National Wildlife Refuge Bluff Unit habitat types. Obtained from Haven Barnhill.

Schrecengost, J.D., J.C. Kilgo, H.S. Ray, and K.V. Miller. 2009. Home range, habitat use and survival of coyotes in western South Carolina. American Midland Naturalist. 162: 346-355.

U.S. Fish and Wildlife Service. 2008. Santee National Wildlife Refuge comprehensive conservation plan. Atlanta, Georgia, U.S. Department of the Interior, Fish and Wildlife Service. 216 pp.

Worton, B.J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology. 70: 164-168.

Zar, J.H. 1999. Biostatistical analysis. Fourth edition. Prentice Hall, Upper Saddle River, NJ, USA.

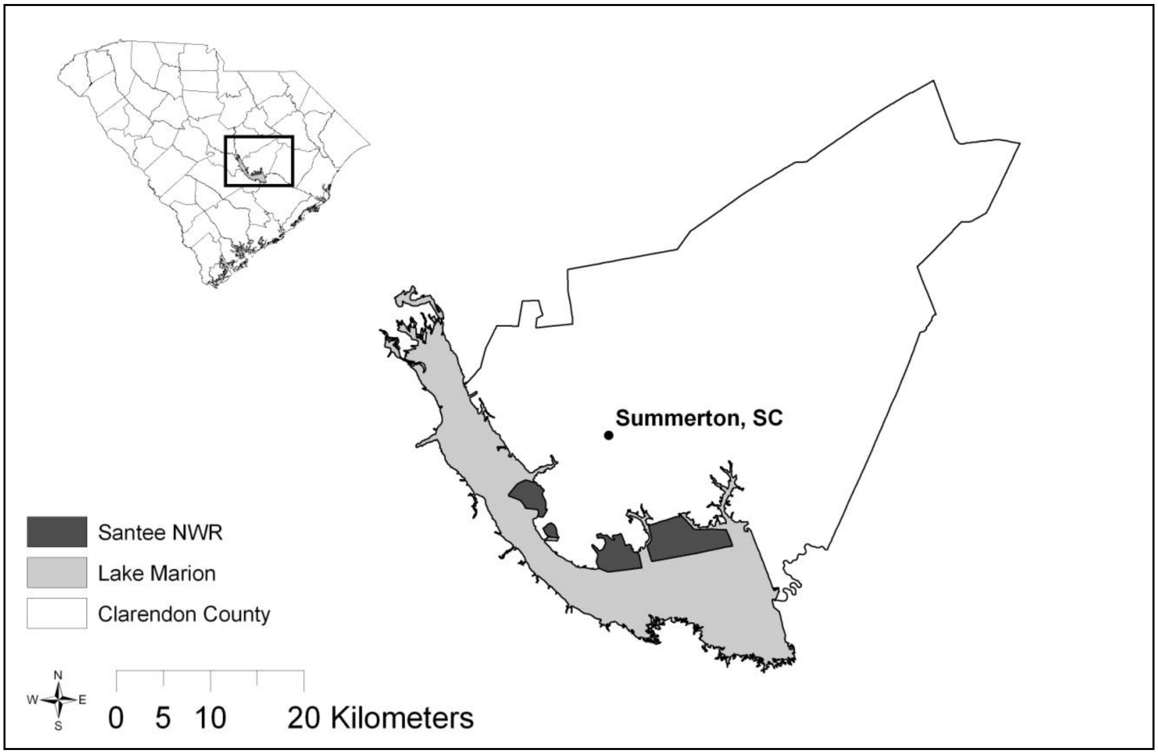


Figure 2.1. Location of Santee National Wildlife Refuge, Clarendon County, South Carolina.

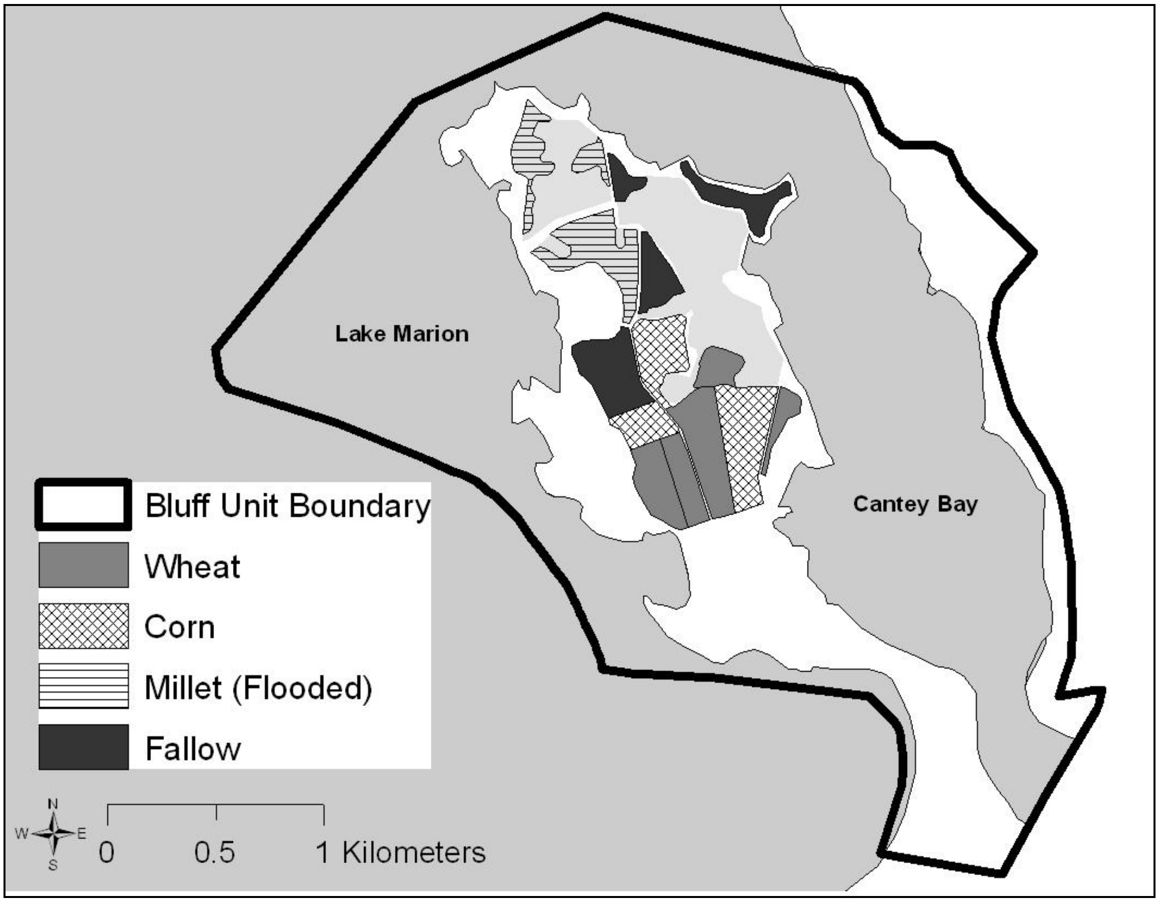


Figure 2.2. Agricultural fields on the Bluff Unit of Santee National Wildlife Refuge, Summerton, South Carolina.

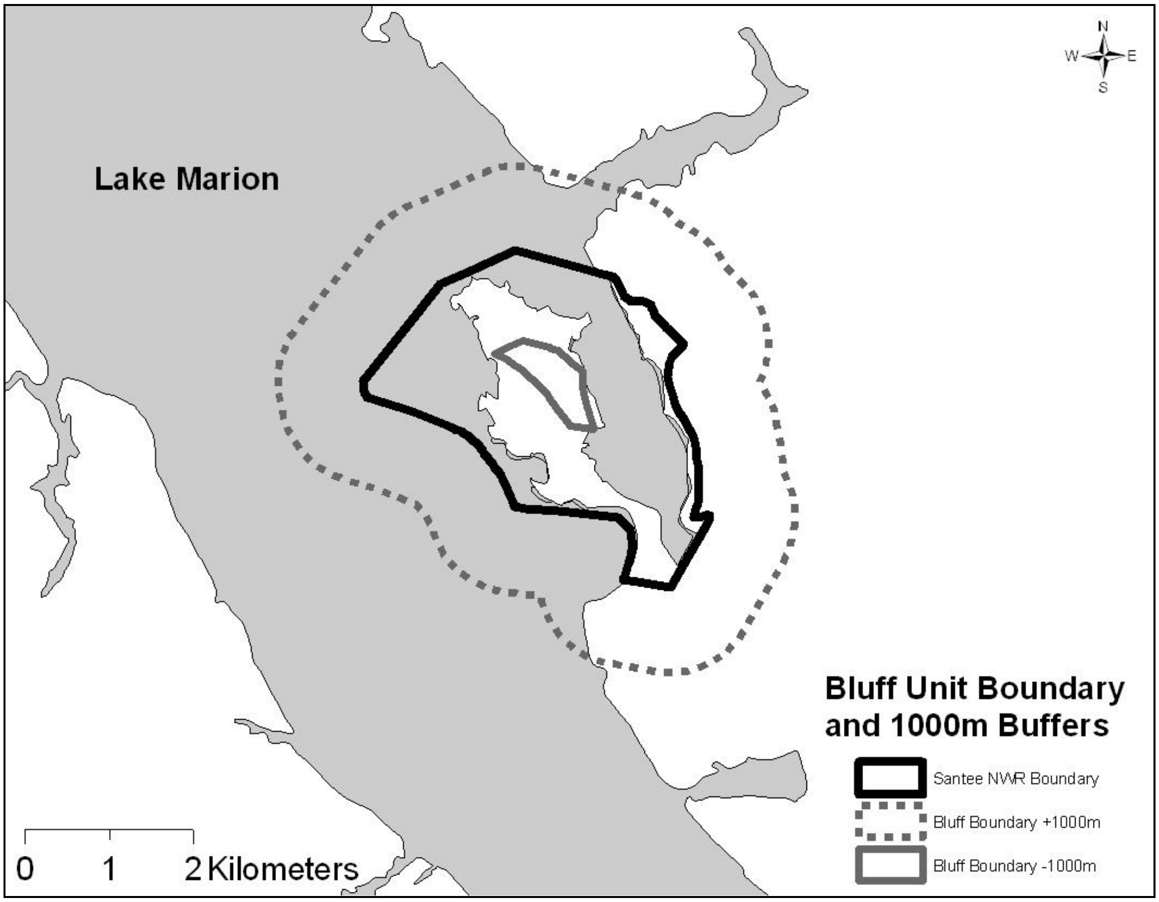


Figure 2.3. Buffers (1,000 m inner and outer) around the Santee National Wildlife Refuge, Summerton, South Carolina.

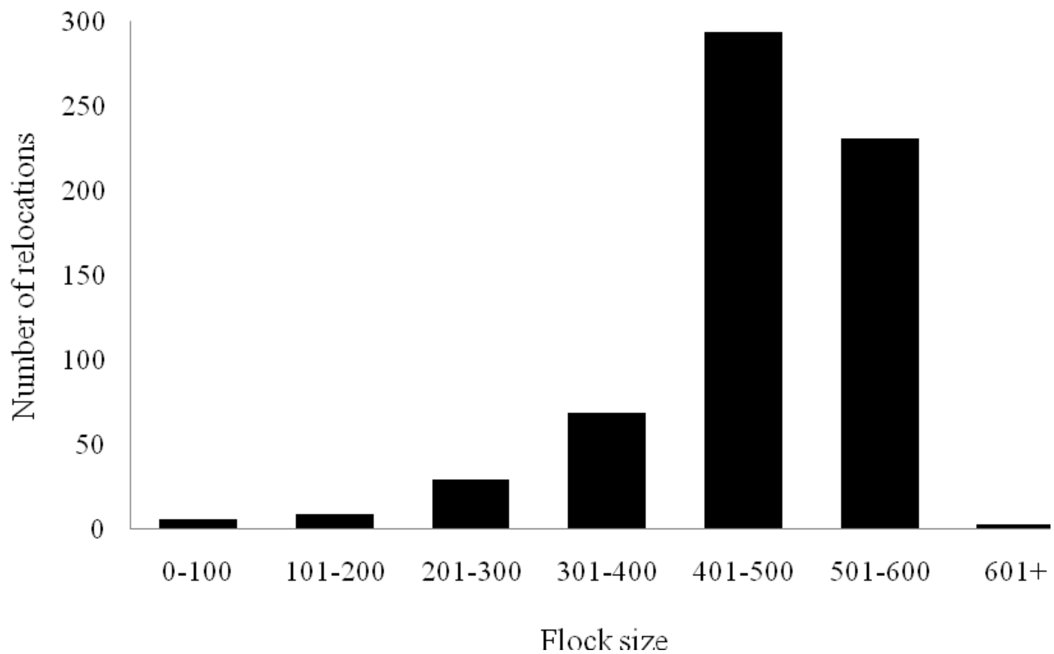
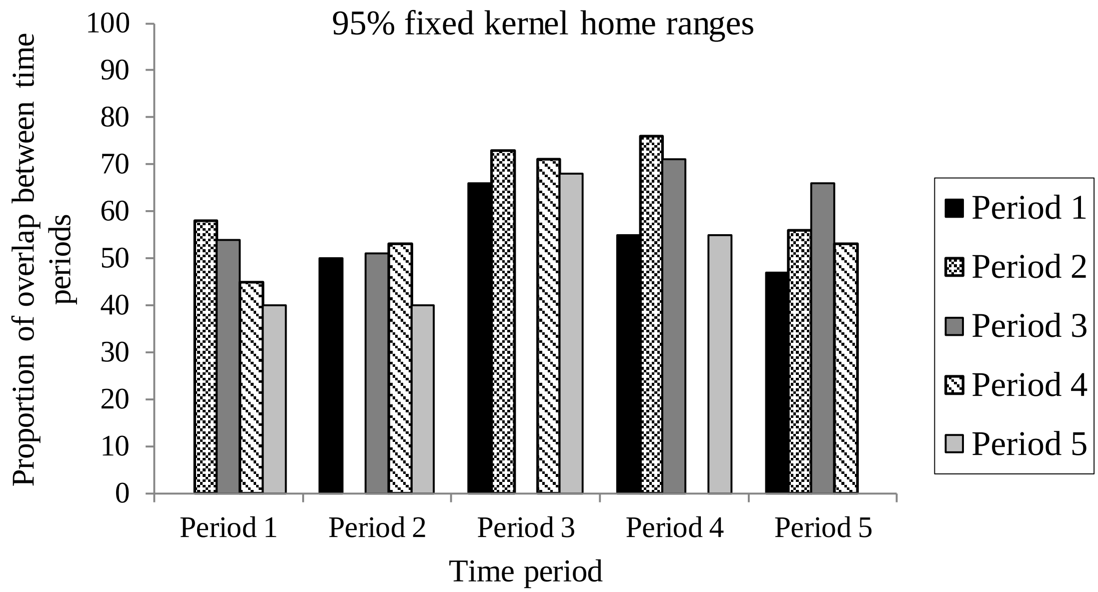


Figure 2.4. Size estimates of flocks of Canada geese that contained VHF-marked birds at Santee National Wildlife Refuge, Summerton, South Carolina, December 2009 – March 2010.



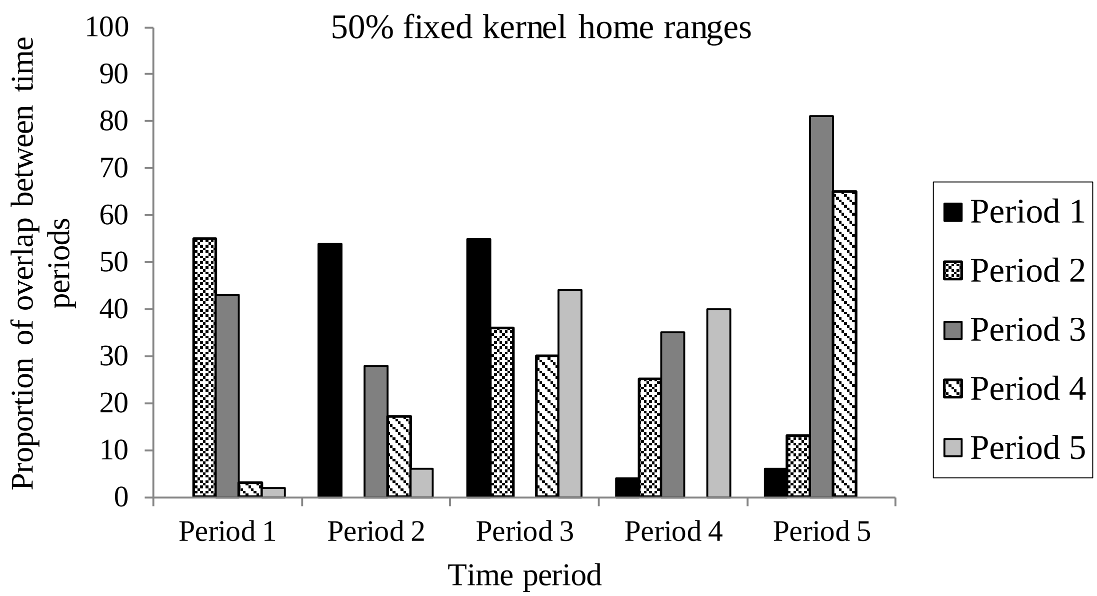


Figure 2.5. Percent overlap between temporal periods in 95% and 50% fixed kernel home ranges for VHF-marked Canada geese at Santee National Wildlife Refuge, Summerton, South Carolina, December 2009 – March 2010. See Table 2.6 for definitions of time periods.

Table 2.1. Body measurements of Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – January 2010.

Goose ID	Transmitter type attached	Age (HY or AHY)	Sex (M or F)	Body mass (g)	Wing chord (mm)	Culmen (mm)	Tarsus (mm)
M1	VHF	AHY	M	3500	460	42.9	98.8
M2	VHF	AHY	M	3600	465	45.7	91.6
M3	VHF	AHY	M	3900	470	55.2	102.0
M4	VHF	AHY	M	3100	440	50.0	94.7
M5	PTT	AHY	M	4200	475	53.1	92.8
Mean ± SE				3175 ± 111.4	426.3 ± 6.4	49.1 ± 1.0	95.6 ± 3.2
F1	VHF	AHY	F	3500	435	51.0	102.0
F2	VHF	AHY	F	3400	435	49.9	105.1
F3	VHF	AHY	F	3000	425	49.9	88.5
F4	VHF	AHY	F	3400	435	42.9	82.4
F5	VHF	AHY	F	2700	415	49.9	91.6
F6	PTT	AHY	F	3200	425	49.9	100.9
F7	PTT	AHY	F	3400	455	51.0	97.9
F8	PTT	AHY	F	2800	400	48.9	86.5
F9	PTT	AHY	F	3300	435	51.0	99.9
F10	PTT	AHY	F	3100	425	48.9	100.9
F11	PTT	AHY	F	3100	410	47.9	91.8
F12	PTT	AHY	F	3200	420	47.9	99.9
Mean ± SE				3660 ± 208.0	462.0 ± 6.8	49.4 ± 2.5	96.0 ± 2.2

Table 2.2. Capture date, relocation dates, and number of relocations for VHF-marked Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – March 2010. Primary and secondary locations are defined in methods.

Goose ID	Capture date	First relocation date	Last relocation date[a]	AM 1°	AM 2°	Noon 1°	Noon 2°	PM 1°	PM 2°	Total
M1	18 Dec 09	19 Dec 09	6 Mar 10	17	15	13	16	15	24	100
M2	11 Jan 10	12 Jan 10	7 Mar 10	15	20	9	22	10	27	103
M3	11 Jan 10	12 Jan 10	7 Mar 10	8	25	15	16	13	26	103
M4	11 Jan 10	12 Jan 10	7 Mar 10	12	20	17	15	10	28	102
F1	18 Dec 09	19 Dec 09	6 Mar 10	15	23	13	15	16	24	106
F2	18 Dec 09	19 Dec 09	6 Mar 10	11	22	11	21	23	16	104
F3	11 Jan 10	12 Jan 10	7 Mar 10	17	16	10	20	11	26	100
F4	11 Jan 10	12 Jan 10	7 Mar 10	10	24	8	22	18	19	101
F5	11 Jan 10	12 Jan 10	7 Mar 10	19	16	8	23	10	29	105
										924

[a] Last relocation date before geese departed Santee National Wildlife Refuge for spring migration.

Table 2.3. Criteria table defining types and number of relocations for VHF-marked Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – March 2010.

Criteria	Type	Description	Count	Percentage
A	Visual Observation	Dye-marked birds visible in flock Appropriate signal direction Appropriate goose habitat	746	81
B	Triangulation	3 or more bearings LOAS error ellipse of ≤4ha[a]	112	12
C	Triangulation	3 or more bearings LOAS error ellipse of 4.1-18ha[b]	66	7
			924	100%

[a] 4 ha is the mean size of all the smallest habitat patches on the Bluff Unit

[b] 18 ha is the mean size of all habitat patches on the Bluff Unit

Table 2.4. Relocation and home range data for Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – March 2010 and fitted with VHF transmitters.

Goose ID	Num. relocations	MCP home range (ha)	95% fixed kernel home range (ha)	50% core use area (ha)
M1	100	579.8	230.7	50.5
M2	103	850	247.8	52.5
M3	103	915.4	226.4	48.4
M4	102	836.3	222.3	46
Mean ± SE	102.0 ± 0.7	795.4 ± 73.9	231.8 ± 5.6	49.4 ± 1.4
F1	106	663.4	263.6	55.5
F2	104	660.2	258.9	55.8
F3	100	733.9	214.2	48.7
F4	101	915.4	216.3	48.8
F5	105	672.6	223.6	46.7
Mean ± SE	103.2 ± 1.2	729.1 ± 48.5	235.3 ± 10.7	51.1 ± 1.9

Table 2.5. Percent overlap in 95% and 50% fixed kernel home range estimates for Canada geese at Santee NWR, Summerton, South Carolina, December 2009 – March 2010.

		X									X								
		95% Kernel home ranges									50% Core use areas								
		M1	M2	M3	M4	F1	F2	F3	F4	F5	M1	M2	M3	M4	F1	F2	F3	F4	F5
	M1		0.82	0.88	0.89	0.84	0.87	0.95	0.92	0.90		0.82	0.79	0.83	0.85	0.80	0.81	0.87	0.92
	M2	0.88		0.93	0.94	0.84	0.83	0.94	0.94	0.94	0.85		0.89	0.91	0.82	0.83	0.89	0.91	0.92
	M3	0.86	0.85		0.90	0.79	0.79	0.92	0.93	0.88	0.76	0.82		0.91	0.74	0.73	0.89	0.85	0.85
	M4	0.85	0.84	0.89		0.75	0.79	0.93	0.92	0.88	0.75	0.80	0.86		0.76	0.74	0.80	0.83	0.84
Y	F1	0.96	0.89	0.92	0.89		0.91	0.93	0.91	0.93	0.93	0.87	0.85	0.92		0.87	0.82	0.88	0.92
	F2	0.97	0.87	0.90	0.92	0.89		0.94	0.95	0.92	0.89	0.88	0.84	0.90	0.88		0.83	0.89	0.94
	F3	0.88	0.82	0.87	0.89	0.76	0.78		0.89	0.89	0.79	0.83	0.90	0.85	0.72	0.72		0.87	0.89
	F4	0.86	0.82	0.88	0.89	0.75	0.80	0.90		0.88	0.84	0.85	0.86	0.88	0.77	0.78	0.88		0.92
	F5	0.87	0.85	0.87	0.89	0.79	0.79	0.93	0.90		0.85	0.82	0.82	0.85	0.78	0.79	0.85	0.88	
Mean		0.89	0.85	0.89	0.90	0.80	0.82	0.93	0.92	0.90	0.83	0.84	0.85	0.88	0.79	0.78	0.85	0.87	0.90
SE		0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01

Number in the cell represents the percentage of bird X's home range that is overlapped by bird Y.

Table 2.6. Number of locations used and 95% and 50% home range area for VHF-marked Canada geese during two-week temporal periods at Santee NWR, Summerton, South Carolina, December 2009 – March 2010.

Time period	Weeks included	Number of points/period	95% fixed kernel home range (ha)	50% core use area (ha)
Period 0[a]	22 Dec to 26 Dec 27 Dec to 2 Jan	4		
Period 1	3 Jan to 9 Jan 10 Jan to 16 Jan	35	251.8	63.1
Period 2	17 Jan to 23 Jan 24 Jan to 30 Jan	66	294.9	63.3
Period 3	31 Jan to 6 Feb 7 Feb to 13 Feb	104	206.6	49.2
Period 4	14 Feb to 20 Feb 21 Feb to 27 Feb	97	205.6	42.6
Period 5	28 Feb to 6 Mar 7 Mar to 13 Mar	48	211.8	26.4
Mean ± SE			234.2 ± 17.4	48.9 ± 6.9

[a] Time period 0 was not used in analysis due to small sample size

Table 2.7. Proportion of overlap between consecutive and non-consecutive temporal periods in 95% and 50% fixed kernel home range for VHF-marked Canada geese at Santee NWR, Summerton, South Carolina, December 2009 – March 2010.

Temporal periods	Lag between temporal periods	Proportion of overlap between temporal periods	Mean overlap	SE
		95% kernel home ranges		
1 and 2	1	0.58	0.59	0.04
2 and 3		0.51		
3 and 4		0.71		
4 and 5		0.55		
1 and 3	2	0.54	0.58	0.05
2 and 4		0.53		
3 and 5		0.68		
1 and 4	3	0.45	0.43	0.02
2 and 5		0.40		
1 and 5	4	0.40	0.40	
		50% core use areas		
1 and 2	1	0.55	0.38	0.06
2 and 3		0.43		
3 and 4		0.03		
4 and 5		0.02		
1 and 3	2	0.28	0.35	0.09
2 and 4		0.17		
3 and 5		0.06		
1 and 4	3	0.30	0.05	0.02
2 and 5		0.44		
1 and 5	4	0.40	0.02	

Table 2.8. Habitat types and proportion of each type on the Bluff Unit of Santee NWR during the winter of 2009 - 2010, Summerton, South Carolina.

Habitat type	**Total hectares**	**Proportion of total**	**Number of relocations**
Cantey Bay subdivision	2.0	0.0023	0
Corn	22.2	0.0258	192
Cypress/tupelo	104.6	0.1212	0
Dike	7.8	0.0090	0
Ditch	4.5	0.0052	0
Electric line	0.3	0.0003	0
Fallow	24.6	0.0285	0
Field	0.9	0.0010	0
Fort Watson	0.7	0.0008	0
Hardwood	11.1	0.0129	0
Millet	13.2	0.0153	30
Mixed pine/hardwood	66.6	0.0772	0
Moist soil	24.5	0.0284	99
Open water	463.7	0.5375	372
Paved road	4.0	0.0047	0
Pine	47.0	0.0545	0
Santee Cooper residential lease area	0.7	0.0008	0
USFWS area	3.4	0.0040	0
Non-planted wetland	36.1	0.0419	2
Wheat	24.7	0.0286	21
Total	**862.8**	**1**	**716**

Table 2.9. Selection ratios and p-values for habitat types utilized by Canada geese at Santee NWR, Summerton, South Carolina, January 2010 – March 2010.

Habitat type	Proportion available	Proportion used	Ratio	SE	p-value[a]
Corn	0.04	0.27	6.630	0.644	**≤0.0001**
Millet	0.02	0.04	1.741	0.489	**0.0018**
Moist soil	0.04	0.14	3.101	0.455	**≤0.0001**
Open water	0.85	0.52	0.616	0.035	**≤0.0001**
Wheat	0.05	0.03	0.653	0.221	0.0444
Total	1	1			

[a] P-value is significant if ≤0.01 using the Bonferroni correction method. Value in bold if significant.

Table 2.10. Selection ratios and p-values for habitat types utilized by Canada geese during three daily sampling periods at Santee NWR, Summerton, South Carolina, January 2010 – March 2010.

		AM period[a]			Noon period[b]			PM period[c]		
Habitat type	Proportion available	Prop. used	Ratio ± SE	p-value[d]	Prop. used	Ratio ±SE	p-value	Prop. used	Ratio ±SE	p-value
Corn	0.04	11.67	11.508 ±1.290	**≤0.0001**	0.22	5.203 ±1.072	**≤0.0001**	0.15	3.441 ±0.838	**≤0.0001**
Millet	0.02	0.04	1.657 ±0.851	0.1211	Habitat not used during this period.			0.08	3.113 ±1.074	**≤0.0001**
Moist soil	0.04	0.28	6.263 ±1.053	**≤0.0001**	0.16	3.539 ±0.870	**≤0.0001**	Habitat not used during this period.		
Open water	0.85	0.20	0.237 ±0.050	**≤0.0001**	0.58	0.671 ±0.062	**≤0.0001**	0.74	0.838 ±0.050	**≤0.0001**
Wheat	0.05	0.01	0.296 ±0.267	0.0219	0.04	0.879 ±0.463	0.6915	0.03	0.715 ±0.386	0.3010

[a] Includes the hours of 0730 – 0900.
[b] Includes the hours of 1200 – 1330.
[c] Includes the hours of 1600 – 1730.
[d] P-value is significant if ≤0.01 for tests using five habitat categories, or if P ≤ 0.0125 for tests using four habitat categories (based on Bonferroni correction method). Value in bold if significant.

Table 2.11. Selection ratios and p-values for habitat types utilized by Canada geese during four two-week temporal periods at Santee NWR, Summerton, South Carolina, January 2010 – March 2010

	Temporal period 2[a,b]			Temporal period 3[c]			Temporal period 4[d]			Temporal period 5[e]		
Habitat type (proportion available)	Prop. used	Ratio ±SE	p-value[f]	Prop. used	Ratio ±SE	p-value	Prop. used	Ratio ±SE	p-value	Prop. used	Ratio ±SE	p-value
Corn (0.04)	0.19	4.416 ±1.731	**≤0.0001**	0.16	3.956 ±0.972	**≤0.0001**	0.38	9.155 ±1.134	**≤0.0001**	0.26	6.168 ±1.519	**≤0.0001**
Millet (0.02)	Habitat not used during this period.			Habitat not used during this period.			Habitat not used during this period.			0.24	9.420 ±2.473	**≤0.0001**
Moist soil (0.04)	Habitat not used during this period.			0.21	4.485 ±0.961	**≤0.0001**	0.03	0.712 ±0.376	0.2940	0.36	7.628 ±1.502	**≤0.0001**
Open water (0.85)	0.77	0.847 ±0.089	**≤0.0001**	0.59	0.680 ±0.062	**≤0.0001**	0.55	0.640 ±0.056	**≤0.0001**	0.14	0.161 ±0.058	**≤0.0001**
Wheat (0.05)	0.04	0.796 ±0.761	0.6841	0.04	0.891 ±0.469	0.7226	0.03	0.707 ±0.374	0.2843	Habitat not used during this period.		

[a] Temporal period 1was not included in analyses due to small sample size.
[b] Includes dates between 17 January and 30 January.
[c] Includes dates between 31 January and 13 February.
[d] Includes dates between 14 February and 27 February.
[e] Includes dates between 28 February and 6 or 7 March(when birds departed Santee NWR).
[f] P-value is significant if ≤ 0.0125 for tests using four habitat categories, and if ≤0.016 for tests using three habitat categories (based on Bonferroni correction method). Value in bold if significant.

Table 2.12. Capture date, relocation dates, and number of relocations for PTT-marked Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – March 2010.

Goose ID	Capture date	First relocation date	Last relocation date[a]	Location class 3	Location class 2	Location class 1	Total[b]
M5	15 Dec 09	17 Dec 09	5 Mar 10	6	20	1	27
F6	15 Dec 09	19 Dec 09	5 Mar 10	9	13	0	22
F7	15 Dec 09	17 Dec 09	5 Mar 10	3	18	7	28
F8	15 Dec 09	17 Dec 09	5 Mar 10	7	17	5	29
F9	15 Dec 09	17 Dec 09	5 Mar 10	0	12	15	27
F10	15 Dec 09	17 Dec 09	5 Mar 10	1	12	14	27
F11	18 Dec 09	20 Dec 09	5 Mar 10	0	5	23	28
F12	18 Dec 09	20 Dec 09	5 Mar 10	1	10	18	29
							217

[a] Last relocation date before geese left Santee for spring migration.
[b] Number of relocations after filtering Argos data to include only one relocation per day.

Table 2.13. Relocation and home range data for Canada geese captured at Santee NWR, Summerton, South Carolina, December 2009 – March 2010 and fitted with satellite transmitters.

Goose ID	Num. of relocations[a]	95% fixed kernel home range (ha)	50% core use area (ha)
M5	27	1190.2	267.3
F6	22	1669.0	439.2
F7	28	1598.3	302.2
F8	29	1427.3	264.3
F9	27	1915.6	515.2
F10	27	1891.2	446.6
F11	28	1890.6	439.5
F12	29	1481.4	395.4
Mean ± SE	27.1 ± 0.8	1633.0 ± 92.3	383.7 ± 32.6

[a] Number of relocations after filtering Argos data to include only one relocation per day.

Table 2.14. Number and proportion of relocations obtained from satellite-marked geese within each buffered area of the Santee NWR Bluff Unit, Summerton, South Carolina, December 2009 – March 2010.

Goose ID	Num. of relocations	Proportion of relocations on refuge[a]	Proportion of relocations possibly on refuge[b]	Proportion of relocations off refuge[c]
M5	27	7	82	11
F6	22	0	55	45
F7	28	14	54	32
F8	29	14	62	24
F9	27	7	45	48
F10	27	7	56	37
F11	28	10	54	36
F12	29	7	55	38
Mean		8	58	34
SE		1.6	3.8	4.2

[a] Points within the inner 1,000m buffer
[b] Points within the refuge boundary
[c] Points within the outer 1,000m buffer or outside all buffers

CHAPTER THREE

SPRING MIGRATORY PATHWAYS AND MIGRATION CHRONOLOGY OF CANADA GEESE WINTERING AT THE SANTEE NATIONAL WILDLIFE REFUGE

INTRODUCTION

Three populations of migratory Canada geese occur in the Atlantic Flyway; the Atlantic Population (AP), North Atlantic Population (NAP), and the Southern James Bay Population (SJBP). Atlantic Population Canada geese (predominately *Branta canadensis interior*) nest north of 48° latitude in northern Quebec along the northeastern shore of the Hudson Bay and the interior of the Ungava Peninsula (Davies and Hindman 2008). AP geese winter from southern Ontario eastward through the southernmost part of Quebec and southward to North Carolina, with major concentrations occurring on the Delmarva Peninsula and in portions of New York, southeastern Pennsylvania, New Jersey, and Virginia (Davies and Hindman 2008). North Atlantic Population geese (predominately *B. c. canadensis*) breed in Labrador, interior Newfoundland, and eastern Quebec, and winter along the Atlantic coastal zone from Labrador to South Carolina (Hindman et al. 2004). Southern James Bay Population geese (predominately *B. c. interior*) breed along the southwestern shore of the James Bay in Ontario, and on Akimiski Island in Nunavut, Canada (Hindman et al. 2004). Geese from the SJBP can be found wintering in both the Atlantic and Mississippi Flyways and are managed jointly by each flyway council (Hindman et al 2004). In the Atlantic Flyway these geese migrate through western Pennsylvania and winter in the Piedmont regions of North and South Carolina (Hindman et al. 2004).

Of the three aforementioned populations, it is the SJBP that are typically associated with wintering grounds in the southeastern region of the United States. In the Mississippi flyway, SJBP geese are historically associated with national wildlife refuges (NWRs) such as Wheeler NWR in Alabama, and Cross Creeks and Tennessee NWR's in Tennessee. In the Atlantic flyway, the SJBP is also found wintering on public lands, and in South Carolina these birds can be found at Santee NWR. Wintering numbers of SJBP geese in the southeastern Atlantic Flyway have been declining over the past two decades (Malecki and Trost 1986; Orr et al. 1998; Abraham et al. 2008), however migration and wintering habitat are not considered a limiting factor for these geese (Abraham et al. 2008). The main cause of the decline is linked to the short-stopping of geese in northern parts of the flyway as well as to the differential survival of southern cohort geese (Abraham et al. 2008; Davies and Hindman 2008).

Despite this declining trend in migrant goose numbers in the southeast, geese still winter at Santee NWR. Research on neck-collared geese in winter in the 1980's has shown an affiliation between South Carolina wintering grounds and both AP (previously referred to as the Mid-Atlantic Population) and SJBP (previously referred to as the Tennessee Valley Population) geese (Malecki and Trost 1986), however no recent assessments have been conducted. With wintering numbers declining throughout the southeastern U.S. as goose distributions shift to northern parts of the Atlantic flyway, current and updated information regarding population affiliation with specific refuges is needed. Additionally, once population affiliation is determined, migratory habitats used by geese can also be addressed.

Satellite and GPS telemetry are effective tools for the tracking of many migratory bird species, and can aid in the identification of breeding, migratory, and wintering habitats. The objectives of this study were to use satellite transmitters (PTT's) to 1) identify the migratory pathways and migration chronology of geese wintering at the Santee NWR, and 2) to determine breeding ground affiliation of geese wintering at the Santee NWR. This information will lend insight into the stopover and staging areas used by migrant geese and the populations that may be utilizing South Carolina wintering grounds.

METHODS

Capture Site

Geese were captured on the Santee NWR, which is located in Clarendon County, South Carolina, approximately 12.5 km southwest of Summerton (Fig.3.1). The refuge includes 5,082 ha of mixed hardwoods, mixed pine-hardwoods, pine plantations, marsh, croplands, old fields, ponds, impoundments, and open water (USFWS 2008; Barnhill, personal communication). The refuge is located on the shores of Lake Marion, a 44,758-ha reservoir created by the South Carolina Public Service Authority between 1939 and 1942 as a hydroelectric project on the Santee River. Shortly after the creation of Lake Marion in 1942, the USFWS recognized this area as highly beneficial to migratory birds, and established Santee NWR under the Migratory Bird Conservation Act and the Refuge Recreation Act (USFWS 2008). The refuge is the most significant inland area for migratory waterfowl in South Carolina (USFWS 2008), and is managed in part to support the last remaining migratory flock of SJBP geese in the southeastern Atlantic states. Migrant geese winter at Santee NWR from late November to early March. The refuge is also adjacent to private lands, predominantly agricultural fields planted with corn, wheat, and soybeans, as well as residential areas. There has been recent concern that some of these agricultural fields will experience residential development in the near future.

Research was conducted on the 862-ha Bluff Unit of Santee NWR. A primary management goal of Santee NWR is to ensure wintering habitat for SJBP geese by supplying high-energy foods and green browse (USFWS 2008). Therefore, crops such as corn, winter wheat, and millet are planted annually on the Bluff Unit. During the winter of 2009-2010 there were approximately 22 ha of corn, 25 ha of winter wheat, and 16 ha of millet available to migrant geese in refuge agricultural fields and impoundments.

Goose Capture and Satellite Transmitter Attachment

Canada geese were captured on the Bluff Unit of Santee NWR during December of 2009. Geese were captured using rocket nets which were placed in agricultural fields on the Bluff Unit. Rocket nets were camouflaged with vegetation and surrounded by decoys of Canada geese. I also used a digital game-caller (FoxPro, Lewistown, PA, USA) to attract flying flocks of geese to the trap area. Trapping occurred mainly in the early morning and evening, when geese foraged at the Bluff Unit. I measured the body mass (±100 g), culmen length (± 0.01 mm), tarsus length (± 0.01 mm), and wing cord (± 5 mm) for all captured geese. I used these measurements to distinguish subspecies (Bellrose 1980) and only fitted individuals deemed to be migratory *Branta canadensis* *interior* (SJBP or AP) or *B. c. canadensis* (NAP) with radio transmitters. Resident geese (*B. c. maxima*) were not fitted with transmitters.

I fitted both after hatch year males and females with either a VHF or satellite (PTT) backpack-style transmitter. The transmitter was attached dorsally between the wings using a harness made of Teflon® ribbon (Bally Ribbon Mills, Bally, PA, USA). I attached PTT transmitters to both males and females; however females were favored for PTT deployment due to their likely experience with migration routes and breeding grounds. Satellite transmitters were either a 45 gram (Microwave Telemetry Inc., Columbia, MD, USA) or a 60 gram (TAV-2456 Telonics Inc., Mesa AZ, USA). Transmitters were deployed with an initial three-day duty cycle from 30 September 2009 to 30 April 2010 in order to collect spatial information while birds were on the wintering grounds (See Chapter 2) as well as while birds were migrating north in spring. From 30 April 2010 to 30 September 2010 transmitters ran on a ten-day duty cycle in order to preserve battery life while birds were nesting on the breeding grounds. These three and ten-day duty cycles continue for the life of the transmitter.

Instrumented geese were fitted with a USGS aluminum leg band and a green leg band with white alphanumeric code (X01–X51), and were also dye-marked with a yellow stain on the cheek patch, undertail coverts, and flank. Dye-marking allowed for the resighting of geese during the wintering season, which was beneficial to assessment of home range and habitat use (See Chapter 2). Captured birds were held overnight (< 12 hours) to acclimate to transmitters. Geese were released at 0730 the morning after capture, at which time I checked the backpack again to make sure it was not impeding the bird's movement. Trapping did not take place the morning of a goose release, but did resume later that evening. All trapping and handling procedures were approved by the Clemson University Institutional Animal Care and Use Committee.

Data Analysis

Satellite locations were obtained using the ARGOS data collection system (ARGOS 2008). ARGOS assigns a Location Class (LC) to each to location, which is an estimate of accuracy. I used the criteria presented in Miller et al. (2005) to choose one location per bird per day to use in analyses. As in Miller et al. (2005) and Haukos et al. (2006), I favored Location Classes 3 (estimated error of <150 m), 2 (estimated error of 150 to 350 m), and 1 (350 to 1,000 m). I used ArcGIS 9.3 (ESRI, Redlands, California) to plot locations of Canada geese and delineate migratory pathways. Hawth's Tools (Beyer 2004) for ArcGIS 9.3 was used to determine migratory pathways and to calculate the total migration distance, as well as distances between stopover sites. Data from the date of departure from the Santee NWR wintering grounds, until the date of arrival on breeding grounds was used to track spring migration. For each goose, I documented stopover and staging sites utilized, migration chronology, and breeding ground affiliation.

I used North American land cover data (Commission for Environmental Cooperation 2010) to identify the main land cover types at each stopover or staging area used by Canada geese during spring migration. I chose this data because it depicted land cover in a consistent way across North America at regular intervals. I buffered each stopover site with a 10 km buffer, and determined the percentage of each type of land cover within the buffered area. The spatial range of all PTT-relocations at individual stopover sites was usually contained within a 20 km area, thus I chose a buffer size of 10 km in order to include all possible areas utilized by geese while staging in that area. Reed et al. (1977) also found that Canada geese staging along the St. Lawrence River in Quebec made flights of 1 to 13 km a day while on staging grounds. These distances are likely similar to those that would be traversed by geese in my study. Therefore the 10 km buffer would encompass all habitats that may be used rather than just the habitat associated with only the relocation. I used this information to identify the percentage of agricultural land use at stopover and staging areas. Information obtained in this analysis was used to better understand the habitat types that geese utilize, and to make inferences about how these habitat types provide geese with resources needed during migration.

RESULTS

A total of 24 trap days (143 trap hours) occurred during December 2009 on the Bluff Unit of Santee NWR, resulting in six geese captured on 15 December 2009, and five captured on 18 December 2009. Eight satellite transmitters were available for deployment. I deployed six satellite transmitters on 15 December 2009 and two satellite transmitters on 18 December 2009 (Table 3.1). I obtained 164 relocations (after filtering ARGOS data) of satellite-marked geese between the date of departure from Santee NWR and the date of arrival on the breeding grounds (Table 3.2). Of the eight transmitters deployed, three ceased transmission during the spring migration, although the exact cause of transmitter failure is unknown. The remaining five geese completed a spring migration to breeding grounds associated with the Atlantic Population (hereafter AP) on the Ungava Peninsula in Quebec, Canada. Satellite-marked geese departed Santee NWR between 5 March and 7 March 2010. Subsequent relocations occurred on either 8 or 9 March 2010 in northeastern North Carolina (6 birds) or 8 March 2010 in northeastern Ohio (2 birds; Table 3.3). Hence, an eastern and western migratory route were identified.

Six birds followed the eastern route, stopping in northeastern North Carolina and western New York. Three of these transmitters (M5, F7, and F9) failed in late April in southeastern Ontario (Fig. 3.2). Birds F6, F8, and F10 completed the spring migration to the eastern shores of the Hudson Bay within AP breeding grounds (Fig. 3.3). Along the eastern migration route, the longest stopovers occurred in southeastern Ontario and southern Quebec (Table 3.3), with geese remaining in these areas from ca. 19 March 2010 to 1 April 2010, and 3 April 2010 to 2 May 2010. Mean distance between stopovers for birds F6, F8, and F10 was 417.3 ± 76.0 km and mean total migratory distance was 2837.9 ± 345.6 km (Table 3.4). Geese arrived on the breeding grounds ca. 24 May 2010.

Two birds (F11 and F12) followed a more western route initially, stopping in northeastern Ohio, before moving to southeastern Ontario and southern Quebec. Birds following this route also completed a spring migration to AP breeding grounds on the Ungava Peninsula (Fig. 3.4). The longest stopovers along this migration route also occurred in southeastern Ontario (Table 3.3), with geese staying in these areas from ca. 17 March 2010 to 4 April 2010, and 10 April 2010 to 30 April 2010. Geese following this route also staged in areas along the Ottawa and St. Lawrence Rivers before continuing north. Birds F11 and F12 completed the spring migration to the eastern shores of the Hudson Bay around 9 June 2010, however goose F11 took a longer migratory path, with a mean distance between stopover sites of 402.0 km and a total migration distance of 4020.4 km, while bird F12 had a mean distance between stopover sites of 365.1 km and a total migration distance of 3650.5 km (Table 3.4). Goose F12 made a direct flight from southern Quebec to the AP breeding grounds on the Hudson Bay, while F11 first flew to the south shore of the Ungava Bay, then along the Ungava Bay coast and across the Ungava Peninsula before settling on the east side of Hudson Bay.

DISCUSSION

Of the eight geese captured and marked with satellite transmitters at Santee NWR during the winter of 2009-2010, none were affiliated with SJBP breeding grounds. Instead, five of the eight birds completed a spring migration to AP breeding grounds. The remaining three transmitters failed during the flight north, however two of those birds were previously captured on AP breeding grounds in 2001 (goose M5) and 2003 (goose F7). Although all the birds marked for this research were found to be affiliated with AP breeding grounds, it appears that SJBP geese winter at Santee NWR as well. For example, daily surveys at Santee NWR suggest that approximately 400-600 migratory geese used the refuge during the winter of 2009-2010. Within this flock a few (<5) geese marked with neck collars on SJBP breeding grounds were observed. Unfortunately the proportion of wintering geese at Santee NWR originating from the SJBP breeding grounds or the AP breeding grounds cannot be determined from these sparse data.

An eastern and a western migratory route were identified for geese trapped at Santee NWR. Geese captured together appeared to migrate together, as the six geese captured on 15 December 2009 used the eastern migratory route, and two geese captured on 18 December 2009 used the western migratory route. After leaving Santee NWR, birds either traveled to northeastern North Carolina or northeastern Ohio. Geese passing through North Carolina stopped in Northampton County before heading north to western New York. The aforementioned stopovers were also utilized by geese captured in various areas of the North Carolina coastal plain during winter, including Northampton County (Fuller 2000) as well as by geese captured on wintering grounds in the southeastern states, including Santee NWR and Carolina Sandhills NWR (Malecki and Trost 1986).

The three to ten day lag between PTT relocations may have resulted in a lack of identification of stopover or staging sites. However, migratory pathways used by geese captured at Santee NWR are similar to pathways of geese marked with satellite transmitters on the Hudson and Ungava Bay coasts during the summers of 1996-1997 by Malecki et al. (2001), which used three and eight day duty cycles. Although birds marked on AP breeding grounds had a wide range of terminal wintering locations, including New Jersey, Maryland, Delaware, Virginia, Massachusetts, and Connecticut, the migratory pathways and migration timing of geese in both studies was similar.

My data and those of Malecki et al. (2001) demonstrate that geese remain on staging grounds in southern Ontario until early May. Migratory geese staging in this area are primarily found on private agricultural lands, as there are no significant public lands in the area that are managed for waterfowl (Hughes 2010, personal communication). The primary forage crop in southeastern Ontario and southwestern Quebec is corn, but some soybean, wheat, oats, and barley are available, as well as dairy farms which provide foraging areas (Hughes 2010, personal communication). Canada geese and snow geese (*Chen caerulescens atlanticus*) staging along the St. Lawrence River, which provides similar habitats to those along the Ottawa River, feed in cornfields, hayfields, and marshes, and roost in flooded fields, rivers, and marshes (Bechet et al. 2003; Bechet et al 2004). Due to the large amount of agricultural fields in this area, food depletion is not believed to be a driving force that causes birds to leave the area in early May (Hughes 2010, personal communication). Birds can remain on the staging grounds until weather conditions in the far north permit departure (Reed et al. 1977).

Following a lengthy staging event in southeastern Ontario and southwestern Quebec, birds flew north, making a few shorter flights in southern Quebec. These short stopovers were made during mid to late May all in areas below 57° latitude, which is the primary nesting region of AP geese. The six birds following the eastern route arrived on the breeding grounds by 24 May 2010, similar to spring migrating geese in Malecki et al. (2001), however geese taking the western route arrived slightly later around 9 June 2010.

Staging areas, like the St. Lawrence and Ottawa River Valleys, and the Great Lakes area provide valuable food and habitat resources to migrating geese. Geese are largely believed to be capital breeders, obtaining nutrient stores used for nesting and incubation prior to their arrival on the breeding grounds (Ankney and MacInnes 1978; Raveling 1979; Drent et al. 2007). Geese arrive on nesting grounds before food is abundant, or even available, and egg-laying occurs shortly after snow and ice melt (Raveling 1979). When Cackling Canada geese (*B. c. minima*) arrived on breeding grounds on the Yukon-Kuskokwim Delta in Alaska in May and June, body mass had increased 26% for males and 46% for females compared to body masses in April at staging areas in California (Raveling 1979). Both lipid and protein reserves increased in males and females, with females gaining 1.8 times more body mass, 2.4 times more lipid, and 1.4 times more protein than did males. By the onset of incubation, 17 days later, both sexes lost weight nearly equivalent to amounts gained prior to arrival. At the time of hatching, females had lost 42% of their peak spring weight, and were emaciated. Therefore weight gain and nutrient reserves acquired at staging areas are vital to reproductive success. This may explain the longer lengths of stay at areas in southeastern Ontario in my study.

As mentioned earlier, spring staging geese in Ontario are often found in agricultural habitats, and there are many different cereal grains and crops available to these birds (Hughes 2010, personal communication). Land cover analysis of staging sites along the Ottawa River in both Ontario and Quebec show that the area is mainly dominated by deciduous and mixed forest and cropland, with the percentage of land in crop ranging between 16% and 53%. Slightly to the southwest, in the Lake Erie region of Ontario, the amount of cropland was even higher, with a mean of 69%. To the north of these areas, the amount of cropland decreases. In areas of southern Quebec, where birds stopped for only short periods, the land cover is mostly dominated by forest habitats, with smaller percentages of grassland, wetland, and a small amount of agricultural land. Breeding ground areas are mainly dominated by sub-polar or polar grasslands and water. Therefore, the staging areas in southeastern Ontario and southern Quebec may be the vital areas for migratory geese from South Carolina and other southern states to gain body mass and nutrient reserves before heading to the breeding grounds.

To the south of the critical staging areas, the percentage of land in agriculture increases at all stopover sites utilized by migrant geese. In Ohio, New York, North Carolina, and South Carolina, cropland is the dominant land cover type at stopover sites, with percentage of agricultural land ranging from 34% to 74%. Stopover sites in these states may have been utilized by geese in order to take advantage of the food and nutritional resources available in these areas, and to power migratory movements northward.

Geese exhibit site fidelity to habitats used during all parts of the annual cycle, including wintering and migratory habitats used during the non-breeding season (Hanson and Smith 1950; Raveling 1979; Bellrose 1980). Nutrition gained during the non-breeding season has a notable effect on reproductive success (Ankney and MacInness 1978; Raveling 1979). Therefore it is important that habitat and food resources are available during this portion of the annual cycle. In the Mississippi flyway, migratory Canada geese historically exhibited strong wintering site fidelity to refuges (Combs et al. 2001). The same is true for geese in the Atlantic flyway, for example the AP is historically associated with habitats at Mattamuskeet NWR (Bellrose 1980). In both flyways there is still an affiliation between migratory geese and publics lands. A review of 1980-1989 January survey data by Orr et al. (1998) showed that 96% of all Canada geese in the southeastern U.S. (i.e. KY, AR, TN, LA, MS, AL, NC, SC, GA, FL) occurred on public land, with 75% associated with NWR's and 21% associated with state refuge areas. Geese in my study obviously wintered on public lands, but migratory movements were not linked to any public lands. However, birds using the eastern migratory route stopped in Orleans County, New York which contains Iroquois NWR, and Montezuma NWR is located just two counties to the east in Seneca, Wayne, and Cayuga Counties. Both of these refuges support large numbers of geese during fall and spring migration. In North Carolina, Mattamuskeet NWR is associated with migrant geese, however this refuge is about 150-200 km from the stopover site used by geese in my study. Although my data do not show a stopover site on public lands, the migratory pathway used by geese may have a traditional link to public lands nearby that geese may utilize in other years.

In both the Mississippi and Atlantic flyways, factors linked to short-stopping and differential survival have caused a decline in the numbers of wintering geese at many refuges in the south. Both AP and SJBP geese face possible changes to their non-breeding habitats. According to the AP Management Plan (Davies and Hindman 2008), the quality and quantity of habitats at staging and wintering areas is changing for AP geese due to development and increased use of agricultural food resources by large populations of greater snow geese and resident geese. The number of SJBP geese wintering in the southeast has been declining for nearly two decades, with causes attributed to changes in the farming and land use practices on wintering grounds and along the migratory pathway, as well as to the differential survival of southern cohort geese (Abraham et al. 2008; Davies and Hindman 2008). In the Atlantic flyway, AP geese in particular are not as highly associated with public lands during the winter (Addy and Heyland 1968).

For example, in Maryland geese rely heavily on private lands where landowners provide sanctuary ponds for roosting, manage hunting, and leave unharvested or waste grain in fields (Harvey 1987; Harvey et al. 1998). Although there is little that waterfowl managers can do to control land use changes on private lands, public lands can still be managed for wintering and migratory geese to ensure their survival into the breeding season. Therefore, refuges should continue to be managed for geese in ways that provide cereal grains and green browse, and offer sanctuary from hunting activities. Crops such as corn, winter wheat, and millet are planted at Santee NWR, and these crops are important food sources for wintering geese. Habitat and food resources such as these are not only important to the geese exhibiting strong site fidelity to this wintering ground, but also to birds migrating through the area, or to those birds that may be forced from wintering grounds further north during years with severe winter conditions.

Satellite-marked geese captured at Santee NWR during the winter of 2009-2010 have shown affiliations with both public and private lands during the non-breeding season. My results show that at least five of the eight geese captured at Santee NWR have some affinity for breeding grounds on the eastern side of the Hudson Bay. Though it is believed that SJBP geese winter at Santee, my data did not successfully show a link between wintering birds and SJBP breeding grounds. Preliminary PTT-marking of geese wintering at Santee NWR during the winters of 2007-2008 and 2008-2009 has also shown links between AP breeding grounds and South Carolina. In 2008, a PTT-marked goose from the wintering grounds at Santee NWR also migrated to AP breeding grounds in spring. The bird then made a fall migration to the Chesapeake Bay in Maryland prior to signal loss in December 2008. Another bird captured in December 2008 left Santee NWR in March and flew to Maryland, where it stayed until January 2010 prior to signal loss. This suggests that some geese wintering at Santee NWR may be resident geese from northern states that may travel south in the winter.

No matter the population utilizing this wintering habitat or the migratory pathways between non-breeding and breeding areas, it is clear that geese wintering at Santee NWR make long distance migratory flights and therefore expend large amounts of energy flying to and from this area. The wintering, pre-migratory, and migratory periods are all energetically costly and successful reproduction depends on nutrient reserves obtained during these times. To ensure or improve survival and reproductive success waterfowl managers must identify the crucial habitats used during these annual periods, and guarantee that they are available to geese. Satellite telemetry-based studies have aided in the identification of important habitats used by wintering and migratory geese throughout the flyway. The goal of this study was to identify these areas for birds wintering in South Carolina, and to determine their breeding ground affiliation to provide information that will help waterfowl managers to understand and better manage goose populations. Future capture and satellite-marking of geese at Santee NWR would be beneficial in order to get a larger and perhaps more representative sample of geese wintering in South Carolina.

REFERENCES CITED

Abraham, K.F., W.A. Phelps, and J.C. Davies. (Eds). 2008. A management plan for the Southern James Bay Population of Canada geese. Mississippi and Atlantic Flyway Council Technical Sections. 55pp.

Addy, C.E., and J.D. Heyland. 1968. Canada goose management in eastern Canada and the Atlantic flyway. Pages 10-23 in Hine, R.L., and C. Schoenfield (Eds). Canada goose management. Dembar Educ. Res. Serv. Madison, WI, USA.

Ankney, C.D., and C.D. MacInnes. 1978. Nutrient reserves and reproductive performance of female lesser snow geese. The Auk. 95: 459-471.

Argos Inc. 2008. User's manual. Landover, Maryland, USA. Retrieved from http://www.argos-system.org/manual.

Bechet, A., J.-F. Giroux, and G. Gauthier. 2004. The effects of disturbance on behavior, habitat use and energy of spring staging snow geese. Journal of Applied Ecology. 41: 689-700.

Bechet, A., J.-F. Giroux, G. Gauthier, J.D. Nichols, and J.E. Hines. 2003. Spring hunting changes the regional movements of migrating greater snow geese. Journal of Applied Ecology. 40: 553-564.

Bellrose, F. C. 1980. Ducks, geese and swans of North America. Third edition. Stackpole Books, Harrisburg, PA, USA.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Retrieved from http://www.spatialecology.com/htools.

C.E.C. 2010. 2005 Land Cover of North America at 250 meters. Commission for Environmental Cooperation. Retrieved from http://www.cec.org/atlas/.

Combs, D.L., K.L. Morgan, E.F. Bowers, and D.H. Orr. 2001. Migratory Canada goose population affiliation and interchange among four national wildlife refuges in Tennessee and Alabama. Proc. Annu. Conf. Southeastern Assoc. Fish and Wildlife Agencies. 55: 517-527.

Davies, J.C., and L. Hindman (Eds.). 2008. A management plan for the Atlantic population of Canada geese. Canada Goose Committee and Atlantic Flyway Technical Section. 52pp.

Drent, R.H., G. Eichhorn, A. Flagstad, A.J. Van der Graaf, K.E. Litvin, and J. Stahl. 2007. Migratory connectivity in arctic geese: spring stopovers are the weak links in meeting targets for breeding. The Journal of Ornithology. 148: S502-S514.

Fuller, J. 2000. Movement and arrival dates of coastal plain, North Carolina winter banded Canada geese, 1984-1996. North Carolina Wildlife Resources Commission. 39pp.

Hanson, H.C., and R.H. Smith. 1950. Canada geese of the Mississippi flyway, with special reference to an Illinois flock. Bulletin of Illinois Natural History Survey. 25: 59-210.

Harvey IV, W. F. 1987. Winter movements and resource use by Canada geese affiliated with Kent County, Maryland. M.S. Thesis, Cornell Univ., Ithaca, N.Y. 96pp.

Harvey IV, W.F., R.A. Malecki, and E.C. Soutierre. 1998. Roost site use and foraging flights by Canada geese wintering in Maryland. Pages 199-206 in Rusch, D.H., M.D. Samuel, D.D. Humburg, and B.D. Sullivan (Eds.). Biology and management of Canada geese. Proc. Int. Canada Goose Symposium. Milwaukee, WI, USA.

Haukos, D.A., M.R. Miller, D.L. Orthmeyer, J.Y. Takekawa, J.P. Fleskes, M.L. Casazza, W.M. Perry, and J.A. Moon. 2006. Spring migration of northern pintails from Texas and New Mexico, USA. Waterbirds. 29: 127-136.

Hindman, L.J., K.M. Dickson, W.F. Harvey IV, and J.R. Serie. 2004. Atlantic flyway Canada geese: new perspectives in goose management. Pages 12-21 in Moser, T.J., R.D. Lien, K.C. VerCauteren, K.F. Abraham, D.E. Andersen, J.G. Bruggink, J.M. Coluccy, D.A. Graber, J.O. Leafloor, D.R. Luukkonen, and R.E. Trost (Eds.). Proc. Int. Canada Goose Symposium. Madison, WI, USA.

Malecki, R.A., B.D.J. Batt, and S.E. Sheaffer. 2001. Spatial and temporal distribution of Atlantic population Canada geese. Journal of Wildlife Management. 65: 242-247.

Malecki, R.A., and R.E. Trost. 1986. Status and population affiliation of Canada geese wintering in North and South Carolina. Proc. Annu. Conf. Southeastern Assoc. Fish and Wildlife Agencies. 40: 446-453.

Miller, M.R., J.Y. Takekawa, J.P. Fleskes, D.L. Orthmeyer, M.L. Casazza, and W.M. Perry. 2005. Spring migration of northern pintails from California's central valley wintering area tracked with satellite telemetry: routes, timing, and destinations. Canadian Journal of Zoology. 83: 1314-1332.

Orr, D.H., E.F. Bowers, and O.J. Florschutz. 1998. Canada geese population trends, distributions, and management strategies in the southeastern United States. Pages 239-248 in Rusch, D.H. M.D. Samuel, D.D. Humburg, and B.D. Sullivan (Eds.). Biology and management of Canada geese. Proc. Int. Canada Goose Symposium. Milwaukee, WI, USA.

Raveling, D.G. 1979. The annual cycle of body composition of Canada geese with special reference to control of reproduction. The Auk. 96: 234-252.

Reed, A., G. Chapdelaine, and P. Dupuis. 1977. Use of farmland in spring by migrating Canada geese in the St. Lawrence Valley, Quebec. Journal of Applied Ecology. 14: 667-680.

U.S. Fish and Wildlife Service. 2008. Santee National Wildlife Refuge comprehensive conservation plan. Atlanta, Georgia, U.S. Department of the Interior, Fish and Wildlife Service. 216 pp.

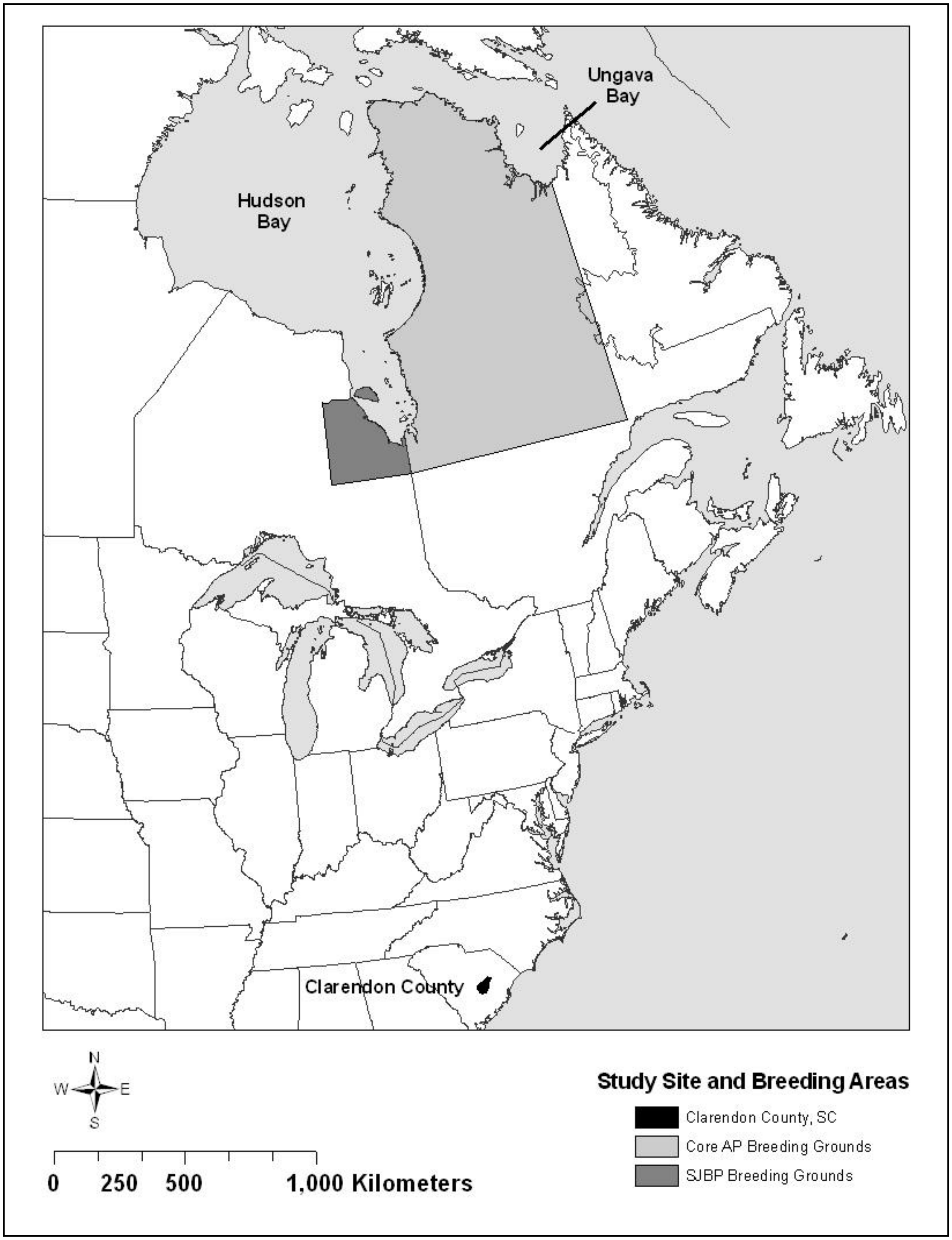


Fig. 3.1 Location of Clarendon County, South Carolina, which encompasses the Santee National Wildlife Refuge, and location of core breeding areas for both SJBP and AP Canada geese.

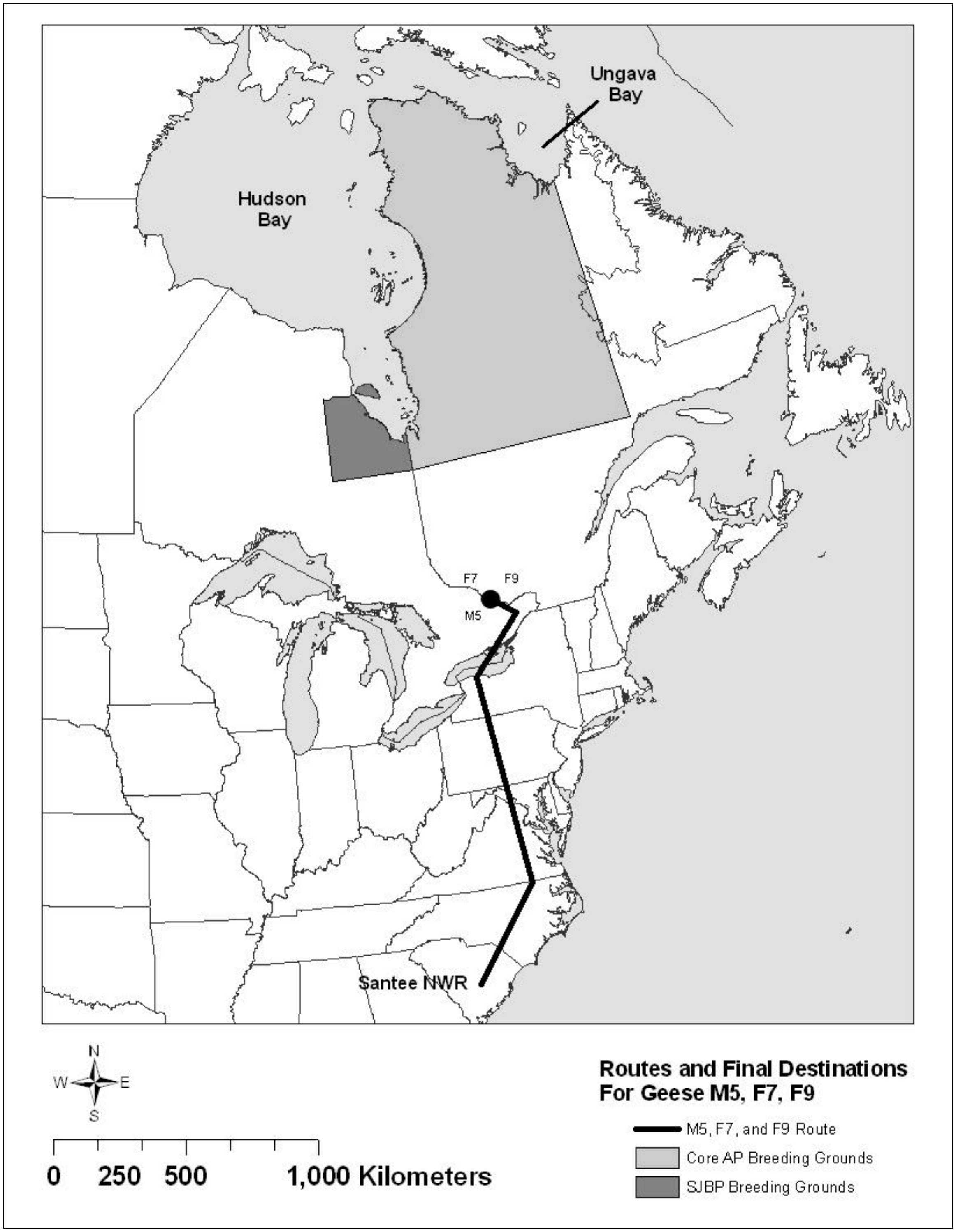


Figure 3.2 Migratory pathway used by geese M5, F7, and F9 during spring migration from wintering grounds at Santee NWR, 5 March 2010 to late April 2010.

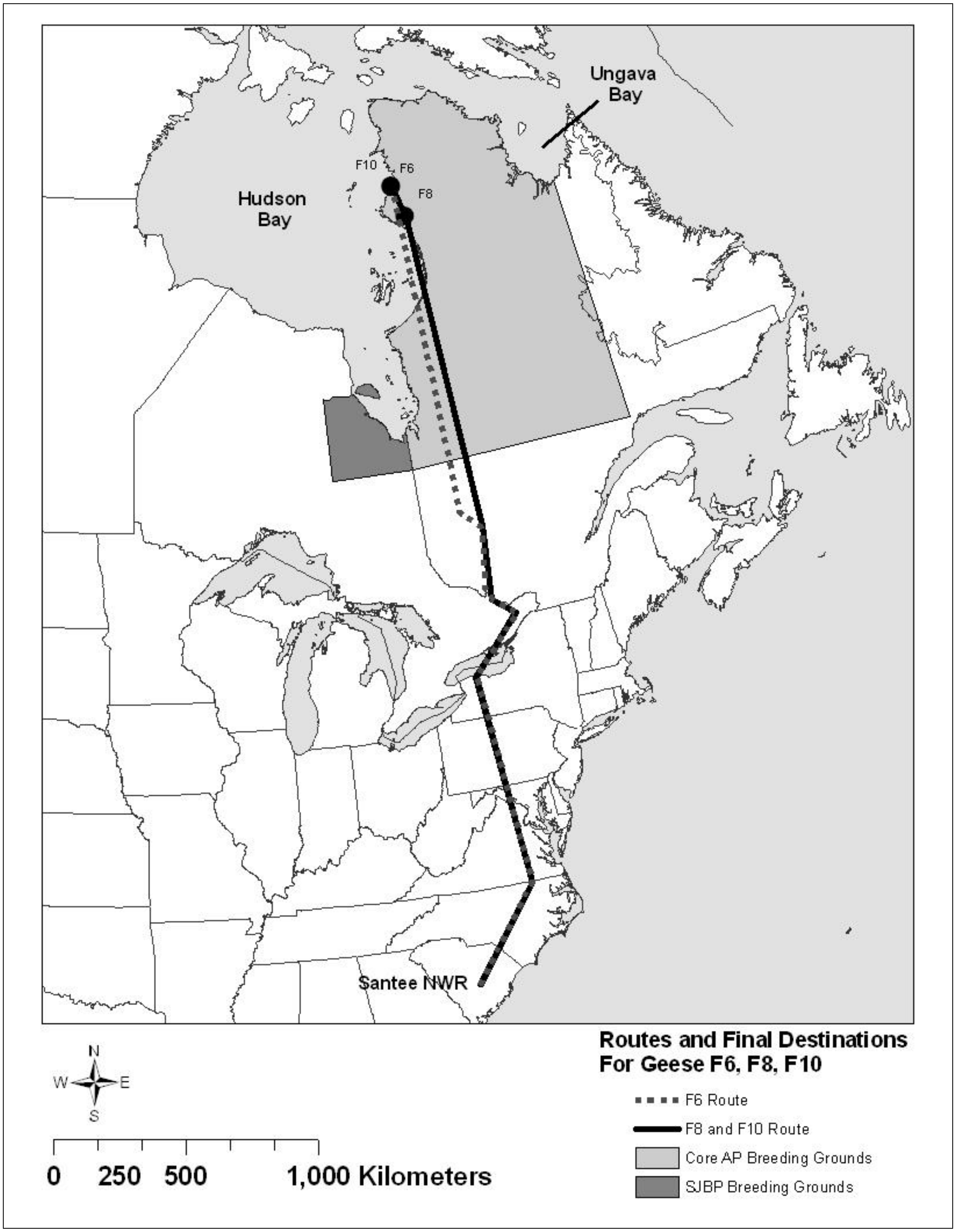


Figure 3.3 Migratory pathways used by geese F6, F8, and F10 during spring migration from wintering grounds at Santee NWR, 5 March 2010 to arrival on breeding grounds ca. 24 May 2010.

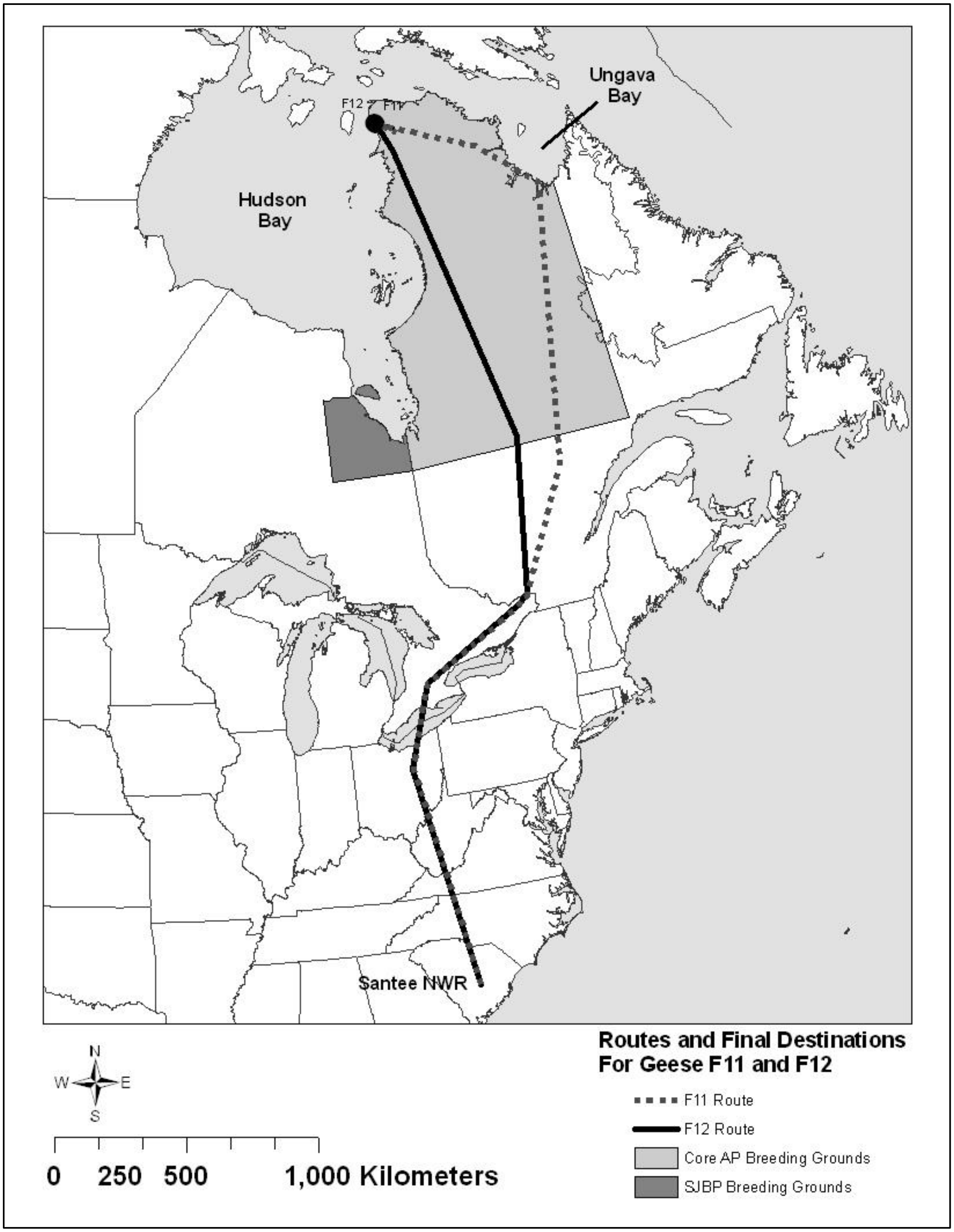


Figure 3.4 Migratory pathways used by geese F11 and F12 during spring migration from wintering grounds at Santee NWR, 5 March 2010 to arrival on breeding grounds ca. 9 June 2010.

Table 3.1. Body measurements of Canada geese captured at Santee NWR, Summerton, South Carolina in December 2009, and fitted with satellite transmitters.

Goose ID[a]	Capture date	Age (HY or AHY)	Sex (M or F)	Body mass (g)	Wing chord (mm)	Culmen (mm)	Tarsus (mm)
M5	15 Dec. 2009	AHY	M	4200	475	53.1	92.8
F6	15 Dec. 2009	AHY	F	3200	425	49.9	100.9
F7	15 Dec. 2009	AHY	F	3400	455	51.0	97.9
F8	15 Dec. 2009	AHY	F	2800	400	48.9	86.5
F9	15 Dec. 2009	AHY	F	3300	435	51.0	99.9
F10	15 Dec. 2009	AHY	F	3100	425	48.9	100.9
F11	18 Dec. 2009	AHY	F	3100	410	47.9	91.8
F12	18 Dec. 2009	AHY	F	3200	420	47.9	99.9
Mean ± SE				3288 ± 145	430.6 ± 8.6	49.8 ± 0.6	96.3 ± 1.9

[a] Goose ID's were assigned in order of capture and marking, which included VHF-transmittered birds which were not included in this analysis.

Table 3.2 Capture date, date of last transmission on wintering grounds, and migratory relocation data for Canada geese captured at Santee NWR, Summerton, South Carolina in December 2009 and fitted with satellite transmitters.

Goose ID	Capture date	Date of last relocation on wintering grounds	Total number of relocations[a]	Complete migration to breeding grounds?	Last transmission date	Location of last transmission
M5	15 Dec. 2009	5 Mar. 2010	16	No	25 April 2010	Southeastern Ontario, Ottawa/St. Lawrence Rivers
F6	15 Dec. 2009	5 Mar. 2010	24	Yes	Still transmitting as of 20 Nov. 2010	Fall migration; Haliburton County, Ontario
F7	15 Dec. 2009	5 Mar. 2010	19	No	30 April 2010	Southeastern Ontario, Ottawa/St. Lawrence Rivers
F8	15 Dec. 2009	5 Mar. 2010	21	Yes	20 May 2010	Atlantic Population breeding grounds
F9	15 Dec. 2009	5 Mar. 2010	16	No	22 April 2010	Southeastern Ontario, Ottawa/St. Lawrence Rivers
F10	15 Dec. 2009	5 Mar. 2010	22	Yes	9 June 2010	Atlantic Population breeding grounds
F11	18 Dec. 2009	5 Mar. 2010	23	Yes	Still transmitting as of 23 Nov. 2010	Fall migration; Talbot County, Maryland
F12	18 Dec. 2009	5 Mar. 2010	23	Yes	28 August 2010	Atlantic Population breeding grounds

[a] Number of relocations after filtering Argos data to include only one relocation per day from location classes 1 - 3.

Table 3.3 Description of migration routes and range of stay at stopover sites used by Canada geese captured at Santee NWR, Summerton, South Carolina in December 2009.

Migration Route	Stopover State/Province	Stopover Description	Range of PTT transmission days at stopover[c]
Eastern route[a]	NC	Northeastern North Carolina	8 Mar. 2010 - 9 Mar. 2010
	NY	Western New York	11 Mar. 2010 - 17 Mar. 2010
	ON	Southeastern Ontario	19 Mar. 2010 - 1 Apr. 2010
	ON or QC	Southeastern Ontario; southern Quebec	3 Apr. 2010 - 2 May 2010
	QC	F6 & F10 Southern Quebec; south of 57°N latitude F8 AP breeding grounds; above 57°N latitude (20 May)	5 May 2010 - 20 May 2010
	QC	AP breeding grounds; above 57°N latitude	Arrival ca. 24 May 2010
Western route[b]	OH	Northeastern Ohio	8 Mar. 2010 - 14 Mar 2010
	ON	Southeastern Ontario	17 Mar. 2010 - 4 Apr. 2010
	ON	Southeastern Ontario	7 Apr. 2010
	ON	Southeastern Ontario	10 Apr. 2010 - 30 Apr. 2010
	QC	Southern Quebec; south of 57°N latitude	10 May 2010
	QC	F11 Ungava Bay coast, F12 Hudson Bay coast	20 May 2010 - 30 May 2010
	QC	AP breeding grounds; above 57°N latitude	Arrival ca. 9 June 2010

[a] Route taken by birds F6, F8, F10, and M5. Birds M5, F7, and F9 also followed this route until late April when the transmitters failed.
[b] Route taken by birds F11 and F12.
[c] Represents range of dates during which all birds traveling the route were present in the area. Dates may not be the same for each goose due to particular duty cycle of the transmitter, but were usually only one day apart.

Table 3.4 Migration routes, number of stopover sites, and distance traveled by Canada geese captured at Santee NWR, Summerton, South Carolina in December 2009, and fitted with satellite transmitters.

	Goose ID	Migration route	Number of stopovers	Breeding Ground	Mean distance between stopovers (km)	Total migration distance (km)
Geese that completed spring migration	F6	Eastern route	7	AP	286.9	2150.9
	F8	Eastern route	5	AP	519.2	3115.4
	F10	Eastern route	6	AP	463.9	3247.3
	Mean ± SE				417.3 ± 76.0	2837.9 ± 345.6
	F11	Western route	8	AP	402.0	4020.4
	F12	Western route	8	AP	365.1	3650.5
	Mean ± SE				383.5 ± 18.5	3835.5 ± 185.0
Geese that did not complete spring migration	M5	Eastern route	4	N/A	407.0	1628.1
	F7	Eastern route	4	N/A	407.2	1628.9
	F9	Eastern route	4	N/A	407.3	1629.5

CONCLUSION

Migratory Canada geese in the southeastern United States have high site fidelity to wintering grounds, namely National Wildlife Refuges. I studied geese wintering at Santee NWR during the winter of 2009-2010 in order to assess space use and habitat selection of birds on public and private lands. I also determined the migratory pathways and population affiliation of geese in order to better understand the flyway-scale needs of the birds wintering at Santee NWR.

Chapter two of this thesis, "Home range and habitat selection of Canada geese in and adjacent to the Santee National Wildlife Refuge", examined home range size of migrant geese, and determined the amount of home range overlap between individual birds and the amount of home range overlap between five two-week wintering periods. Home ranges of all VHF-marked geese were compact and mainly contained within the refuge boundary. I also examined home range size of PTT-marked geese wintering at Santee NWR. Although home ranges were larger than those estimated with VHF transmitters, home ranges were still mainly contained within the refuge boundary or within ca. 2 km of the refuge. Within this chapter I also assessed habitat selection by geese. Geese selected for corn, millet, and moist soil areas in proportion to availability throughout the wintering season. Selection varied among daily time periods and also among bi-weekly time periods.

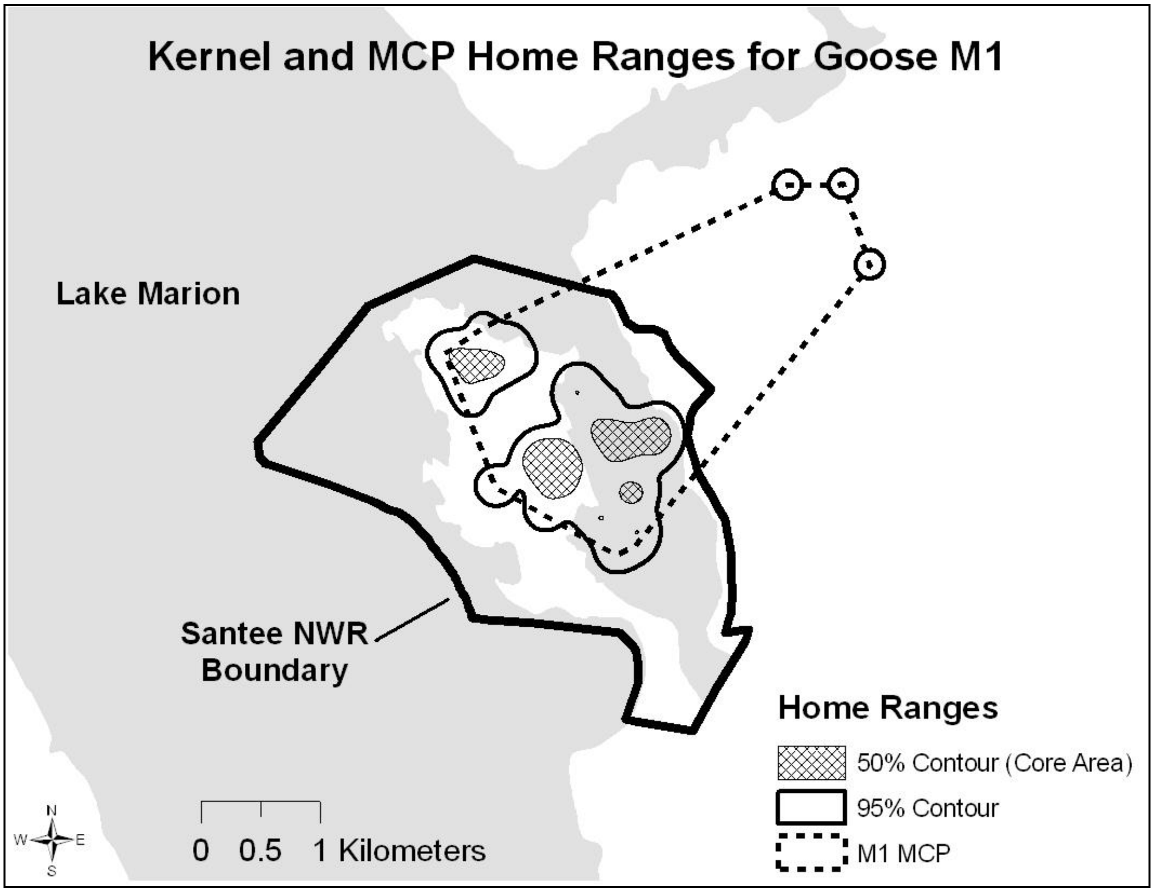
Chapter three of this thesis, "Spring migratory pathways and migration chronology of Canada geese wintering at the Santee National Wildlife Refuge", identified migratory pathways and migration chronology of PTT-marked geese after departure from Santee NWR. I identified two migration routes, an eastern and western route taken between South Carolina wintering grounds and breeding grounds associated with the Atlantic Population of Canada geese. I determined total migration distances and distance between stopover sites, as well as length of stay at stopover sites, and date of arrival on breeding grounds.

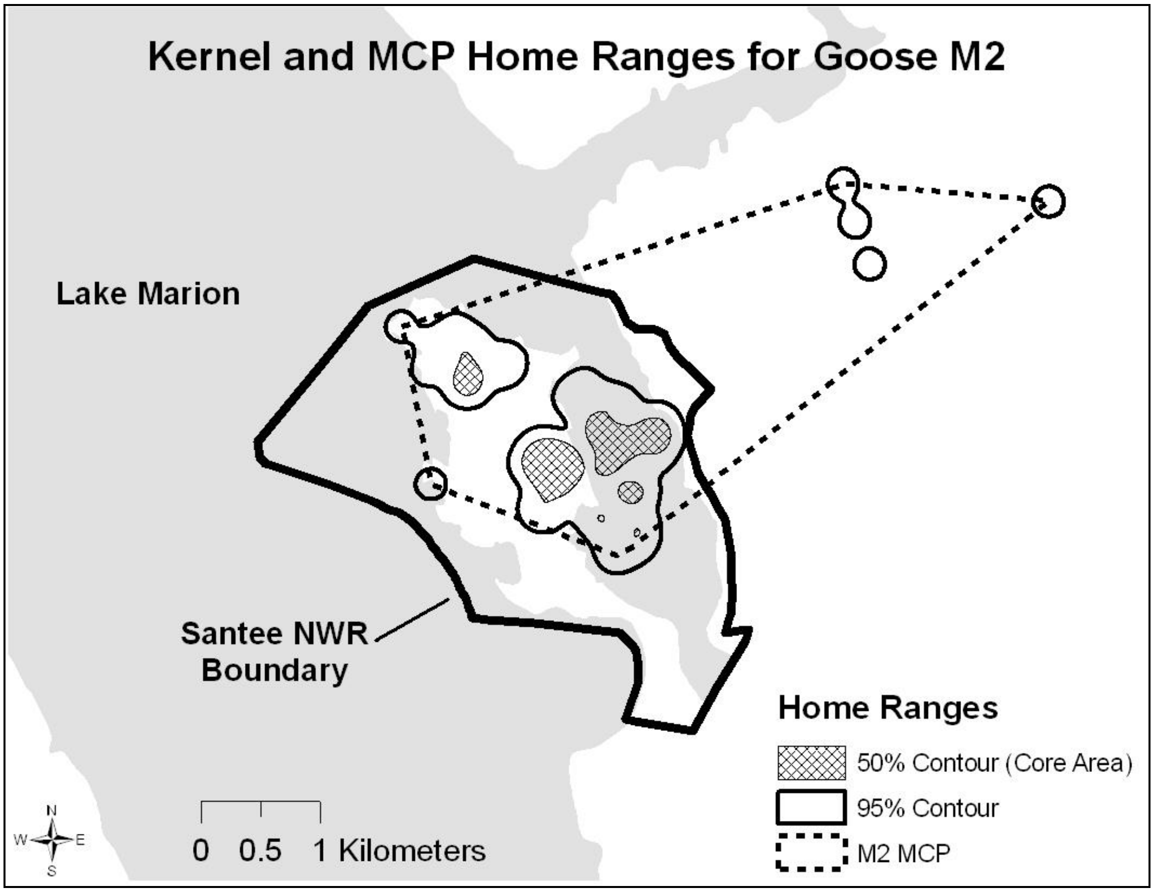
Information gained on Canada geese associated with wintering grounds at Santee NWR is important to the understanding of local-scale and flyway-scale space use of goose populations. While on wintering grounds, geese utilized mainly public lands, and the refuge provided adequate food and habitat resources for geese during this harsh period of the annual cycle. Flyway-scale movements show links between South Carolina wintering grounds, stopover throughout the U.S. and Canada, and breeding grounds affiliated with the Atlantic Population of Canada geese. Identification of these significant habitats can aid in the management of Atlantic flyway goose populations.

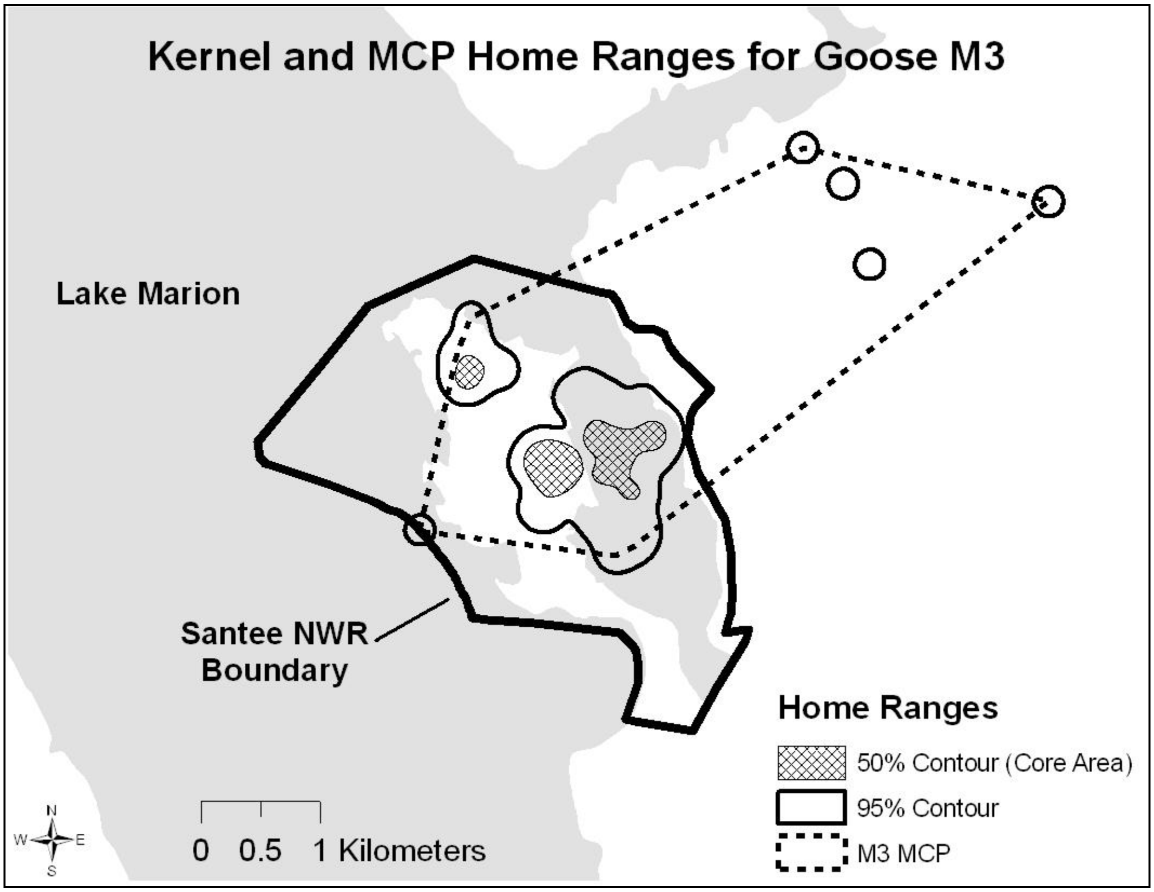
APPENDICES

Appendix A

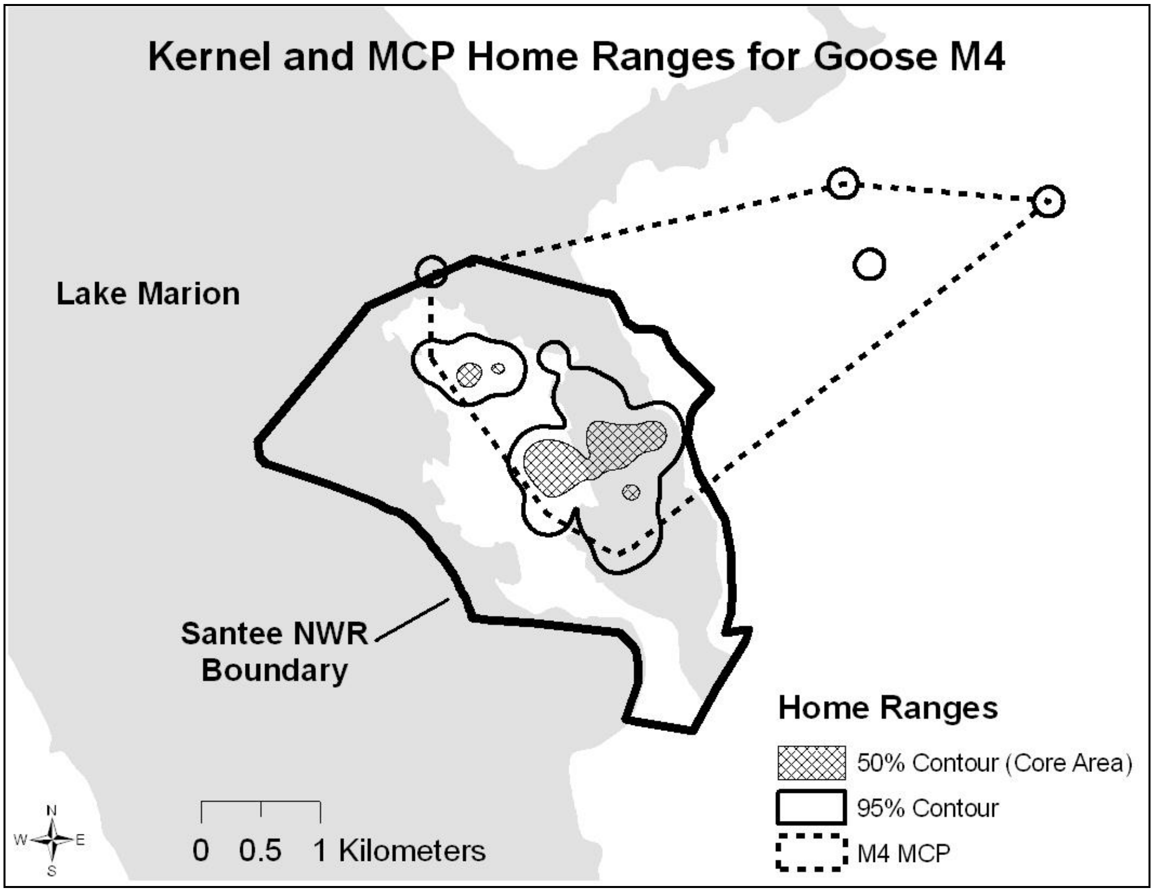
95% Fixed Kernel Home Ranges, 50% Core Use Areas, and
MCP Home Ranges for VHF-marked Canada Geese

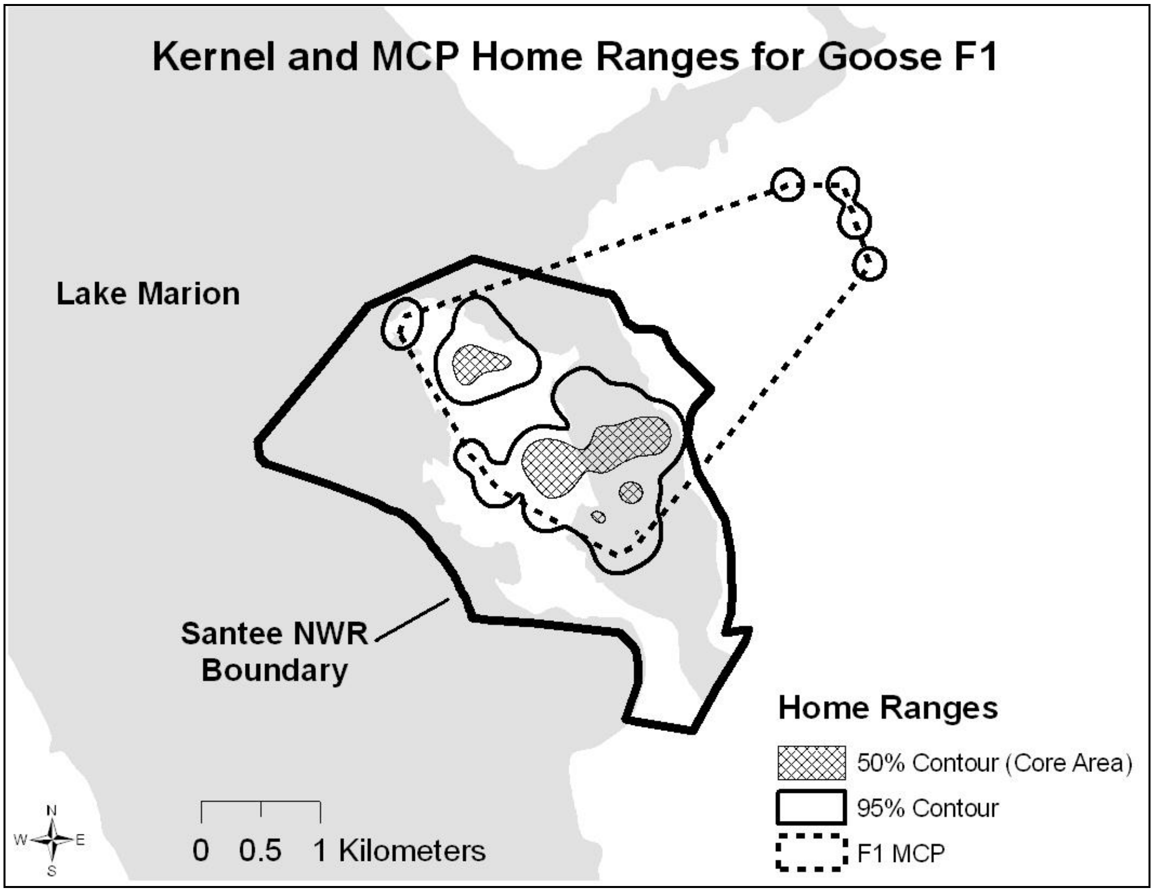

Kernel and MCP Home Ranges for Goose M1
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
M1 MCP
N
W
E
S
0 0.5 1 Kilometers

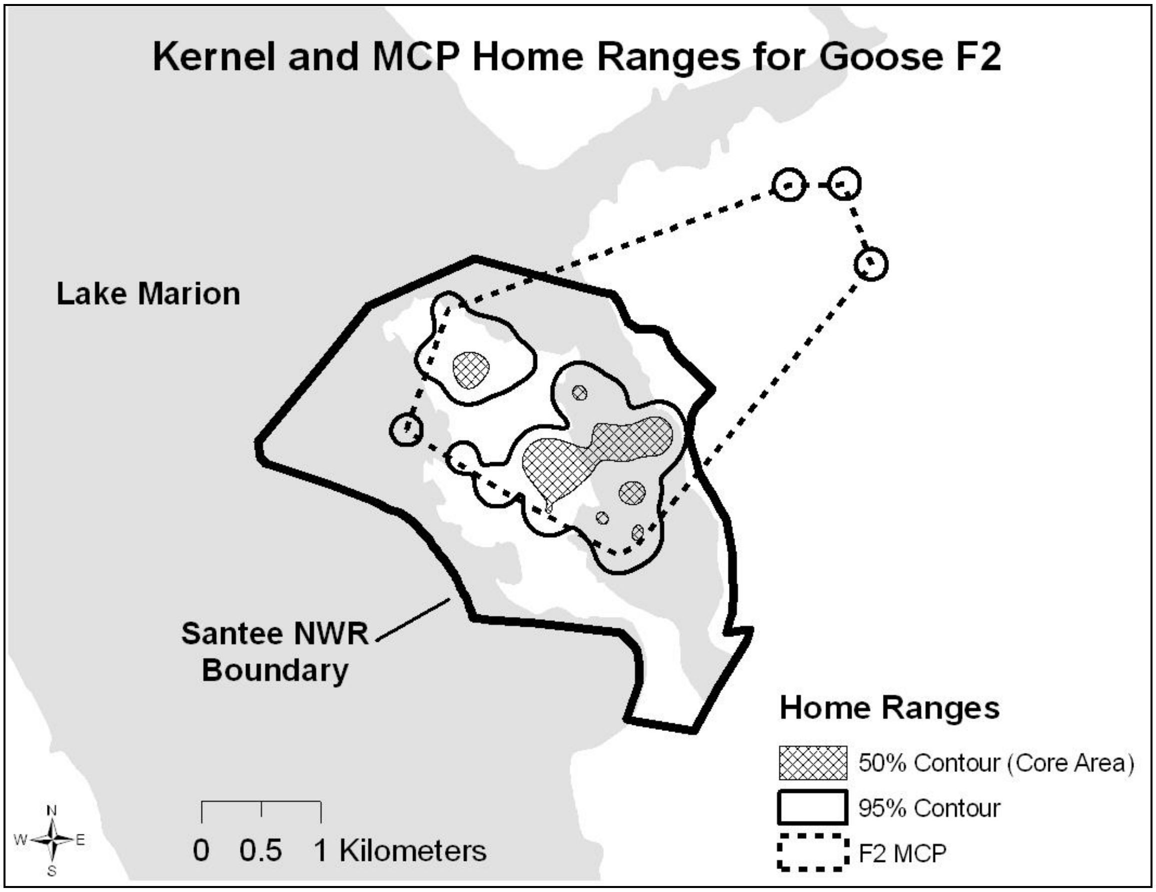

Kernel and MCP Home Ranges for Goose M2
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
M2 MCP
0 0.5 1 Kilometers
N
W
E
S

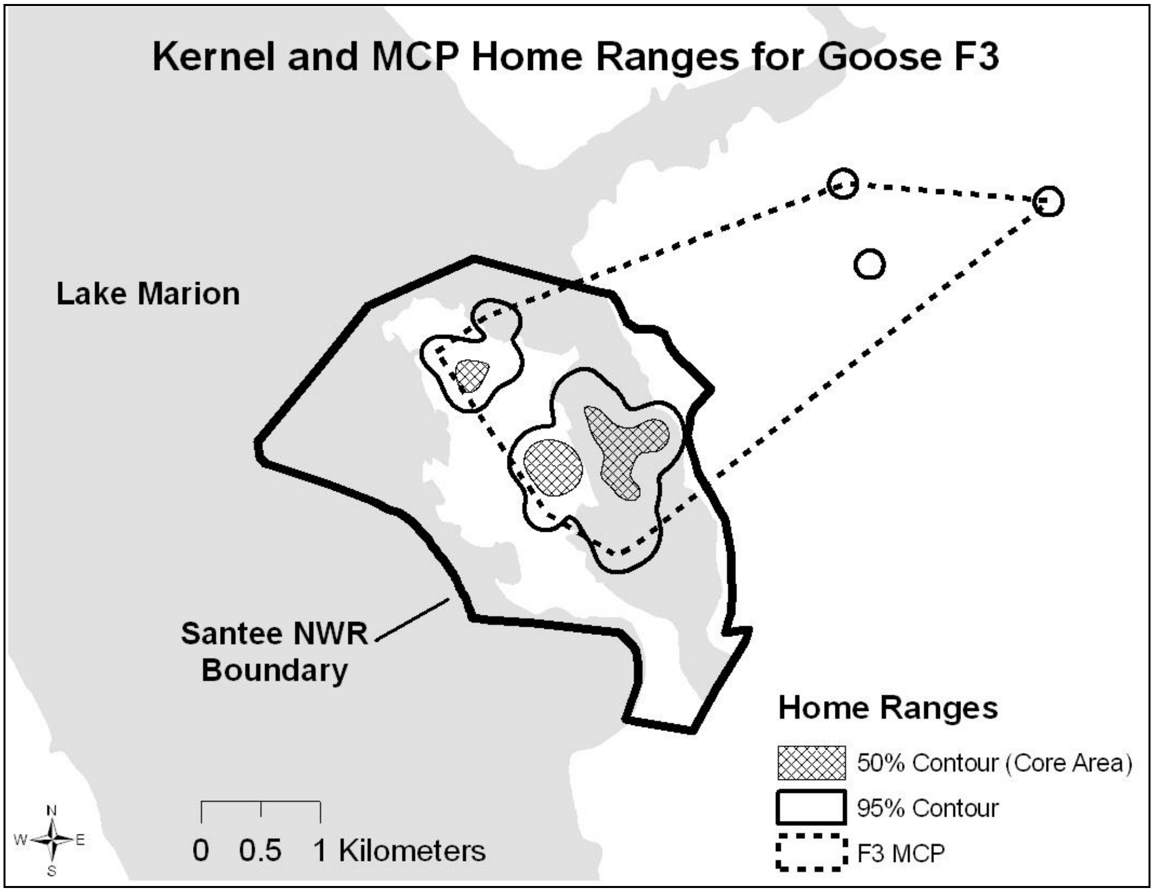


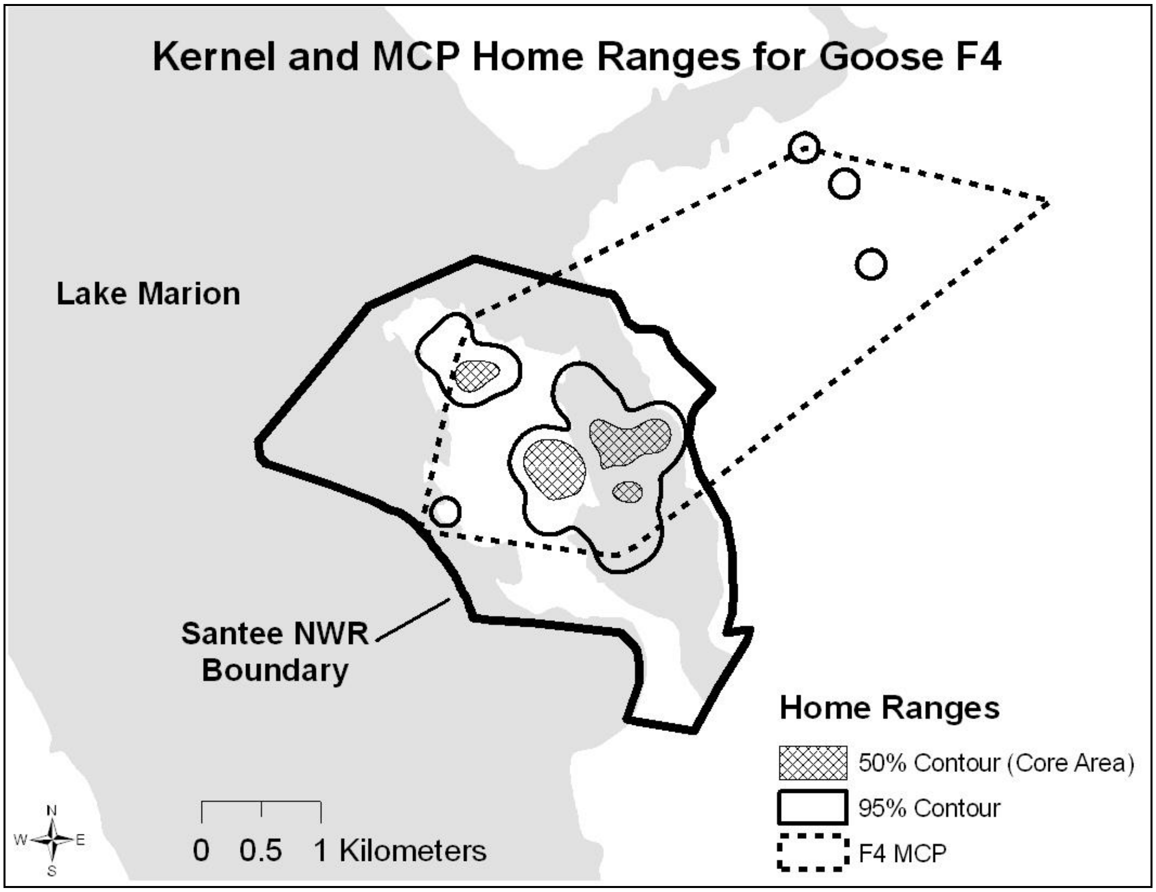
Kernel and MCP Home Ranges for Goose M3
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
M3 MCP
N
W
E
S
0 0.5 1 Kilometers

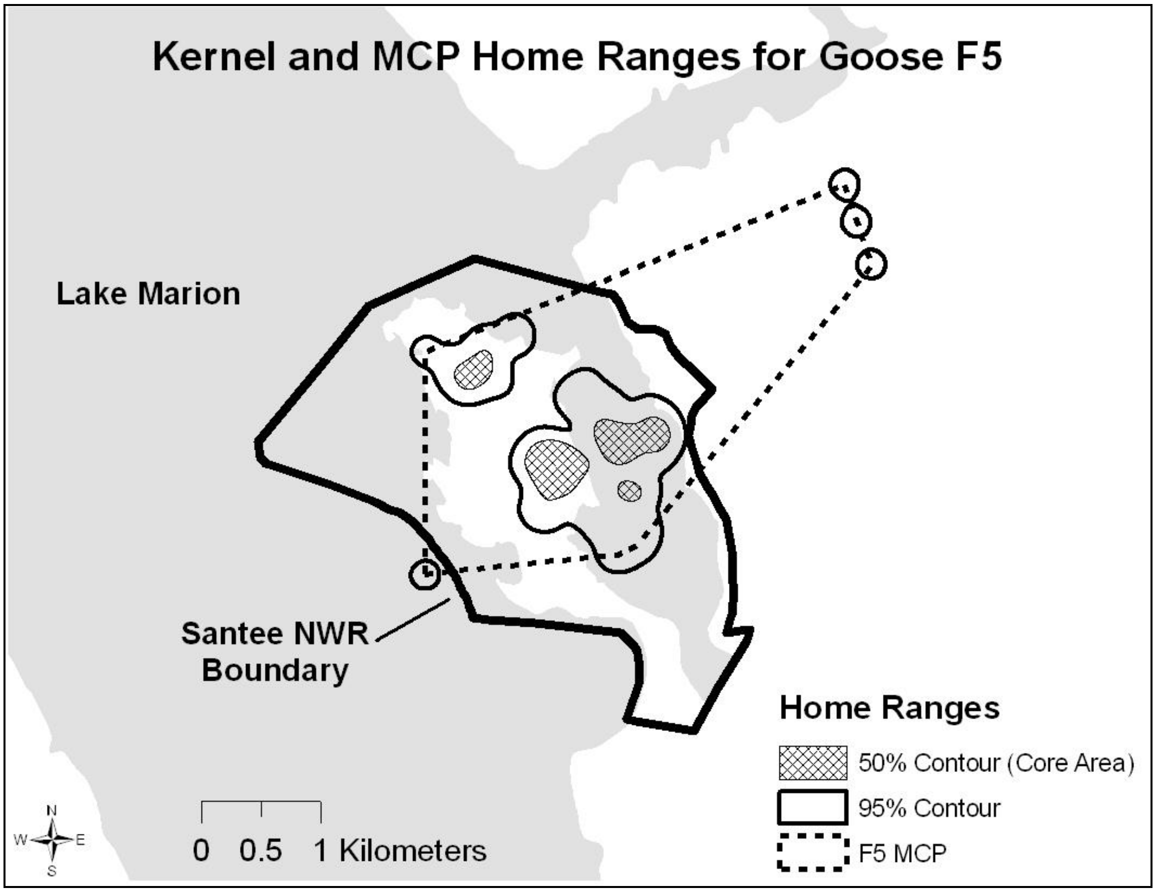

Kernel and MCP Home Ranges for Goose M4
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
M4 MCP
N
W
E
S
0 0.5 1 Kilometers


Kernel and MCP Home Ranges for Goose F1
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
F1 MCP
0 0.5 1 Kilometers
N
W
E
S


Kernel and MCP Home Ranges for Goose F2
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
F2 MCP
N
W
E
S
0 0.5 1 Kilometers

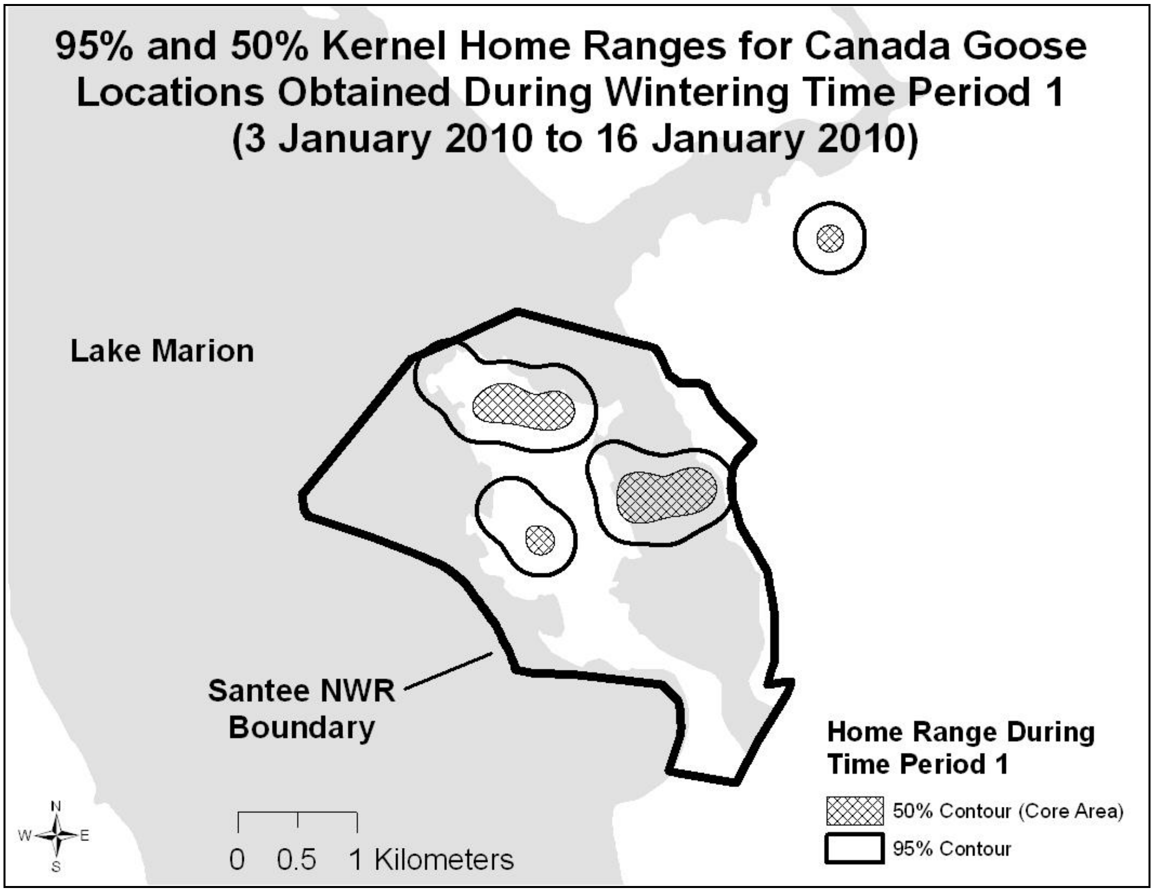

Kernel and MCP Home Ranges for Goose F3
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
F3 MCP
N
W
E
S
0 0.5 1 Kilometers

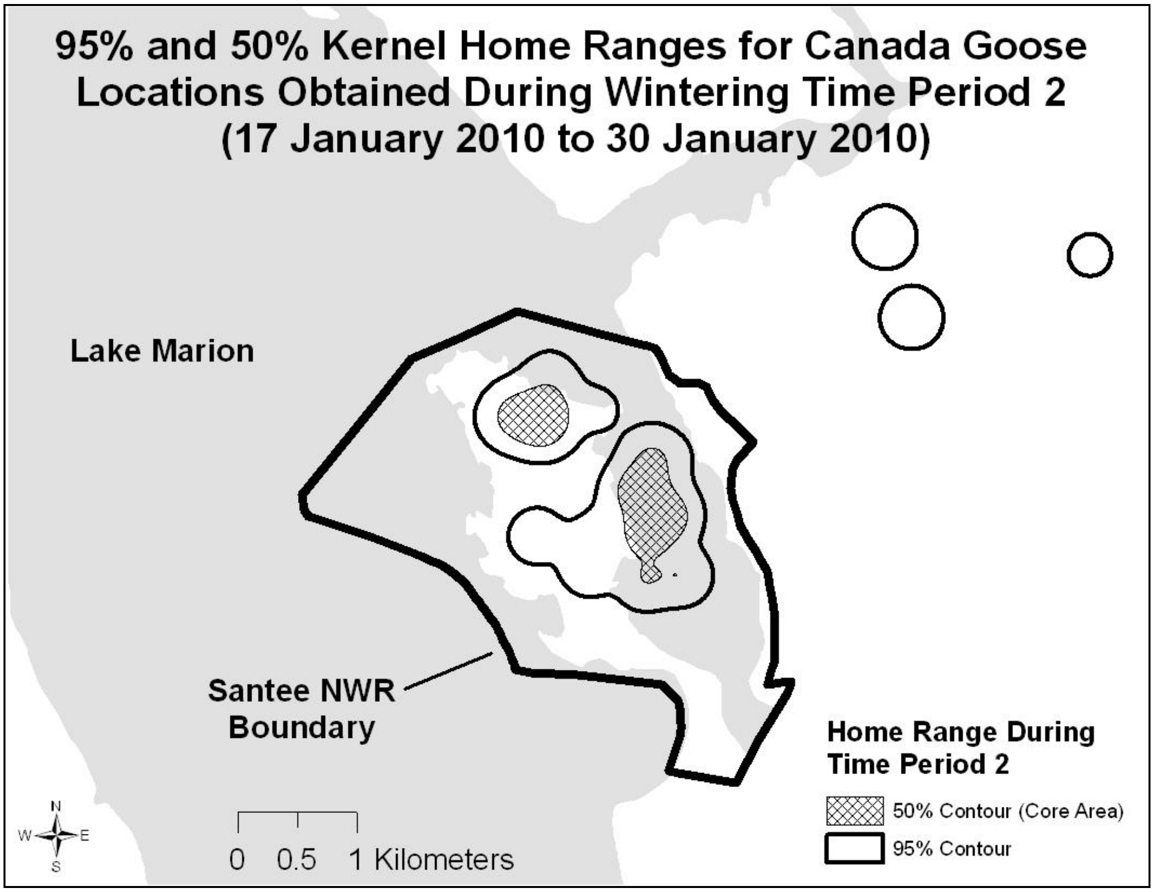

Kernel and MCP Home Ranges for Goose F4
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
F4 MCP
N
W
E
S
0 0.5 1 Kilometers

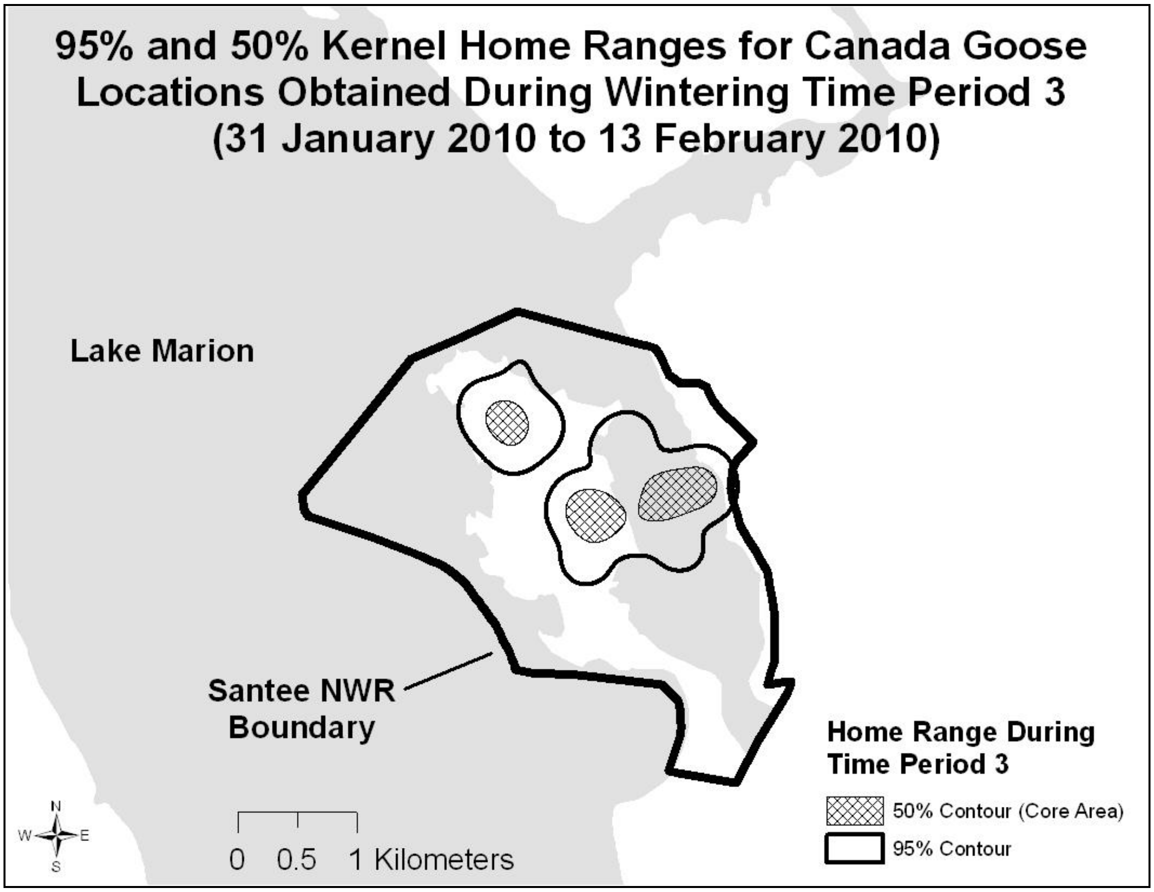

Kernel and MCP Home Ranges for Goose F5
Lake Marion
Santee NWR
Boundary
Home Ranges
50% Contour (Core Area)
95% Contour
F5 MCP
0 0.5 1 Kilometers
N
W
E
S

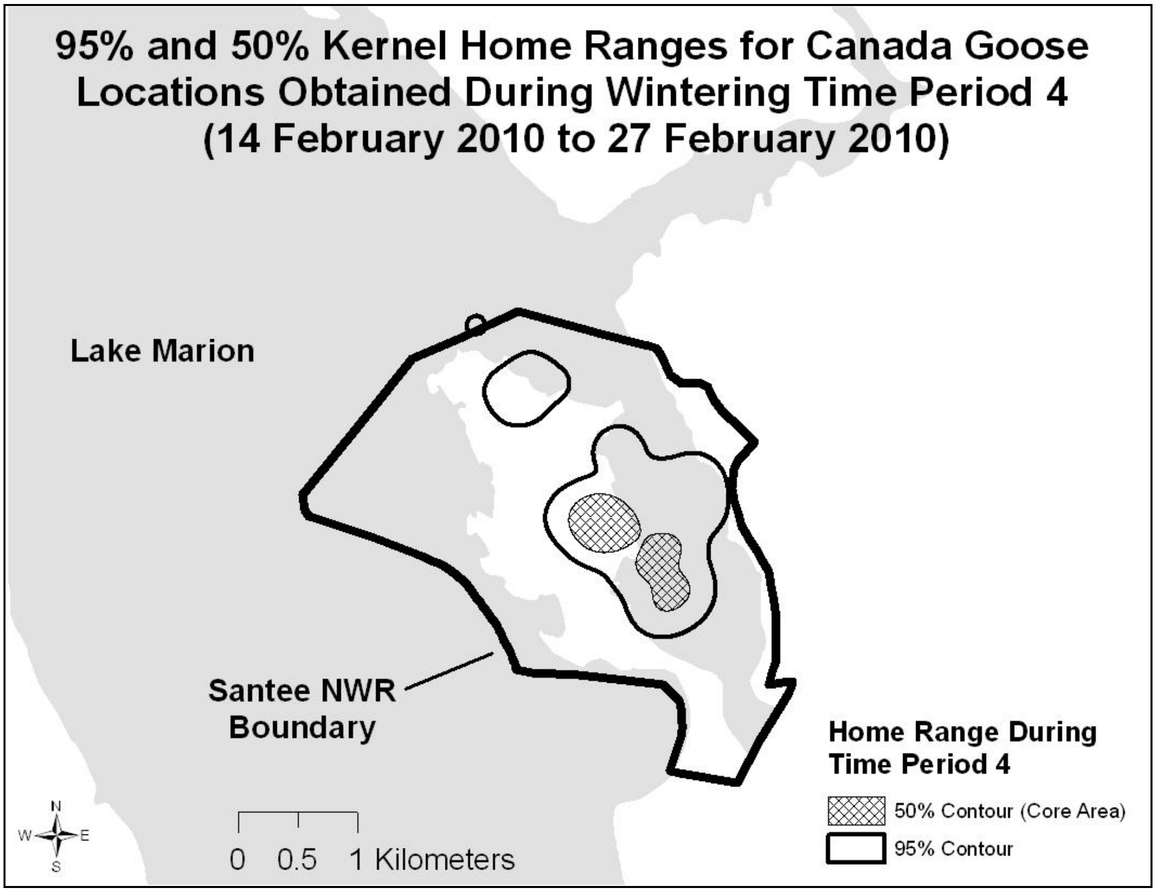
<u>Appendix B</u>

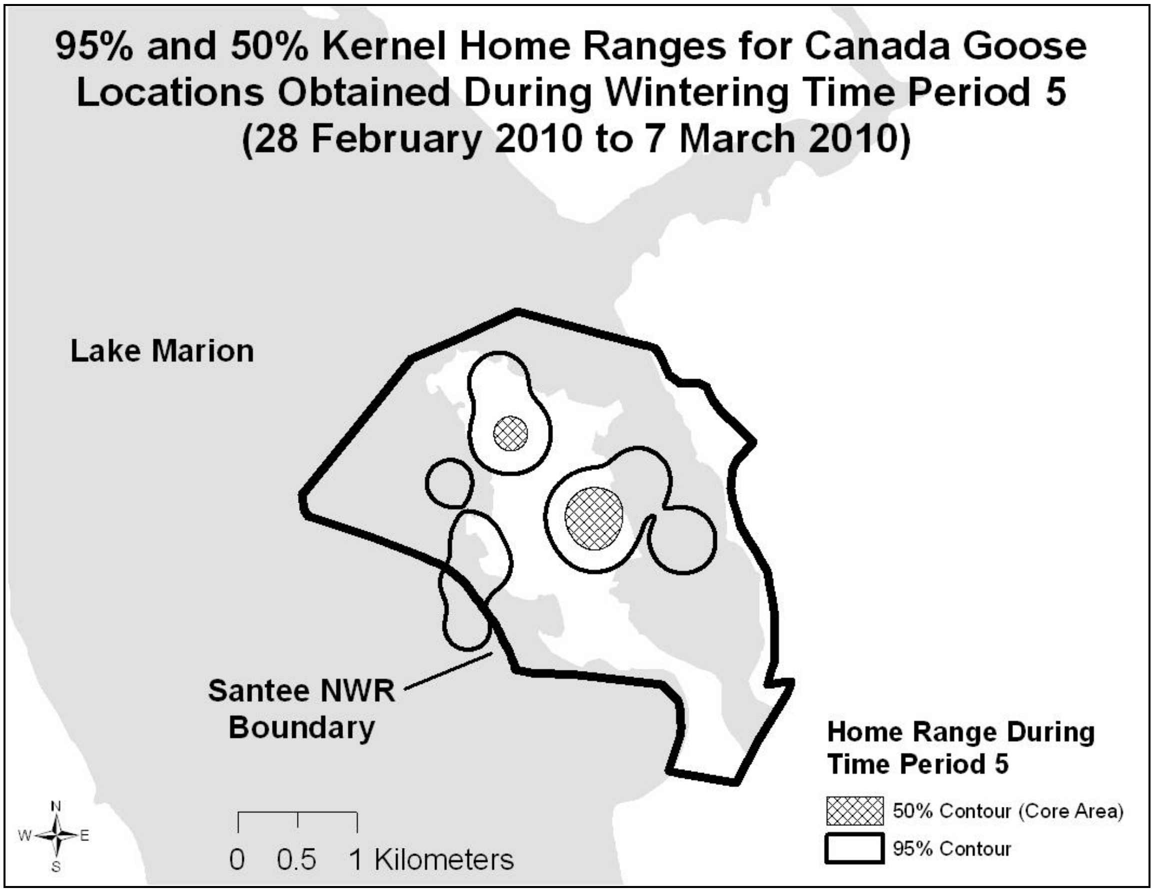
95% and 50% Fixed Kernel Home Ranges for VHF-marked Canada Geese During Five Wintering Time Periods


95% and 50% Kernel Home Ranges for Canada Goose
Locations Obtained During Wintering Time Period 1
(3 January 2010 to 16 January 2010)
Lake Marion
Santee NWR
Boundary
Home Range During
Time Period 1
50% Contour (Core Area)
95% Contour
N
W
E
S
0 0.5 1 Kilometers


95% and 50% Kernel Home Ranges for Canada Goose
Locations Obtained During Wintering Time Period 2
(17 January 2010 to 30 January 2010)
Lake Marion
Santee NWR
Boundary
Home Range During
Time Period 2
50% Contour (Core Area)
95% Contour
N
W
E
S
0 0.5 1 Kilometers

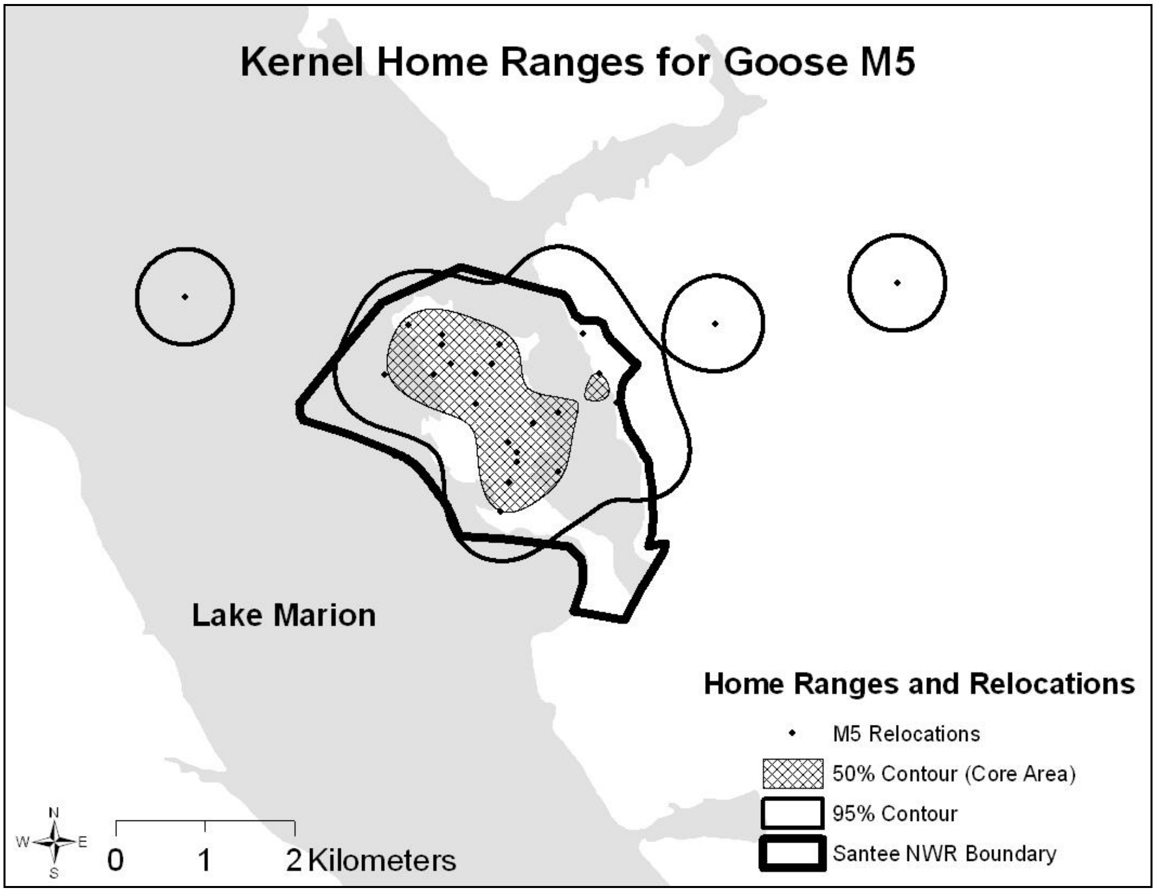

95% and 50% Kernel Home Ranges for Canada Goose
Locations Obtained During Wintering Time Period 3
(31 January 2010 to 13 February 2010)
Lake Marion
Santee NWR
Boundary
Home Range During
Time Period 3
50% Contour (Core Area)
95% Contour
N
W
E
S
0 0.5 1 Kilometers

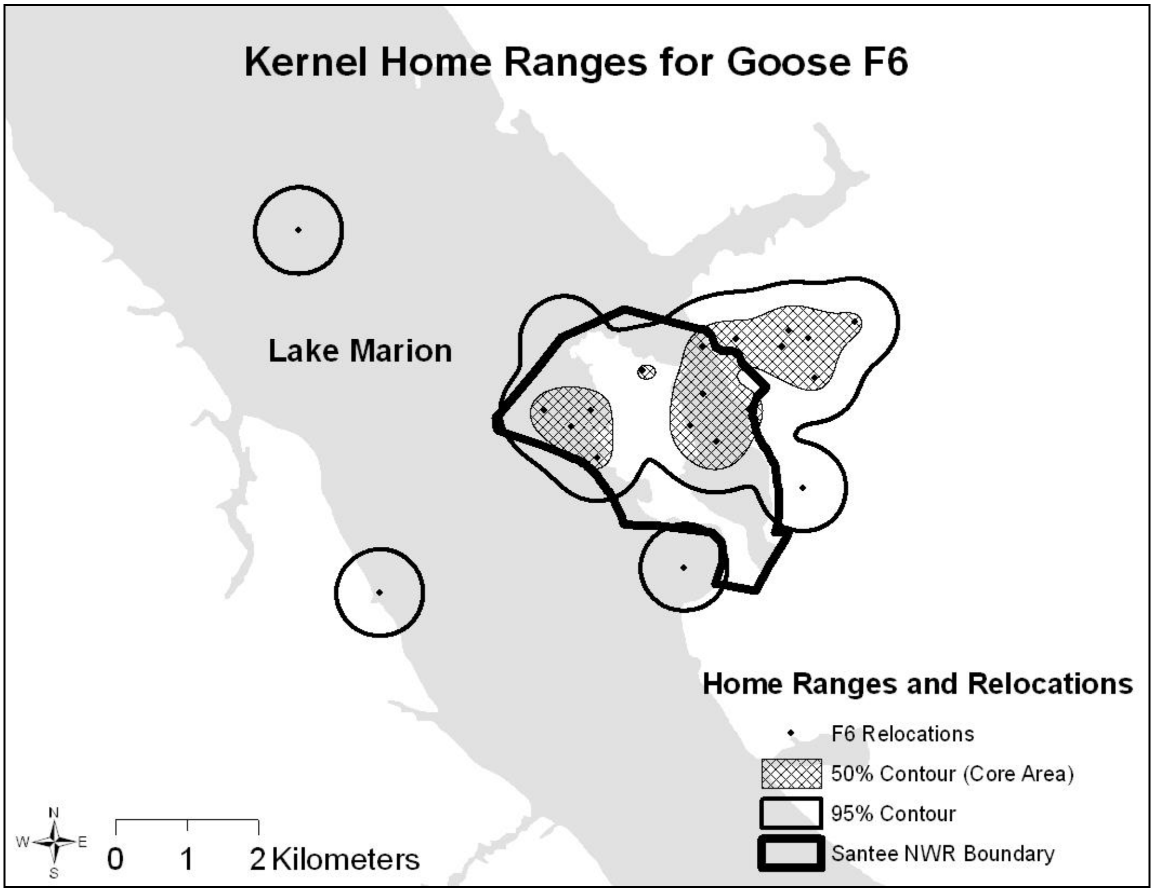

95% and 50% Kernel Home Ranges for Canada Goose
Locations Obtained During Wintering Time Period 4
(14 February 2010 to 27 February 2010)
Lake Marion
Santee NWR
Boundary
Home Range During
Time Period 4
50% Contour (Core Area)
95% Contour
N
W
E
S
0 0.5 1 Kilometers


95% and 50% Kernel Home Ranges for Canada Goose
Locations Obtained During Wintering Time Period 5
(28 February 2010 to 7 March 2010)
Lake Marion
Santee NWR
Boundary
Home Range During
Time Period 5
50% Contour (Core Area)
95% Contour
0 0.5 1 Kilometers
N
W
E
S

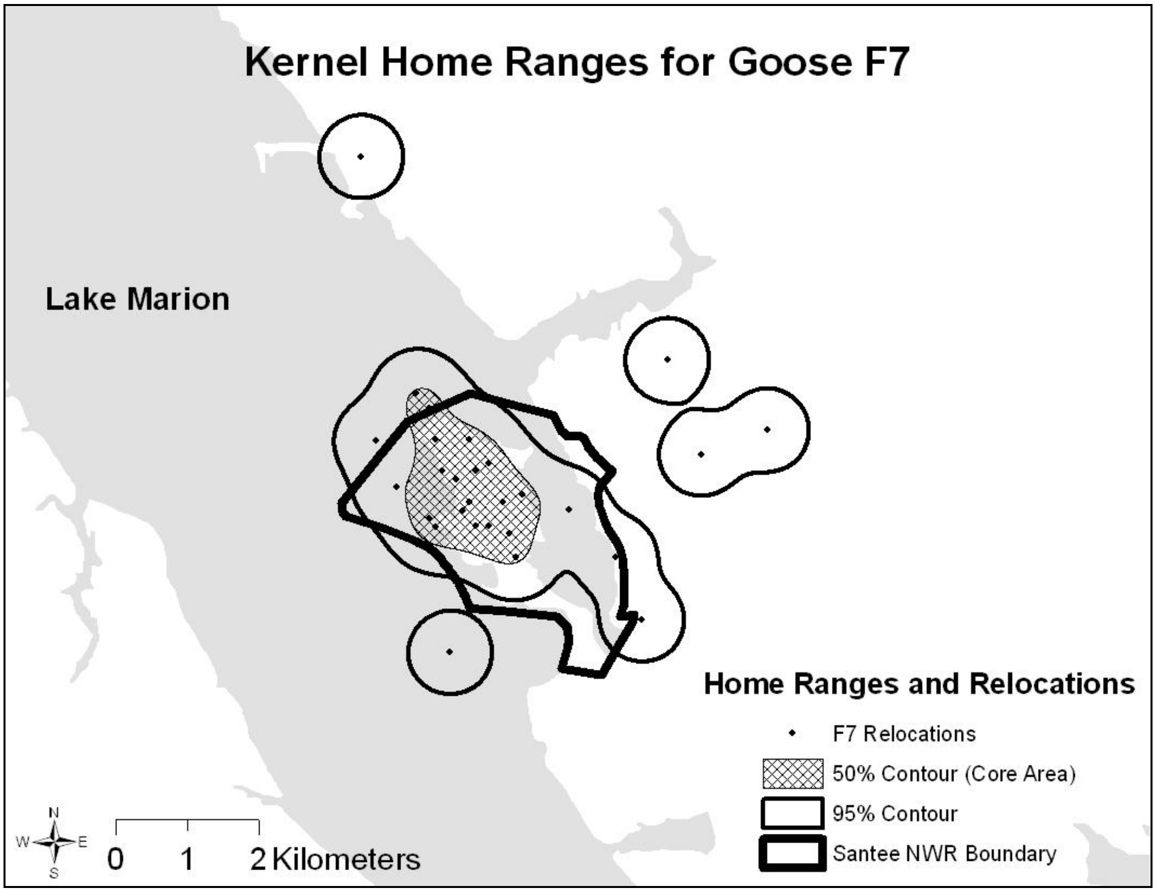
Appendix C

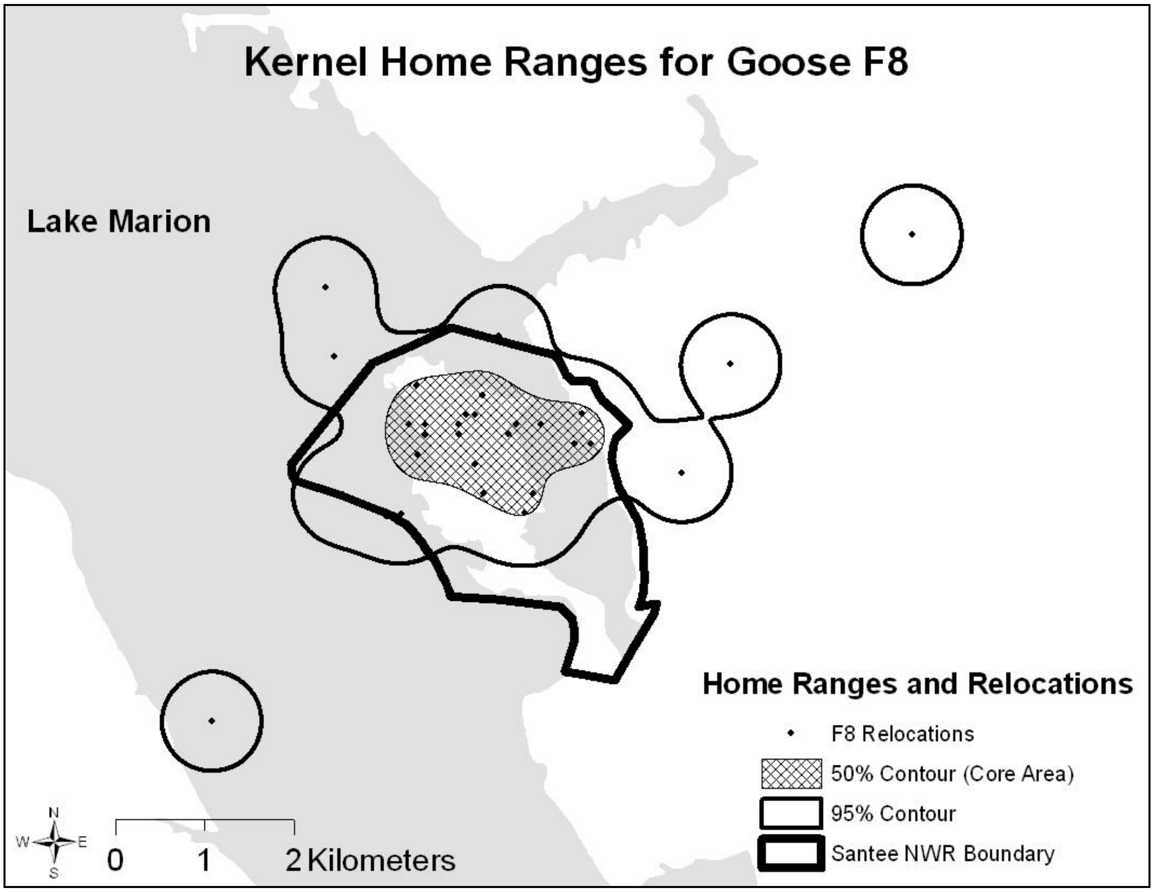
95% Fixed Kernel Home Ranges and 50% Core Use Areas for
Satellite-marked Canada Geese

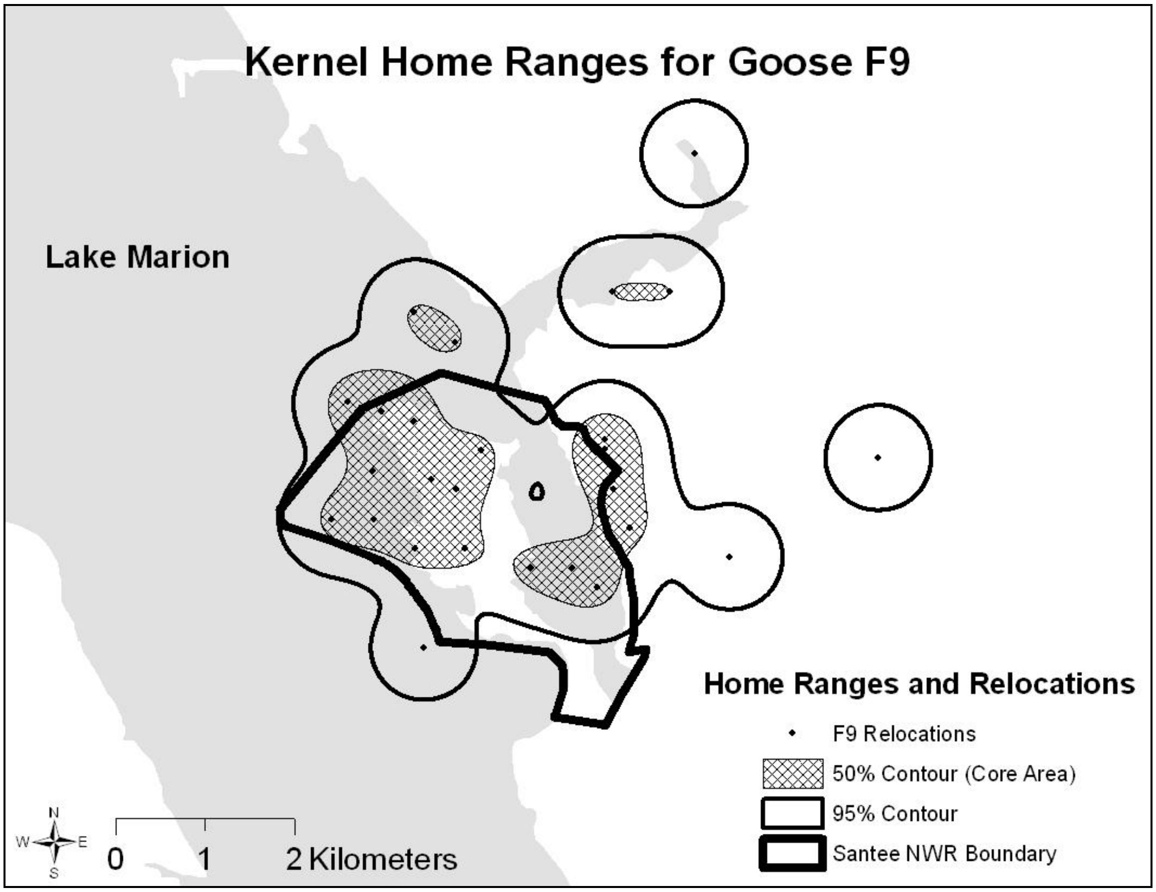

Kernel Home Ranges for Goose M5
Lake Marion
Home Ranges and Relocations
M5 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers



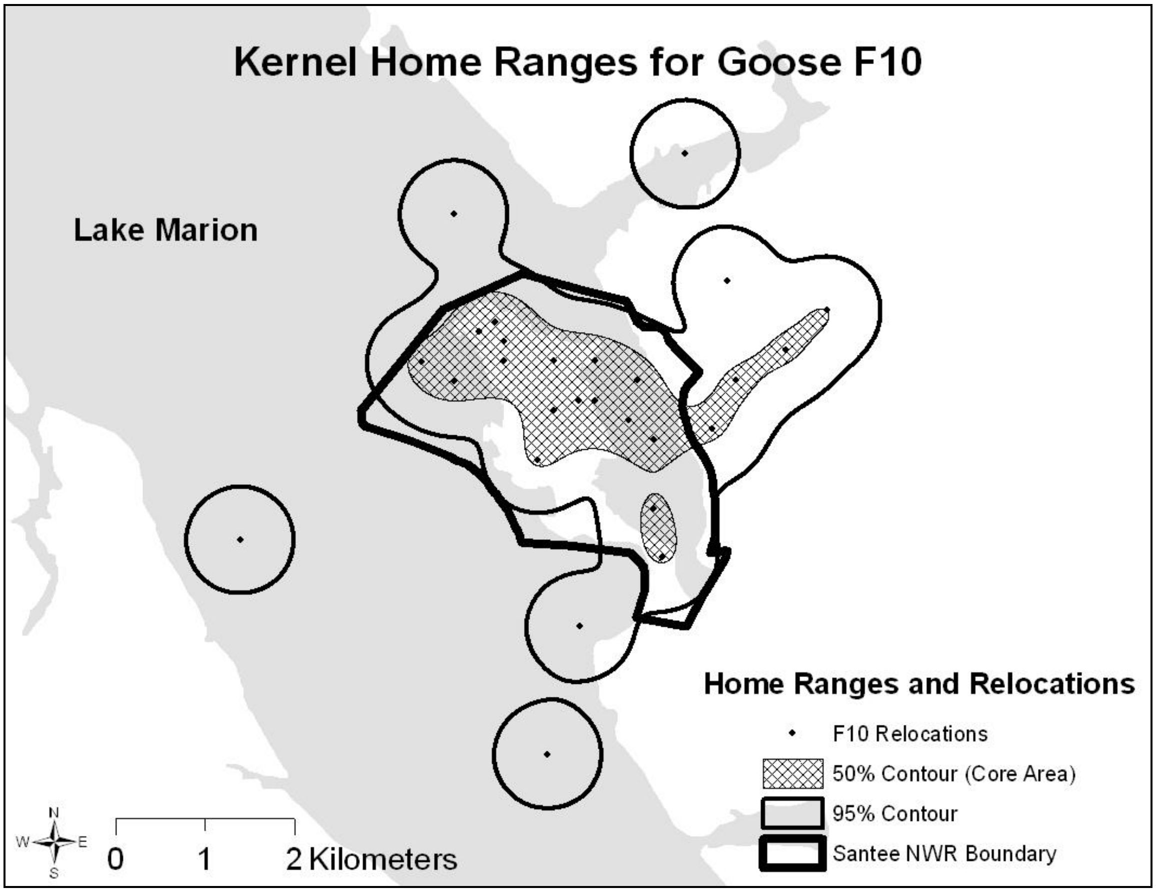
Kernel Home Ranges for Goose F6
Lake Marion
Home Ranges and Relocations
F6 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers


Kernel Home Ranges for Goose F7
Lake Marion
Home Ranges and Relocations
F7 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers

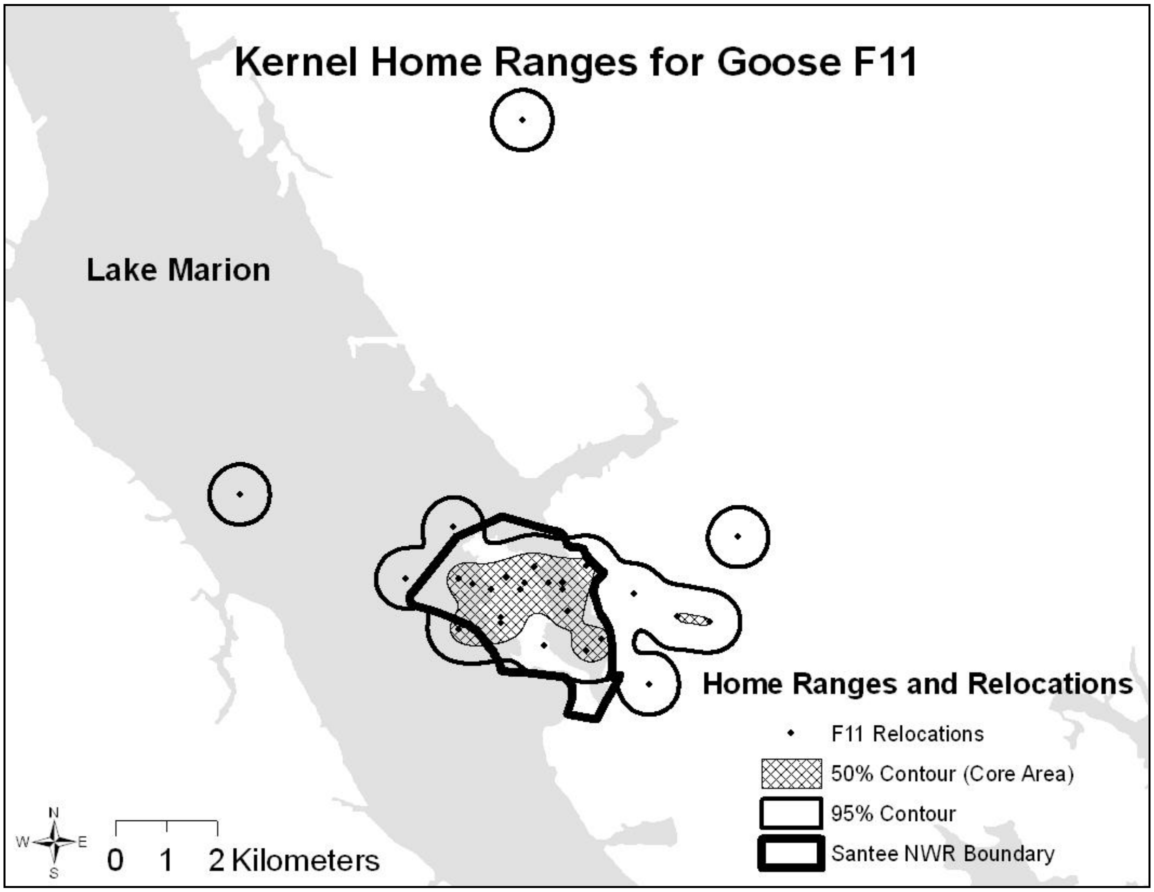

Kernel Home Ranges for Goose F8
Lake Marion
Home Ranges and Relocations
F8 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers

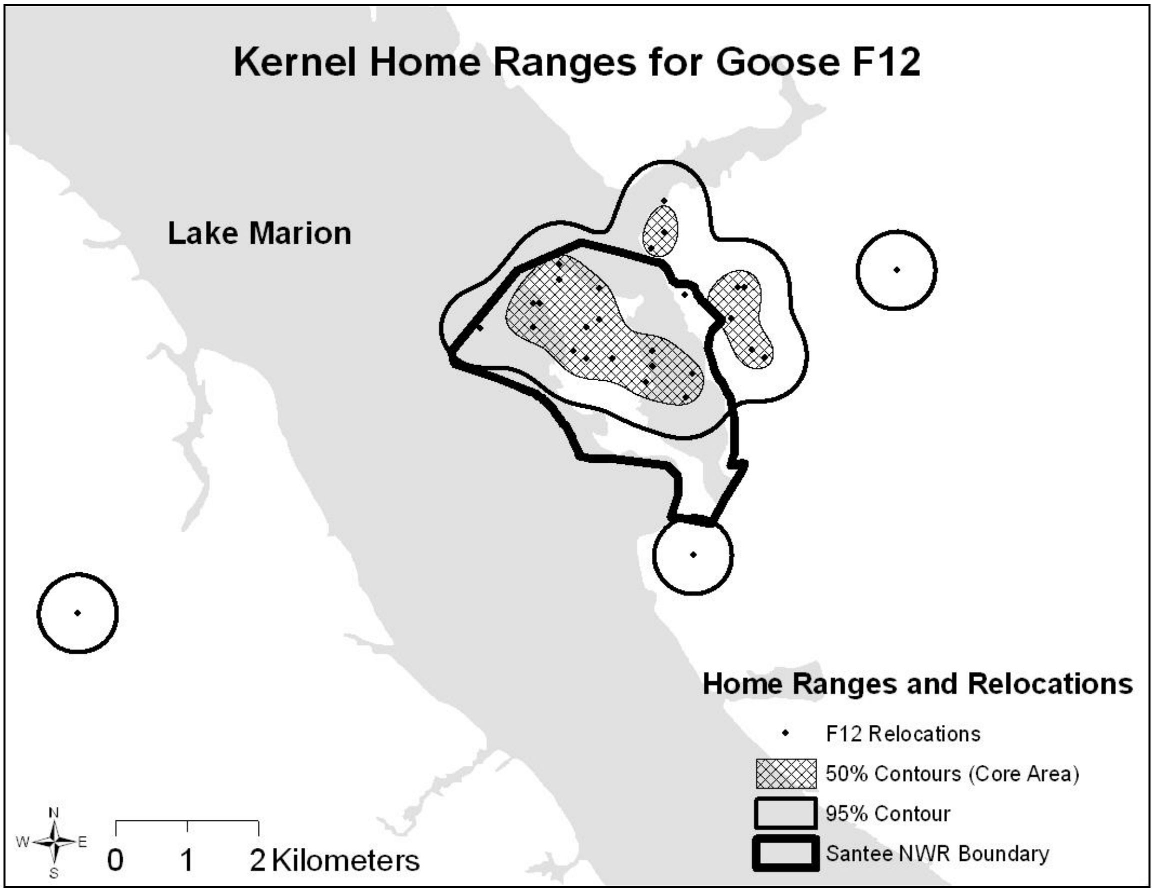


Kernel Home Ranges for Goose F9
Lake Marion
Home Ranges and Relocations
F9 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers



Kernel Home Ranges for Goose F10
Lake Marion
Home Ranges and Relocations
F10 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers


Kernel Home Ranges for Goose F11
Lake Marion
Home Ranges and Relocations
F11 Relocations
50% Contour (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0 1 2 Kilometers


Kernel Home Ranges for Goose F12
Lake Marion
Home Ranges and Relocations
F12 Relocations
50% Contours (Core Area)
95% Contour
Santee NWR Boundary
N
W
E
S
0
1
2 Kilometers