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Evaluating Satellite and Conventional VHF Telemetry to Document Molt Migration of Giant Canada Geese (Branta canadensis maxima) From Southeastern Michigan

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Harold H. Prince
Major professor

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EVALUATING SATELLITE AND CONVENTIONAL VHF TELEMETRY TO DOCUMENT MOLT MIGRATION OF GIANT CANADA GEESE (*Branta canadensis maxima*) FROM SOUTHEASTERN MICHIGAN

By

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ABSTRACT

EVALUATING SATELLITE AND CONVENTIONAL VHF TELEMETRY TO DOCUMENT MOLT MIGRATION OF GIANT CANADA GEESE (*Branta canadensis maxima*) FROM SOUTHEASTERN MICHIGAN

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Locations of molting areas and timing of movements of molt migrant giant Canada geese have not been described completely due to the lack of an unbiased technique of study. The utility of using satellite and conventional VHF telemetry was evaluated to identify molting locations and document the chronology of molt migration of unsuccessful breeding geese in southeastern Michigan.

Satellite and VHF transmitters provided similar information with regards to departure times, molt sites and return times of molt migrants with birds departing during late May-early June, showing an affinity during the molting period for habitat along the eastern and western coasts of James Bay, the eastern coast of Hudson Bay and the Belcher Islands, and returned to Michigan between September and October.

Satellite transmitters removed temporal and geographic bias and provided reference points for VHF searches while VHF transmitters provided a means of refining PTT location estimates.

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I am grateful to my parents for encouraging me to pursue my goals and to Lynn for supporting me and always giving me perspective. Finally, I would like to thank my mentor and friend Dr. David H. Ellis. His accomplishments, sense of adventure and encouragement have inspired me and given me focus as I pursue a career in wildlife biology.

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INTRODUCTION

Post-breeding migration of waterfowl in the northern Hemisphere was first described by Ekman (1922) as reported by Hohman et al. (1992). Movements from breeding areas to sites where individuals molt wing feathers occurs between nesting and fall migration and has been termed "molt migration" (Salmonsen 1968). Molt migrations of Canada geese are well documented in North America (Kuyt 1966, Zicus 1981, Davis et al. 1985, and Abraham et al. 1999) and individuals making these northward movements consist primarily of subadults, non-breeding adults and failed breeders (Hanson 1965, Sterling and Ddzubin 1967 and Lawrence et al. 1998). These flights range from short, <150 km localized movements (Dimmick 1968), to > 3,000 km (Krohn and Bizeau 1979). Although molt migration has been well documented, locations of molting areas and timing of movements have not been described completely for the lack of an unbiased technique of study. For example, current data describing molt migration has been collected from band and neck collar studies, which are inherently biased temporally and geographically when used to describe avian movements over broad spatial scales in remote settings. Using satellite transmitters (Platform Transmitting Terminals or PTT's) and conventional VHF radio transmitters may provide a less biased means of documenting these movements.

Conventional radio telemetry has been used to study numerous species of waterfowl for over thirty years including Canada geese, wood ducks (*Aix sponsa)*, mallards (*Anas platyrhynchos)*, canvasbacks (*Aythya valisineria)*, and snow geese (*Chen caerulescens)* (Cochran et al. 1963, Ball 1971, Greenwood and Sargeant 1973, Perry

1981, and Hughes et al. 1994). Until recently, PTT's were only available to study large reptilian, mammalian and avian species, such as loggerhead sea turtles (*Caretta caretta*), polar bears (*Ursus maritimus*) and lesser spotted eagles (*Aquila pomarina*), due to their encumbering sizes and weights (Stoneburner 1982, Messier et al. 1992 and Meyburg et al. 1994). Although traditionally VHF transmitters were used exclusively in telemetry studies of waterfowl, advancements within the past ten years reduced the size and weight of PTT's and made it possible to track movements of smaller avian species including spectacled eiders (*Somateris fischeri)*, lesser white-fronted geese (*Anser erythropus)*, greater snow geese (*Chen caerulescens atlantica*), peregrine falcons (*Falco peregrinus)* and Canada geese (Petersen et al. 1995, Lorentsen et al. 1998, Blouin et al. 1999, Britten et al. 1999, Malecki et al. 2001).

Although both PTT's and VHF transmitters can provide useful location information, few studies have utilized a combination of satellite and VHF transmitters to track animal movements. The objective of this study was to evaluate the utility of satellite and VHF transmitters to identify molting locations and document the chronology of molt migration of unsuccessful breeding geese in southeastern Michigan.

METHODS

Study Area

Study sites were distributed over 11 counties in southeastern Michigan that included major metropolitan areas of Detroit, Pontiac, Ann Arbor and Lansing, and adjoining agricultural lands (Figure 1). Thirteen and 15 study sites were selected during 2000 and 2001, respectively, to provide a spatial distribution of samples that is representative of Canada goose distribution in southeastern Michigan. At each study site, an incubating female was trapped and marked with a PTT. An effort was then made to capture at least 2 more incubating females within 5 km of the PTT marked bird and mark these birds with VHF transmitters in order to compare the two marking techniques.

Telemetry Equipment

PTT and VHF radio transmitters were manufactured by Telonics, Inc. (Mesa, AZ) and were attached to green neck collars provided by the Michigan Department of Natural Resources (MDNR). Each collar had a unique four digit alphanumeric code (Figure 2). Neck collars were made from Romark® (Spinner Plastics, Springfield, IL) plastic tubes (7.0 cm – 7.6 cm wide, 5.0 cm diameter, and 0.2 cm thick with a 2.5 cm overlap of the tube ends). Reward labels were affixed to each transmitter, offering $100 U.S., to increase the probability of return if found. VHF units were designed to have the antenna attached directly to the collar. It was necessary to have an external antenna protruding from the PTT's, otherwise signal strength would have been compromised. Since geese damaged some PTT's the first year (see results), the antenna was redesigned for the 2001

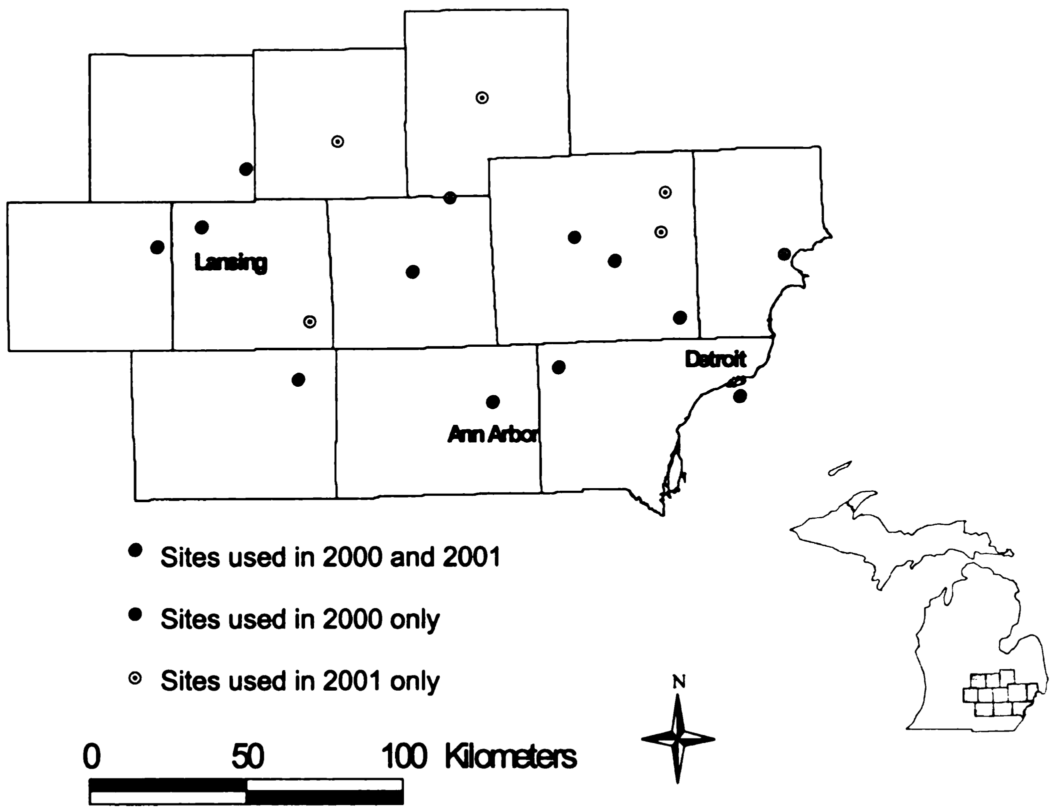


Figure 1. Michigan study area (shaded region enlarged in upper- left), with dots representing Canada goose capture sites, 2000-2001.

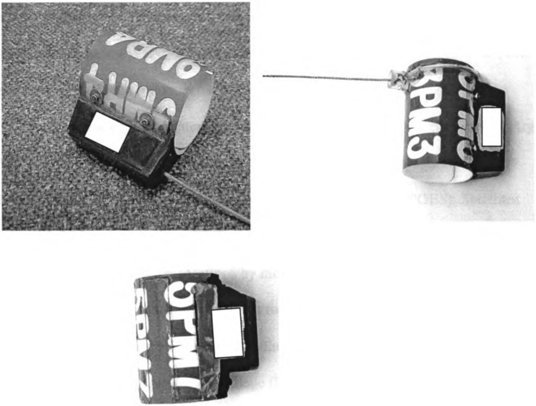


Figure 2. Transmitter designs used during 2000 and 2001: a.) PTT with antenna protruding from base, oriented downward and rested on bird's breast (2000); b.) PTT with reinforced antenna protruding from top of collar, antenna oriented behind bird's head, parallel to the back of the bird; c.) VHF transmitter with antenna wrapped around collar (2000 and 2001).

field season to reduce PTT failure due to antenna damage from preening. Satellite transmitters had a specified battery life of 360 hours that were distributed over four separate monitoring periods (Table 1). The duty cycle was designed to maximize battery life for approximately 11 months over the 4 periods. The duty cycle was altered to begin 16 days earlier during year 2 to ensure that the 4-day cycle would begin prior to peak departure times of molt migrants based on first year results.

Satellite location estimates were received from the Argos System (Service Argos 1996). ARGOS instruments are flown on board National and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites (POES). Satellites receive ARGOS messages from PTT's and relay them to the ground in real-time. ARGOS estimates transmitter locations by measuring the Doppler shift of the PTT signals and provides two location estimates for each satellite pass. ARGOS designates the location with the better signal continuity as the best location (location 1), and the alternate location is designated as the image (location 2). Location classes were assigned by ARGOS based on the estimated accuracy and the number of transmissions received from a PTT during a selected overpass (Table 2). When data are received, location 1 or 2 is chosen from each individual PTT message by removing the biologically implausible location from the pair as described by Britten et al. (1999) and Malecki et al. (2001), entered into a spreadsheet and projected onto a map using ArcView® 3.2 GIS software.

VHF transmitters had a specified battery life of 14 months and transmitted a continuous signal. A mortality sensor was activated following 4 hours of motionless. VHF units had effective ground and aerial ranges of 3 and 16 km, respectively, based on field testing before and after deployment. Ground searches for birds were made using

Table 1. Duty cycle of satellite transmitters used during the 2000 and 2001 field seasons. Signals were transmitted for a 6-hour period on the scheduled transmission day. The battery use percentage is the cumulative amount of battery power used by the end of each transmission period.

Duration					
Period	2000	Battery Use %	2001	Battery Use %	Interval (days)
1	Apr 1 – May 27	13	Apr 1 – May 11	10	8
2	May 28– Oct 26	77	May 12- Oct 22	78	4
3	Oct 27- Dec 21	83	Oct 23- Dec 31	87	14
4	Dec 22- Mar 12	100	Jan 1 – Mar 5	100	8

Table 2. Accuracy of location classes assigned to PTT transmissions. The minimum number of messages received during a satellite overpass are used to calculate locations and designate the location accuracies.

Location Class	Expected Location Accuracy (m)	Minimum number of messages received
3	< 150	4
2	150 – 350	4
1	350 – 1000	4
0	> 1000	3
A	no estimate of accuracy	3
B	no estimate of accuracy	2
Z	insufficient information to obtain a location	< 2

truck mounted whip antennas and 3-element yagi antennas. Aerial searches were conducted with directional "H antennas" mounted to the wing struts of the plane. A Cessna 172 and a Cessna 206 were used to search for VHF marked birds from the air at altitudes ranging from 833 – 1170 meters.

Capturing Geese

Although incubating female Canada geese were the primary focus for capture by nest trapping, rocket nets were also used in attempt to make use of additional VHF transmitters that were not deployed during the nesting season. Rocket netting was used on flocks of geese that were presumed to be engaging in pre-molt migration behavior. Active nests were located during April and May of 2000 and 2001. Capture on nests was accomplished at night 73% and 87% of the time during 2000 and 2001, respectively, while the remainder of the birds were captured during the day. "Night-lighting", similar to the method described by Dennis (1966), was accomplished by one individual carrying a landing net (hoop size of 81.28 cm x 96.52 cm x 91.44 cm deep with a 121.92 cm handle) following closely behind a person shining a 1 x 6^6 candle power q-beam® spotlight directly onto an incubating female. Once the team approached within 1 – 2 m of the nest, the landing net was quickly draped over the bird. Landing nets were also used for capturing birds during the day that would remain on the nest long enough for capture. Upon capture, the bird was quickly secured to prevent wing injuries and damage to eggs in the nest.

Rocket net sites were chosen by looking for areas frequently used by 10-15 geese in mid to late May. Sites used by larger flocks were avoided. Birds were attracted to specific areas by baiting with whole corn (*Zea mays*) 2-3 days prior to launching rocket nets.

Geese were fitted with either a PTT or a VHF transmitter upon capture and an aluminum United States Fish and Wildlife Service (USFWS) leg band. Geese were then sexed by cloacal examination and examined for a brood patch, and weight, skull length, and culmen length measurements were taken (Hanson 1965 and Dzubin and Cooch 1992).

To maximize the chance for molt migration, all nests of captured incubating females were destroyed. Upon capture and processing of an incubating hen, one egg was removed from the nest and aged by examining the developmental stage of the embryo. Embryos were killed by decapitation as recommended by the Michigan State University (MSU) committee on animal use. The entire clutch was removed if the age was determined to be greater than 14 days. If an embryo was less than fourteen days of age, the remainder of the clutch was left in the nest and eggs were removed at a later date to discourage renesting. Each nest site location was documented after all trapping had taken place using a Trimbel™ TSC1™ data collector and GPS Pathfinder ® Pro XRS receiver that provided accuracy to < 1m.

VHF Monitoring

VHF radio tracking from the ground commenced in early May during both years and the level of search effort to document departures and returns was similar to the monitoring schedule for satellite transmitters. Each frequency was searched for on the study area every 5 days through August 2000 and at least every 6 days from September through November 2000 and at least once every 10 days through March 2001. Search effort was increased in year 2 and each frequency was searched for every 3-4 days through mid-June (peak departure period of molt migrants based on first year observations), once per week through August, every 3-4 days during September and October (peak return period of molt migrants to Michigan based on first year observations) and once per week from November through March.

Ground searches for molt migrants during departure and return periods were conducted within an 8-km radius of individual capture sites. Aerial searches were conducted during peak molt migrant departure and return periods to supplement ground searches. Although aerial searches were designed to cover the entire study area based on effective detection ranges of VHF transmitters, access was often denied to air space over Detroit, requiring an increased search effort from the ground. An aerial search was conducted in late July, 2000 and 2001, along the eastern and western coasts of James Bay, the eastern coast of Hudson Bay and the Belcher Islands, to search for VHF marked birds that had presumably departed Michigan and made molt migrant flights north (Figure 3). Search effort was concentrated in areas where PTT marked molt migrants were located. A Garmin® panel mounted aviation GPS unit was used to determine the latitudes and longitudes of VHF marked birds detected on northern molting grounds.

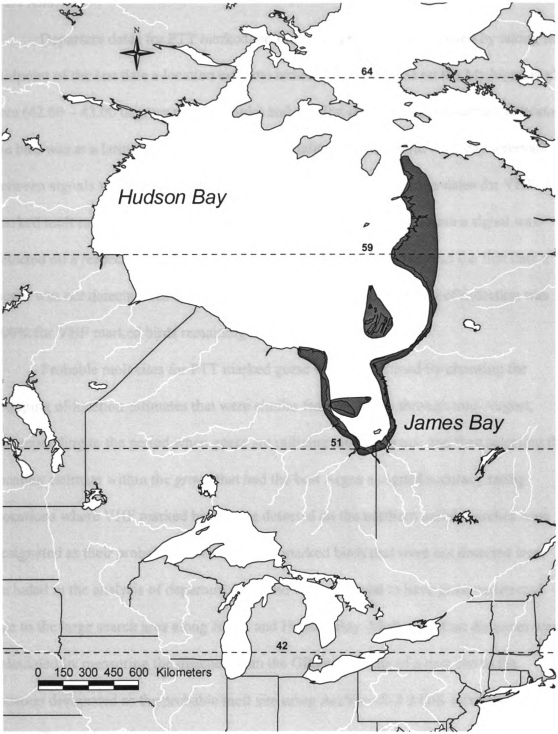


Figure 3. Area searched during 2000-2001 telemetry flights of James and Hudson Bay represented by shaded region. Shaded region is exaggerated to emphasize areas searched. Dashed lines represent degrees north latitude.

Data Analysis

Departure dates for PTT marked molt migrant geese were estimated by taking the midpoint of the last date a location estimate indicated the bird was on the Michigan study area (42.00 – 43.00 degrees north latitude) and the first date a location estimate indicated the bird was at a latitude > 43.00 degrees north latitude. PTT's with > 12-day intervals between signals were not used to estimate a departure date. Departure dates for VHF marked molt migrants were estimated using the midpoint of the last date a signal was detected on a respective capture site within the Michigan study area and the first date a signal was not detected. An assumption was made that the probability of detection was 100% for VHF marked birds remaining on the study area.

Probable molt sites for PTT marked geese were determined by choosing the grouping of location estimates that were similar from mid-July through mid-August, corresponding to the period when geese are utilizing molting areas, and then selecting the location estimate within the group that had the best Argos assigned accuracy rating. Locations where VHF marked birds were detected on the northern aerial searches were designated as their probable molt sites. VHF marked birds that were not detected were included in the analysis of departure dates and were assumed to have gone undetected due to the large search area along James and Hudson Bay. Molt migration distances were calculated by measuring the distance from the GPS coordinate of a nest site to the location designated as the probable molt site using ArcView® 3.2 GIS software.

Return dates for PTT marked molt migrants were calculated by taking the midpoint of the last date a location estimate indicated the bird was at a latitude > 43.00 north latitude and the first date a location estimate indicated the bird was on the Michigan study area (43.00 – 42.00 degrees north latitude). PTT's used during 2000 did not provide accurate estimates of return times, therefore any information gathered was expressed as the latest possible return date. Return dates for VHF marked molt migrants were estimated using the midpoint of the first date a signal was detected on a respective capture site within the Michigan study area and the last date a signal was not detected. Although direct hunter returns of harvested VHF marked birds provided information about return dates these birds were removed from all transmitter comparison analyses because their probability of detection was reduced.

All statistical analyses were performed with JMP®4 statistical software (SAS® Institute Inc.).

Cost estimates for PTT's and VHF transmitters were based on molt migration data that was collected from May through mid-November corresponding to the migration and molting period of molt migrant geese. All results are presented in U.S. dollars.

RESULTS

Equipment, Trapping

Forty-eight geese were marked with either PTT or VHF transmitters during the 2000 breeding season (Table 3). An additional 53 geese were captured and marked during 2001. PTT and VHF transmitters weighed an average of 69.6 g (n = 15, SD 0.7) and 82.8 g (n = 33, SD 0.7), respectively in 2000 and 73.2 g (n = 17, SD 0.8) and 82.3 g (n = 35, SD 0.9) in 2001. PTT and VHF transmitters represented < 3 % of goose body mass for all geese marked in 2000 and 2001. The only death both years immediately following marking was a rocket-netted female found dead near the trap site two days following capture in 2000.

Table 3. Number of giant Canada geese captured on nests or via rocket nets in southeastern Michigan and marked with PTT's or VHF transmitters, 2000-2001.

	2000		2001	
	PTT	VHF	PTT	VHF
Nest trapped females	15	23	17	34
Rocket net	0	10[a]	0	2[b]
Total	15	33	17	36

[a] – sample includes 8 sub-adult females and 2 sub-adult male geese.
[b] – sample includes 1 female with brood patch and 1 male (possible mate)

PTT malfunctions were detected soon after deployment during the 2000 field season. Two transmitters failed to transmit signals until about 1 month after deployment while 4 PTT's failed two months into the study (Figure 4). The number of PTT's functioning declined through September and by late-October all of the PTT's had stopped transmitting signals. Although 3 PTT's stopped transmitting signals by October during 2001, overall transmitter longevity improved. On average, PTT's were operational for 48% (n = 12, sd = 20%) and 78% (n = 13, sd = 14%) of their expected battery life during 2000 and 2001, respectively. PTT's were observed missing antennas during both years (2000, n = 4, and 2001, n = 4). PTT failure was defined as the date a transmitter began to yield only Z location classes, or provided no messages, or a combination of the two.

We received fewer transmissions (Z locations were excluded because they provided no location information)(ANOVA $P < 0.0001$) from PTT's in 2000 (n = 12, $\bar{x}$ = 37.3, SE = 13.7) compared with 2001 (n = 13, $\bar{x}$ = 129.2, SE = 13.18). The percentage for location class ratings for geese banded in 2000 (n = 905 locations) was LC = 3 (0.3%),2 (0.6%), 1 (2.1%), 0 (17.1%), A (10.2%), B (19.1%) and Z (50.6%). Redesign of the antennas by changing the orientation from protruding downward from the base of the radio and resting on the bird's breast (2000) to an orientation of 180 degrees from the radio parallel to the bird's back (Figure 2) (2001) to reduce tampering by individuals resulted in a significant improvement ($X^2_{df=6} = 65.9$, p = < 0.0001) in the percentage for location class ratings to LC = 3 (0.5%),2 (0.7%), 1 (2.3%), 0 (24.7%), A (14.8%), B (21.0%) and Z (39.7%)(n = 2624 locations). There was no significant difference between years upon removing Z locations ($X^2_{df=5} = 6.6$, p = 0.2508) and performing a new Chi-square test, indicating that the improved performance during 2001 was attributed to fewer Z readings. Three PTT's from 2000 were not included in the analysis of PTT performance because they were malfunctioning and removed from the bird prior to the

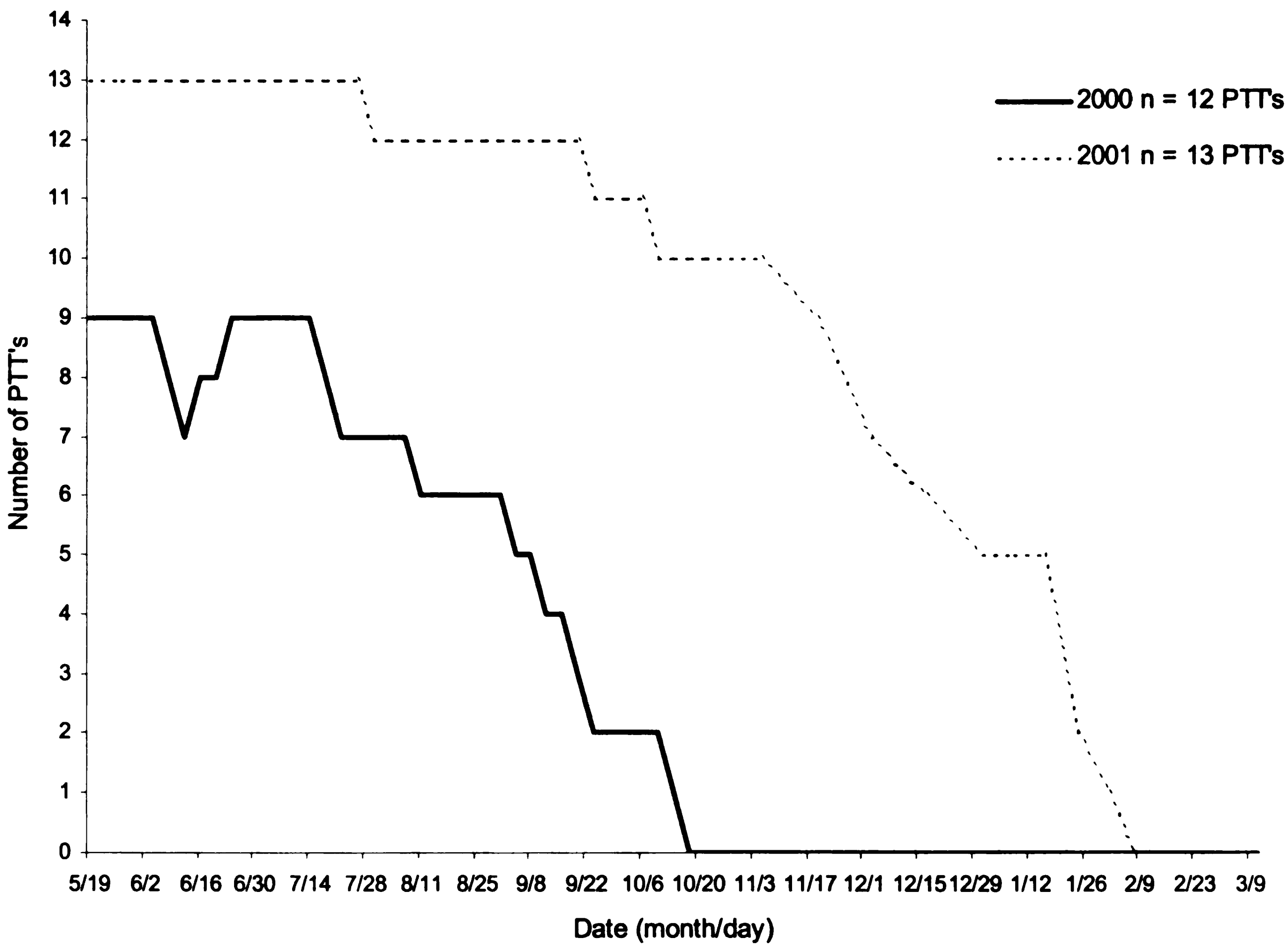


Figure 4. Number of PTT's functioning during scheduled transmission periods, 2000-2001.

expiration of the expected battery life of the transmitters and 4 PTT's that were attached to birds that were harvested by hunters were not included from 2001.

All VHF marked birds were located within 3 km of their respective capture locations through mid-May and contact was lost as molt migration began during both years (Figure 5). Non-molt migrant females remained and molted on breeding territories through mid-August and were routinely found on each search during 2000 and 2001. Non-molt migrants were located with variable success through the end of August during 2000 in comparison to 2001 as detection rates for non-molt migrants improved. Molt migrants returning to Michigan were also located with variable success during 2000. Conversely, detection of molt migrants returning to Michigan improved during 2001. Seventy-three and 62% of molt migrants were located in July 2000 and 2001, respectively, during telemetry flights of James and Hudson Bay. There was no evidence of any significant VHF malfunction both years.

The quality of data obtained from VHF transmitters and PTT's describing molt migration varied within and between years (Figure 6). Although a higher percentage of the PTT's deployed on molt migrants provided information on probable molt sites during 2000, data collected from VHF transmitters yielded more samples for molt sites and migration timing. During 2001 there was a significant improvement in PTT function and we were able to obtain migration timing and probable molt site data for all transmitters. Although VHF transmitters produced similar results during both years, there was a significant improvement for return data collected during 2001.

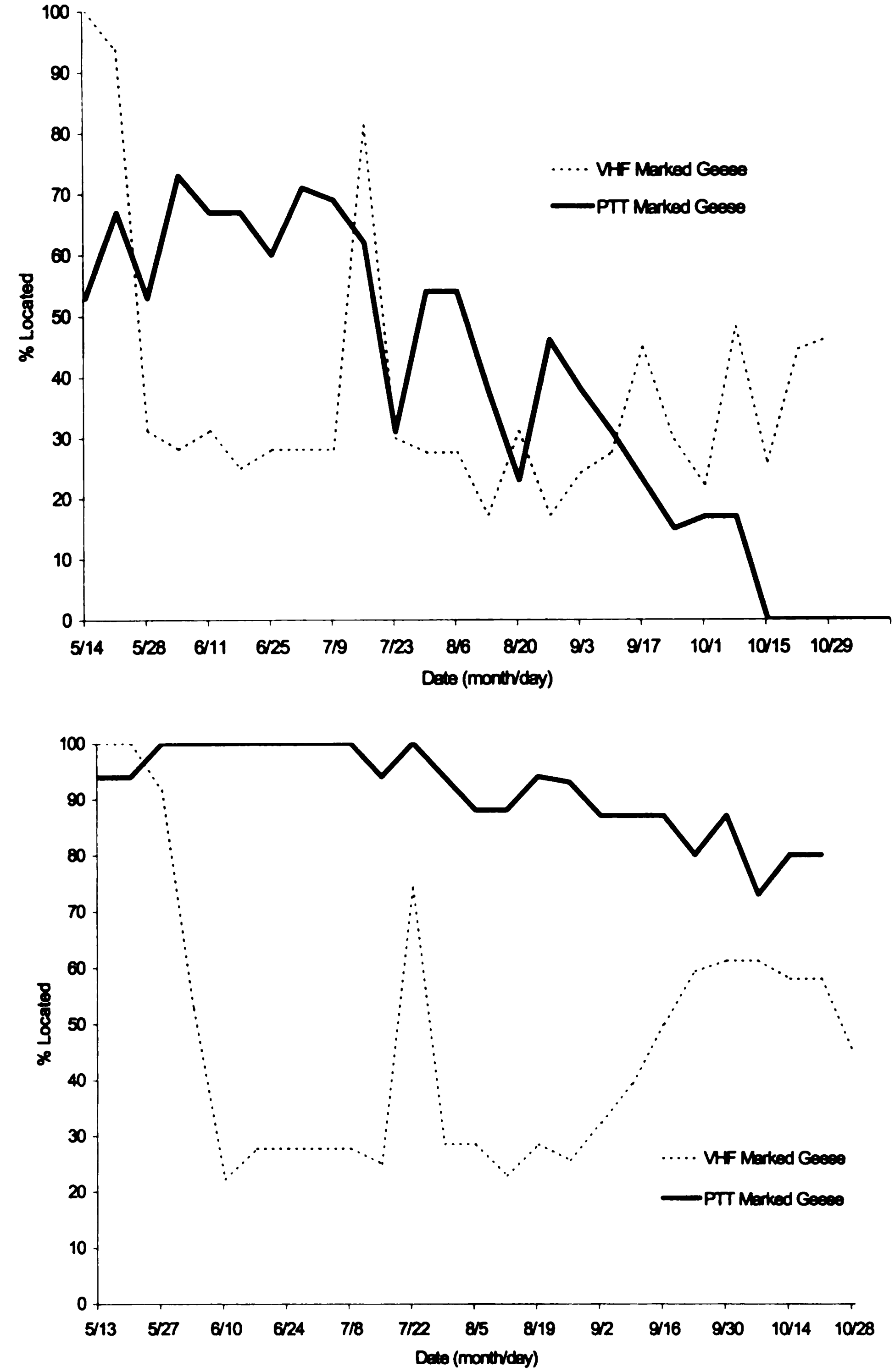
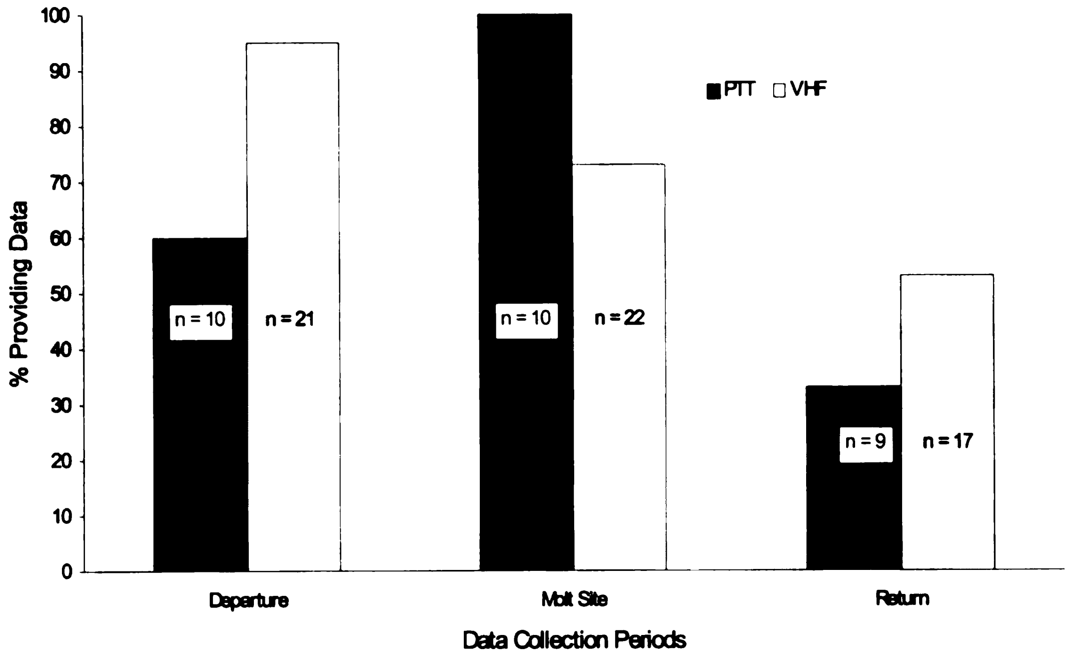


Figure 5. Success in tracking Canada geese from southeastern Michigan marked with PTT and VHF transmitters, 2000-2001.



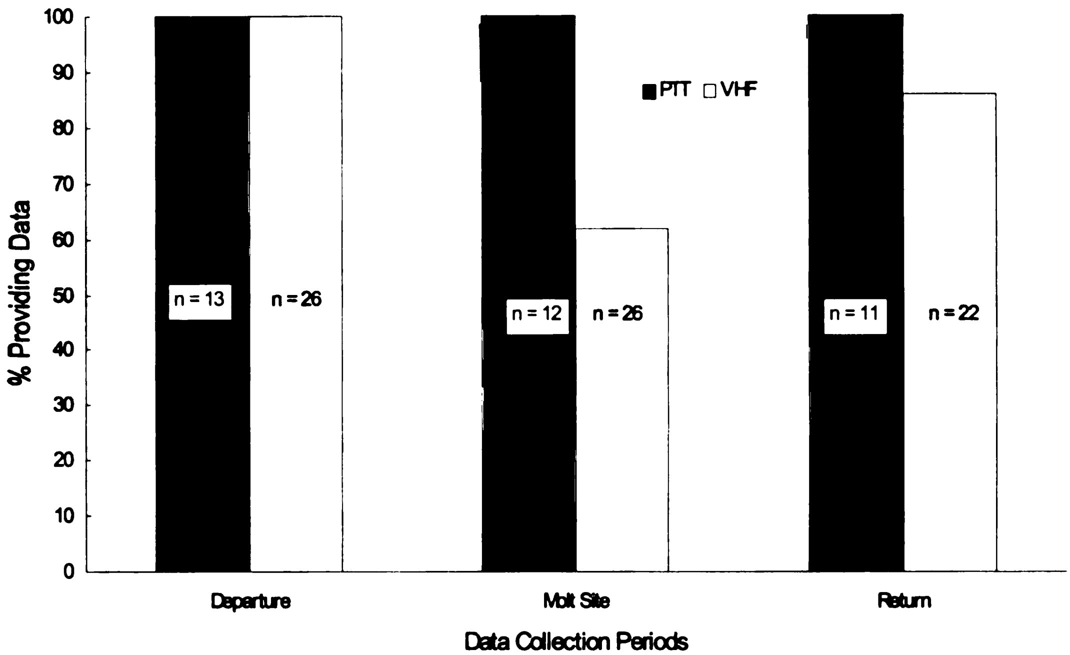


Figure 6. Percentage of PTT's and VHF transmitters providing departure time, molt site and return time data for molt migrants from southeastern Michigan, 2000-2001.

Molt Migration

Among females that lost nests, there was no significant difference in the percentage that made long distance movements during 2000, 62.2% (n = 37), and 2001, 73.1% (n = 52), ($X^2_{df=1} = 1.19$, $p = 0.2745$). All 9 sub-adults marked with VHF transmitters in 2000 molt migrated and 1 adult male marked with a VHF transmitter in 2001 (presumably the mate of the rocket netted female observed with a brood patch) molt migrated. Departure dates of PTT (n = 6) and VHF (n = 21) marked geese in 2000 were similar, with 80% of birds marked with either a PTT or VHF transmitter departing by May 29 (Figure 7). Peak departure dates for PTT and VHF marked birds in 2000 were May 25 and May 27, respectively. PTT (n = 13) and VHF (n = 26) marked geese departed about one week later during 2001, with 80% of the birds marked with either transmitter type departing by June 6. Peak departure dates of PTT and VHF marked geese in 2001 were June 4 and June 2, respectively. Departure dates for each PTT and VHF marked bird are presented in Appendix A.

During 2000, 10 PTT marked geese molt migrated to locations along the east and west coast of James Bay in northern Ontario and Quebec, the northeastern coast of Hudson Bay in Nunavik as well as the Belcher Islands, Nunavut in the southeastern Hudson Bay as far north as the Fox Peninsula of Baffin Island, Nunavut, representing latitudes from 54 degrees north to 64 degrees north (Figure 8). Flight distances for PTT marked birds to probable molt sites ranged from 1,336 km – 2,537 km. Breeding and probable molt site locations and flight distances for each VHF and PTT marked bird are presented in Appendix B. The 4 PTT marked geese that did not molt migrate remained at approximately 42 degrees north latitude during the summer flightless period. These birds

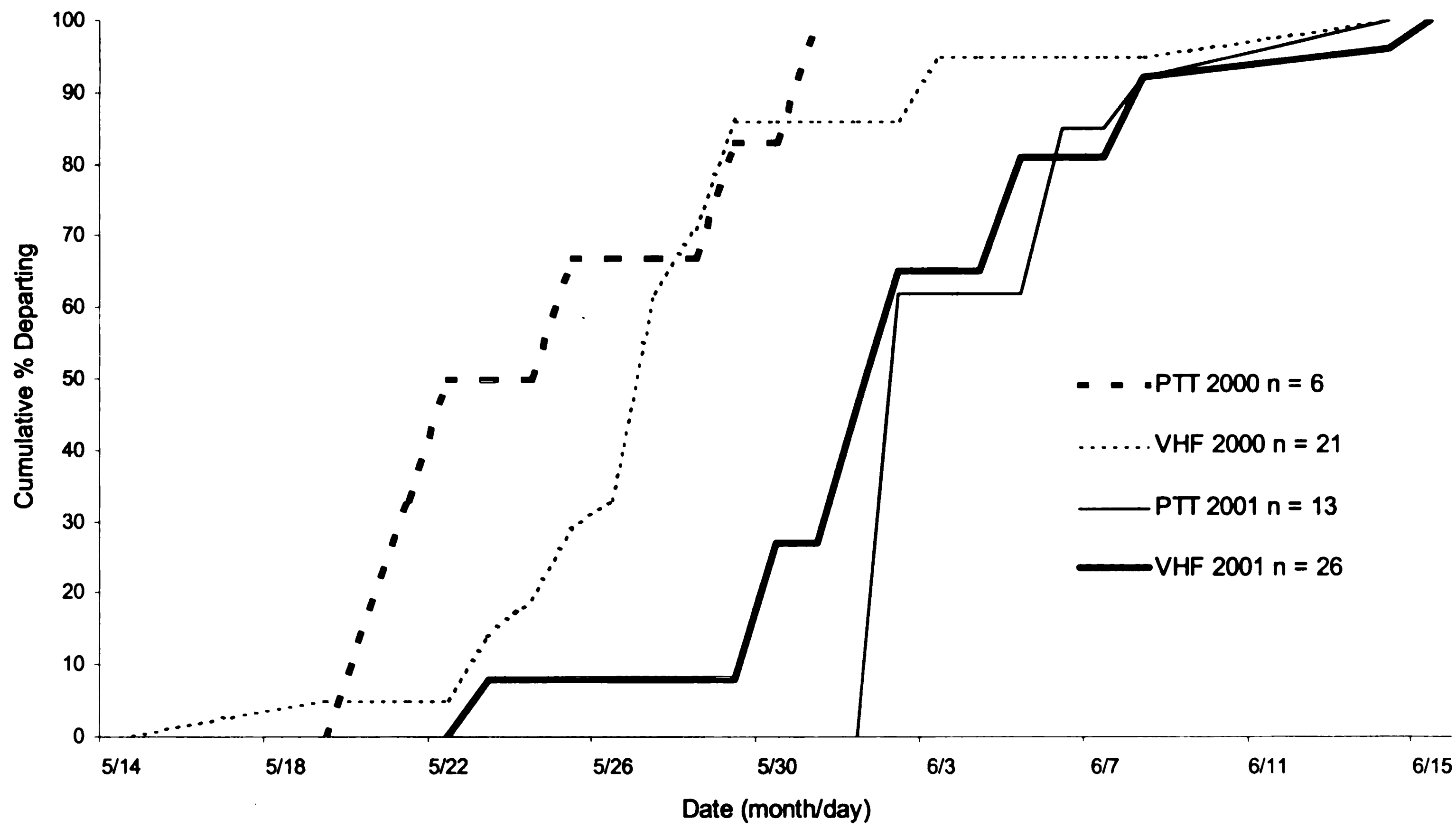


Figure 7. Cumulative departure dates for molt migrant Canada geese from southeastern Michigan marked with PTT's and VHF transmitters, 2000-2001.

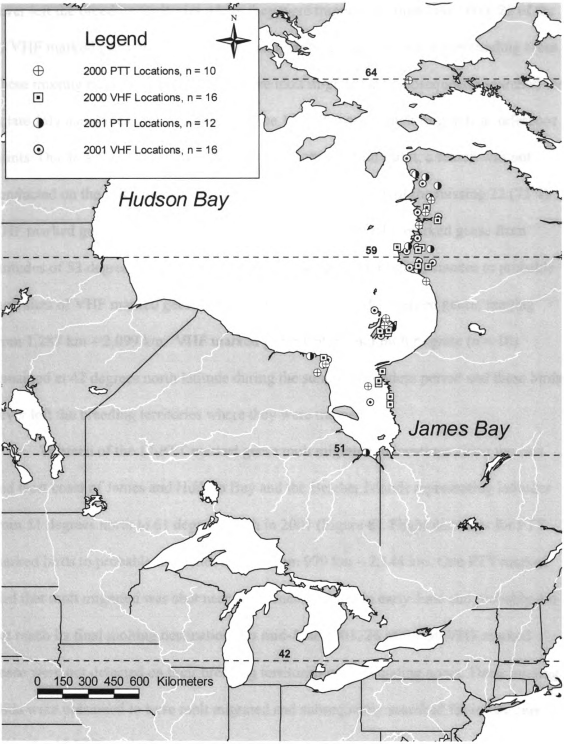


Figure 8. Probable molt site locations of molt migrant Canada geese from southeastern Michigan marked with PTT's and VHF transmitters, 2000-2001. Dashed lines represent degrees north latitude.

never left the breeding territories where they were trapped. By mid-June 2000, 22 of the 32 VHF marked geese were not detected on their breeding territory or surrounding areas. These missing birds were presumed to have molt migrated and subsequently searched for in late July using location estimates from the 10 PTT marked molt migrants as reference points. Due to a flight distance of 405 km across the Hudson Strait, a search was not conducted on the Fox Peninsula of Baffin Island. A total of 16 of the missing 22 (73%) VHF marked geese were located in similar locations to the PTT marked geese from latitudes of 53 degrees north to 60 degrees north (Figure 8). Flight distances to probable molt sites of VHF marked geese were similar to those of PTT marked geese, ranging from 1,287 km – 2,099 km. VHF marked geese that did not molt migrate (n = 10) remained at 42 degrees north latitude during the summer flightless period and these birds never left the breeding territories where they were trapped.

Thirteen of the 17 PTT marked geese molt migrated to locations along the east and west coast of James and Hudson Bay and the Belcher Islands representing latitudes from 51 degrees north to 61 degrees north in 2001 (Figure 8). Flight distances for PTT marked birds to probable molt sites ranged from 979 km – 2,144 km. One PTT marked bird that molt migrated was shot near Moosonee, Ontario in early June and probably did not reach its final molting destination. By mid-June 2001, 26 of the 36 VHF marked geese were not detected on their breeding territories or surrounding areas. These missing birds were presumed to have molt migrated and subsequently searched for in late July using the 12 PTT marked molt migrants as reference points. A total of 16 of the missing 26 (62%) VHF marked geese were located in similar locations to the PTT marked geese from latitudes of 53 degrees north to 62 degrees north. Flight distances to probable molt sites of VHF marked geese were similar to those of PTT marked geese, ranging from 1,233 km – 2,230 km. VHF marked geese that did not molt migrate (n = 10) remained at 42 degrees north latitude during the summer flightless period and never left the breeding territories.

One female marked with a PTT presumably died on the northern molting grounds during 2000, which was based on 2 messages received in late January, indicating that the bird had never left its molting site. Mortality signals were detected for 3 VHF marked geese on molting areas during our aerial search of James and Hudson Bay during 2000. A mortality signal was detected for 1 VHF marked goose on the molting areas during 2001. Direct hunter returns indicated that 2 PTT marked molt migrant geese were harvested near northern molting areas during 2001 (One during the migration north and 1 during the return migration south). Location estimates for the remaining PTT marked birds indicated that all survived to attempt flights south from the molting areas, during 2001.

PTT location estimates for 3 marked birds during 2000 indicated that molt migrants return to Michigan no later than the period between September 16 and 26 September. An estimate of the actual return time was not calculated because the time elapsed between location estimates was too large. Although location estimates from a fourth PTT showed a southern movement from Baffin Island (64 degrees north latitude) to 50 degrees north latitude by September 20, the PTT stopped transmitting at this point and we were unable to track subsequent movements. This bird was observed later on a breeding territory in early March indicating it had survived the return flight to Michigan. During 2000, VHF marked birds (n = 9) began to be detected on the southern Michigan study area as early as August 31 and detecting continued through November 10, with

80% returning by September 21 (Figure 9). Direct hunter returns on September 20, September 21 and October 23 for 3 VHF marked birds provided additional return data, but were not included Figure 9.

PTT location estimates for 10 marked birds in 2001 indicated that molt migrants return to southern Michigan between September 8 and October 30 with 80% returning by September 18. One additional PTT marked bird migrated south, but remained ~ 570 km to the north east of study area through November. We were unable to track subsequent movements since the PTT ceased to transmit in early December. VHF marked birds (n = 19) began to be detected on the southern Michigan study area between September 5 and November 14, with 80% returning by September25, one week later than PTT marked birds . Direct hunter returns on September 3, September 6 and October 6 for 3 VHF marked birds provided additional return data. Return dates for PTT and VHF marked geese are presented in Appendix A.

Molt migrants returned to areas within close proximity (within 16 km) to their breeding territories by mid-November 85% and 88% of the time during 2000 (n = 13) and 2001 (n = 32), respectively. These numbers are based on individuals known to have survived through the following nesting season of each year.

Cost Analysis of Transmitters

The average cost, includes purchasing plus monitoring, to operate PTT's during both years was 1.4 times greater than the cost of operating VHF transmitters. During 2000 the average cost to operate each PTT (n = 15) was $1,920 compared to $1,397 for VHF units (n = 32). During 2001 the cost to operate each PTT (n = 17) was $1,946

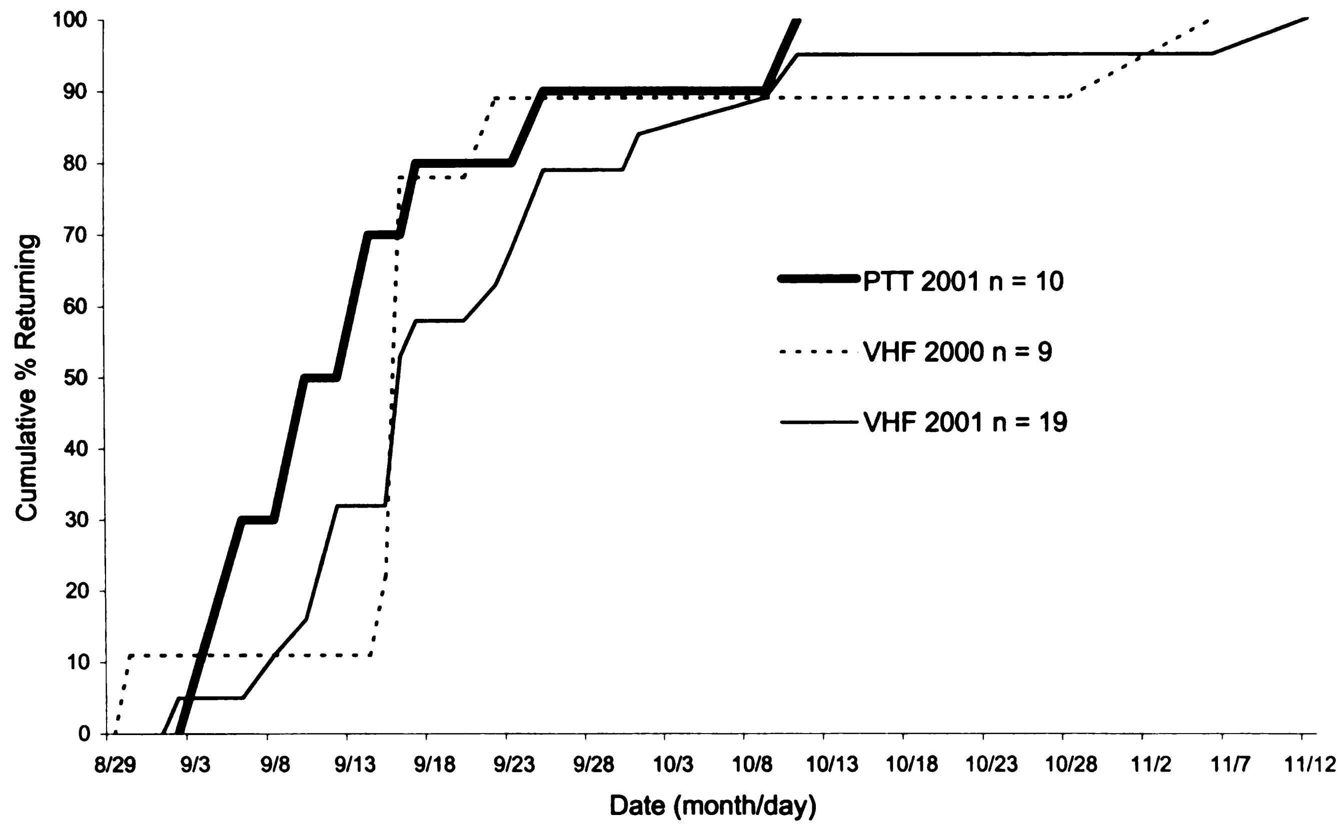


Figure 9. Cumulative return dates of molt migrant Canada geese from southeastern Michigan marked with PTT's and VHF transmitters, 2000-2001. PTT data from 2000 was not included in the analysis of return times (see results).

compared to $1,389 for VHF units (n = 36). Costs associated with each transmitter are presented in Table 4. Although PTT's were more expensive to operate on a *per* transmitter basis, each location acquired from PTT's during both years was less expensive than locations acquired from VHF transmitters. During 2000 the cost to obtain a PTT location (n = 550) was $53 compared to $129 for VHF units (n = 346). During 2001 the cost to obtain a PTT location (n = 1,287) was $26 compared to $99 for VHF units (n = 505). Z locations were not used to determine *per* location costs for PTT's.

Table 4. Costs associated with obtaining location information for PTT and VHF radio transmitters during 2000 and 2001. 2000: PTT (N = 15), VHF (N = 32); 2001 PTT (N = 17[a]), VHF (N = 36[b]).

	2000		2001	
Cost Category	PTT	VHF	PTT	VHF
Manufacturing/ Unit	1594.00	235.69	1594.00	235.69
ARGOS System	5143.00	[e]	8051.00	[e]
Grad/Tech Salary for Radio Searches	[e]	15595.00	[e]	17100.00
Flights[c]	[e]	14482.00	[e]	16226.00
Ground Tracking[d]	[e]	4014.00	[e]	5630.00
Receiver Refurbishment	[e]	2831.18	[e]	2831.18

[a] - 3 PTT's were refurbished at $800.00/unit
[b] - 5 VHF transmitters were refurbished at $145.00/unit
[c] - Flight costs also include meals and lodging during search of sub-Arctic areas
[d] - Total distance traveled was multiplied by $0.36/mile
[e] - Not applicable

DISCUSSION

The orientation and durability of the PTT's antennas had major implications on the results obtained during both years. The reconfiguration of the antenna was the most important factor leading to the significant improvement in PTT longevity and location class ratings during 2001. Although geese were able to remove antennas in 2001, the orientation and reinforcement most likely prevented antenna destruction from occurring early and did not impact molt site and return data. Although the effect of antenna manipulation by birds on PTT location results has not been quantitatively assessed, evidence exists documenting aggressive preening of radios by marked individuals. For example, Perry (1981) suggested that VHF radiomarked canvasbacks may have dislodged backpack mounted transmitters because they failed to adapt to telemetry units and Blouin et al. (1999) documented frequent pulling of the PTT antenna by greater snow geese and would not discount antenna breakage as a possible cause for premature termination of PTT's. Blouin et al. (1999) also suggest that a vertical upward antenna orientation may improve the signal transmission versus an antenna orientation that is pointing toward the ground or a horizontal antenna lying down on the back of the bird. In addition to antenna breakage, the downward orientation may have also contributed to the poor results obtained during 2000.

The cessation of PTT function at 80% of the expected battery life during 2001, despite the improved performance, was most likely a combination of low battery output, latitude and antenna manipulation. PTT's began to fail in October 2001 after they had reached 42 degrees north latitude. The probability of detection by a satellite decreases as a PTT moves away from the poles (Service Argos 1996) and transmissions would be further compromised by a low battery output (D. Crow, Telonics, Mesa, AZ, pers. commun.). Because location results were limited beyond 80% of the expected battery life for PTT's used during 2001, studies considering these particular transmitters should plan to achieve their objectives within this time frame to avoid compromising results.

Although the limited transmission distance of VHF transmitters make their performance evaluation difficult, we had no evidence indicating that transmitters were expiring prior to their expected battery life both years. Additionally, we had similar success both years tracking VHF marked birds during the study period. Although the antenna configuration of VHF units prevented damage by preening geese, the aerial detection range may have been reduced by this design, potentially limiting our ability to detect a higher percentage of molt migrants during aerial telemetry searches along James and Hudson Bay and in Michigan when molt migrants were returning.

The increased detection rates of VHF marked molt migrants returning to Michigan in 2001 may to some degree be attributed to the improved performance of the PTT's during 2001 (Figure 5). This increased our ability to anticipate returns and return locations of VHF marked birds based on PTT locations. Lower detection rates during 2000 may also have been attributed to the higher proportion of sub-adult geese in the sample. The natal origin of the sub-adults rocket netted during 2000 is unknown and therefore our search for returning birds during 2000 may have excluded those areas limiting our ability to detect more returning birds.

We hypothesized that Michigan giants would molt migrate to the west coast of James Bay and the southwest coast of Hudson Bay based on recaptures of banded birds and reported sightings of large molt migrant flocks in these areas (Abraham et al. 1999). Using VHF telemetry alone would have resulted in few locations, since the extent of the migration was greater than anticipated, which highlights the limitations of traditional marking techniques for providing unbiased geographical distribution data.

The limitations of traditional marking techniques involving leg and neck bands and VHF telemetry to describe migration patterns or distributions have been reported frequently and usually are the impetus for initiating PTT studies (Malecki et al. 2001, McCann et al. 2001, Higuchi et al. 1996, Brodeur et al. 1996, and Petersen et al. 1995). Ely et al. (1997) suggest that due to temporal and geographic biases in recovery probabilities, that neck band observations and band recovery information was somewhat misleading when documenting the migration behavior of tundra swans (*Cygnus columbianus columbianus*) while PTT's were not biased by the distribution of observer or hunter.

The data showing the temporal distribution patterns of PTT and VHF marked birds was similar and was consistent with band and neck collar results from other molt migration studies in the Midwest. For example, Zicus (1981) and Lawrence et al. (1998) both reported that molt migrants depart within a two week period during late May and early June from Wisconsin and Illinois, respectively, while return dates occurred over a period from mid-August through mid-November. Although results were similar, PTT's provided less biased estimates of departure dates from Michigan and arrival times of molt migrants on the Michigan study area during return flights in the fall once the antenna problem was resolved. Date estimates from PTT's were less biased because locations were consistently received every 4 days. In contrast, VHF transmitters provided an approximation of a departure or return date based on the assumption that undetected birds had departed the Michigan study area or had not yet arrived in the fall.

Departure dates of VHF marked birds may have met these assumptions based on the high percentage of missing birds that were located on James and Hudson Bay during July and by Zicus (1981) showing that nonproductive Canada geese in Wisconsin that did not molt migrate were often associated with broods during the summer and Flegler (1989) reporting that brood-rearing groups in southeastern Michigan remained close to breeding territories during this period. Therefore any bird that did not molt migrate should have been detected during the summer flightless period.

Conversely, return data obtained from VHF marked individuals required more assumptions. Although a large proportion of marked molt migrants in this study showed fidelity to natal areas during return flights, PTT data and direct harvest recoveries indicate that molt migrants do not always return directly to those territories. This suggests that the return date recorded for some VHF marked individuals may have been later than the actual return date to the study area and may also explain the slightly earlier return times of PTT marked individuals compared with VHF marked individuals during 2001.

Until satellite telemetry became available for waterfowl research VHF telemetry was the only option for projects attempting to document movement over broad spatial scales. For example, Tacha et al. (1991) used a combination of band returns and VHF telemetry to document the migration patterns of interior nesting Canada geese (*Branta canadensis interior*) between their breeding grounds on the James and Hudson Bay to wintering grounds in Illinois and Wisconsin. Similarly, Reed et al. (1989) were able to determine fall staging areas of brant (*Branta bernicla*) from different breeding locations in Alaska using VHF telemtry.

In addition to problems with detection that result in geographic and temporal biases, large costs are incurred on projects utilizing VHF transmitters to document movements over large spatial scales when time must be allocated to search larger areas via fixed-wing aircraft or from the ground with vehicles. Despite the high start up costs of satellite telemetry, the total cost (manufacturing plus tracking) to monitor each transmitter throughout the duration of a study may not greatly exceed the costs associated with obtaining data with VHF transmitters. Furthermore, PTT's are more cost effective on a per location basis. Although the start up costs for the PTT portion of this study was higher than the VHF start up costs and the average cost of operating each PTT to document molt migration was 1.4 times greater than the average cost of operating each VHF transmitter, the average cost of obtaining a location for PTT's was \$39 versus \$114 for VHF transmitters. These results are consistent with Ballard et al. (1998) who reported the cost:benefit ratios of satellite telemetry versus VHF telemetry over a 3 year period in terms of cost per location was \$44 and \$148 respectively, while A. Rodgers (Ontario Min. of Nat. Resour., pers. commun.) estimated that over a 5 year period satellite telemetry reduces project costs by 33% in comparison to VHF telemetry. Hansen et al. (1992) reported that satellite telemetry was more cost effective than VHF telemetry and direct observation when a large amount of data was required and when access and visibility were limited. Although initial start up costs cannot be disregarded, especially when projects are limited by funding, data quality must be weighted more heavily. For example, McCann et al. 2001, suggest that although satellite telemetry provided data at a high expense when documenting blue crane(*Anthropoides paradisea*) migration patterns (a serious consideration for African conservation work), its use was necessary because resighting techniques were not adding new information to their knowledge of the species' movement patterns.

Project logistics may further limit the effectiveness of VHF telemetry (e.g. amount of daylight, tracking in remote areas or when weather conditions begin to deteriorate) (Ballard et al. 1998). During both years problems were encountered when telemetry flights were denied access or rerouted over major metropolitan areas requiring less efficient ground searches to be conducted. During 2001, following the events of September 11, we were unable to make any telemetry flights for the duration of the period that coincides with molt migrant returns. In addition to increased flight costs caused by rerouting, results are compromised when access is denied into search areas. Additionally, inclement weather conditions during 2001 and the logistical challenges of conducting a search on Baffin Island during 2000, prevented us from conducting complete searches of arctic and sub-Arctic habitats for VHF marked molt migrants.

Despite the benefits of using satellite telemetry, its advantages are contingent upon location accuracy and sampling frequency (Keating et al. 1991 and Service Argos 1996). Numerous factors affect location accuracy and sampling frequency including elevational error, study area latitude and topographic interference. The most accurate locations occur when PTT elevations remain constant, e.g. in marine species where uplinks occur only when the PTT is at or near the waters surface. When elevations change frequently, as they do with avian species, poor results are expected. Sampling frequency is affected by latitude since satellites make more passes near the poles than closer to the equator. Sampling frequency is also greater for animals inhabiting open, terrestrial habitats at high latitudes and lowest and most variable for species inhabiting marine, mountain or canyon habitats or species exhibiting elevational or long distance migrations (Keating et al. 1991). Studies using smaller PTT's (from 30-50 grams) are further limited due to battery capacity. To compensate, projects that require PTT's to remain active over longer durations must sacrifice the number of signal transmissions.

This precludes the use of satellite telemetry for studies requiring multiple locations throughout the course of a day and over a several month duration. For example, Greenwood et al. (1997) systematically tracked striped skunks from March through July six out of seven days and frequently at night. Small PTT's, with low battery output would have been an ineffective tool for obtaining locations this regularly.

Additionally, although lower battery powered PTT's have been successful in determining locations within 1.4 – 35 km's of an actual location (Blouin et al. 1999 and Britten et al. 1999) other studies have reported differences as much as 100 km from the true location (Kjellen et al. 1997 and Pennycuick et al. 1996) suggesting that satellite telemetry is a useful tool for tracking long-distance movements, but is limited for detailed habitat use studies where more accurate locations are necessary such as documenting home ranges of aplomado falcons (*Falco femoralis*) and habitat use by nesting ring-necked pheasants (*Phasianus colchicus*)(Perez et al. 1996 and Clark and Bogenschutz 1999).

Ballard et al.(1998) reported that VHF locations were more accurate than satellite PTT data when determining wolf territory size in Alaska, but the larger estimates reported by the PTT's may have been a result of more frequent locations, greater number of locations, acquisition of PTT locations when it was impractical to obtain VHF locations and location error associated with PTT locations. Although an analysis of the accuracy of each transmitter type was not conducted in this study, the high detection rate of VHF marked molt migrants in close proximity to PTT location estimates validated the estimates provided by PTT's.

The decision to use satellite or conventional radio telemetry will be contingent upon study objectives. Although PTT's provided advantages over VHF transmitters once the antenna problem was solved (e.g. removing bias associated with temporal and geographic distribution patterns and reducing observer effort), VHF transmitters effectively supplemented poor PTT results during 2000 and offered a means of refining the location estimates provided by PTT's, allowing us to pin-point molt sites and qualitatively describe habitats used by molt migrants during both years. Studies that are attempting to document avian migrations over large distances may find a similar advantage to using a combination of the two marking techniques.

Management Implications

Accurate descriptions of the geographic and temporal distributions of molt migrants fill an important life history void of the giant Canada goose and may play a role in harvest management strategies as the Michigan giant Canada goose population has increased at a rate near 14% per year since the mid-1960's and currently exceeds 230,000 birds (D. Luukkonen, Mich. Dept. of Nat. Resour., pers. commun.). In addition to increasing human-goose conflicts in urban and sub-urban settings in Michigan that result from the accumulation of droppings and feathers, decreased water quality, aggressive nature near nests and goose aircraft collisions (Smith et al. 1999), Abraham et al. (1999) suggest that increasing populations of giant Canada geese and declining habitat availability on northern brood-rearing areas could result in increasing levels of competition between populations of interior and giant Canada geese. They also suggest the presence of molt migrant giants on northern breeding areas will complicate management of some Arctic and sub-Arctic nesting populations of Canada geese, therefore understanding when molt migrants arrive on James and Hudson Bay will have relevance in the timing of breeding surveys. Additionally, understanding when molt migrant giants return to Michigan in relation to major migrations of interior geese may have relevance in timing hunting seasons to increase mortality of giant Canada geese.

APPENDICES

Appendix A. Departure dates and return dates and an indication of how dates were obtained for VHF (by frequency) and PTT (by ID code) marked geese, 2000 and 2001.

Frequency/PTT ID	Year	Departure Date	Return Date	Method
165.355	2000	5/23/00	9/18/00	Radio Tracking
165.515	2000	5/23/00	[a]	[b]
165.325	2000	5/24/00	11/10/00	Radio Tracking
165.385	2000	5/24/00	9/18/00	Radio Tracking
165.455	2000	5/24/00	9/18/00	Radio Tracking
165.415	2000	5/26/00	[a]	[b]
165.435	2000	5/27/00	[c]	[b]
165.575	2000	5/27/00	9/25/00	Radio Tracking
165.665	2000	5/27/00	9/21/00	Hunter Return
165.685	2000	5/27/00	[a]	[b]
165.775	2000	5/27/00	[d]	Radio Tracking
165.815	2000	5/27/00	[c]	[b]
165.335	2000	5/28/00	[d]	Radio Tracking
165.625	2000	5/28/00	10/23/00	Hunter Return
165.585	2000	5/29/00	[a]	[b]
165.595	2000	5/29/00	[c]	[b]
165.675	2000	5/29/00	9/18/00	Radio Tracking
165.715	2000	5/29/00	[c]	[b]
165.565	2000	6/02/00	8/31/00	Radio Tracking
165.835	2000	6/03/00	9/20/00	Hunter Return
165.765	2000	6/13/00	9/16/00	Radio Tracking
165.635	2000	[d]	[e]	[b]
24999	2000	5/22/00	[f]	[b]
25000	2000	5/22/00	[f]	[b]
25087	2000	5/22/00	9/20/00	Satellite Tracking

Appendix A (cont'd).

Frequency/PTT ID	Year	Departure Date	Return Date	Method
24998	2000	5/25/00	[f]	[b]
25038	2000	5/29/00	[f]	[b]
25088	2000	5/31/00	[f]	[b]
25040	2000	[f]	9/26/00	Satellite Tracking
25066	2000	[f]	9/16/00	Satellite Tracking
25067	2000	[f]	[f]	[b]
25041	2000	[f]	[f]	[b]
166.215	2001	5/23/01	9/13/01	Radio Tracking
166.575	2001	5/23/01	11/05/01	Radio Tracking
166.165	2001	5/30/01	9/28/01	Radio Tracking
166.225	2001	5/30/01	9/28/01	Radio Tracking
166.235	2001	5/30/01	9/19/01	Radio Tracking
166.365	2001	5/30/01	9/24/01	Radio Tracking
166.465	2001	5/30/01	[d]	Radio Tracking
165.735	2001	6/01/01	9/03/01	Hunter Return
166.175	2001	6/01/01	[c]	[b]
166.265	2001	6/01/01	9/14/01	Radio Tracking
166.425	2001	6/01/01	11/14/01	Radio Tracking
166.545	2001	6/01/01	9/14/01	Radio Tracking
166.105	2001	6/02/01	10/03/01	Radio Tracking
166.275	2001	6/02/01	9/18/01	Radio Tracking
166.355	2001	6/02/01	9/25/01	Radio Tracking
166.385	2001	6/02/01	9/18/01	Radio Tracking
166.495	2001	6/02/01	9/18/01	Radio Tracking
166.245	2001	6/05/01	9/14/01	Radio Tracking
166.285	2001	6/05/01	10/06/01	Hunter Return

Appendix A (cont'd).

Frequency/PTT ID	Year	Departure Date	Return Date	Method
166.365	2001	6/05/01	9/08/01	Hunter Return
166.395	2001	6/05/01	10/19/01	Radio Tracking
165.665	2001	6/08/01	9/10/01	Radio Tracking
166.475	2001	6/08/01	[a]	[b]
166.525	2001	6/08/01	[c]	[b]
166.565	2001	6/09/01	9/05/01	Radio Tracking
166.115	2001	6/15/01	9/18/01	Radio Tracking
13718	2001	6/02/01	9/12/01	Satellite Tracking
13724	2001	6/02/01	[g]	[b]
13729	2001	6/02/01	[f]	[b]
13730	2001	6/03/01	[g]	[b]
13731	2001	6/04/01	9/28/01	Satellite Tracking
13732	2001	6/05/01	9/12/01	Satellite Tracking
13713	2001	6/06/01	10/02/01	Satellite Tracking
13721	2001	6/06/01	9/16/01	Satellite Tracking
13725	2001	6/06/01	9/16/01	Satellite Tracking
13733	2001	6/06/01	9/08/01	Satellite Tracking
13734	2001	6/07/01	9/12/01	Satellite Tracking
25086	2001	6/08/01	10/30/01	Satellite Tracking
13722	2001	6/14/01	9/08/01	Satellite Tracking

[a] – mortality signal detected during aerial telemetry search of James and Hudson Bay
[b] – not applicable
[c] – bird was not located during return period or thereafter
[d] – bird located , but well after peak return flights, date not used
[e] – shot during return flight outside of Michigan, date not used
[f] – PTT not functioning
[g] – bird was confirmed shot near molting area

Appendix B. Latitude and longitude (decimal degrees) of breeding and molt sites and distances flown to molt sites for PTT and VHF marked geese from southeastern Michigan, 2000 and 2001.

Frequency/PTT ID	Year	Lat1[a]	Lon1[b]	Lat2[c]	Lon2[d]	Distance Flown (km)
165.415	2000	42.558	83.278	53.817	79.000	1287.37
165.595	2000	42.412	83.430	53.817	79.000	1308.95
165.355	2000	42.790	84.400	54.167	79.100	1319.84
165.435	2000	42.790	84.400	54.167	79.100	1319.84
165.665	2000	42.790	84.400	55.117	82.867	1378.59
165.775	2000	42.672	84.669	54.800	79.683	1394.89
165.575	2000	42.790	84.400	55.733	79.167	1488.11
165.685	2000	42.790	84.400	55.767	79.150	1496.64
165.335	2000	42.790	84.400	55.867	79.867	1497.27
165.835	2000	42.715	84.520	58.700	77.000	1854.29
165.515	2000	42.790	84.400	58.967	77.850	1855.56
165.815	2000	42.790	84.400	59.017	77.850	1882.00
165.625	2000	42.828	84.378	59.200	78.100	1883.52
165.675	2000	42.477	83.161	59.150	77.550	1899.07
165.325	2000	42.478	83.158	60.117	76.800	2014.00
165.715	2000	42.412	83.432	60.883	77.133	2099.88
25067	2000	42.536	82.900	54.260	79.164	1336.32
25040	2000	42.829	84.401	54.860	83.081	1344.17
25066	2000	42.688	84.511	54.682	83.892	1381.75
24999	2000	42.700	83.925	56.546	79.211	1576.41
25087	2000	42.812	84.351	56.841	80.094	1588.83
24998	2000	42.328	84.203	57.873	77.107	1794.69
25088	2000	42.561	83.279	59.900	77.472	1972.38
25000	2000	42.675	84.667	60.337	77.136	2030.57
25041	2000	42.772	83.813	60.558	76.871	2032.51

Appendix B (cont'd).

Frequency/PTT ID	Year	Lat1[a]	Lon1[b]	Lat2[c]	Lon2[d]	Distance Flown (km)
25038	2000	42.275	83.700	64.805	77.893	2537.59
165.735	2001	42.567	83.841	53.367	80.050	1233.13
166.105	2001	42.475	83.155	55.000	82.267	1395.17
166.335	2001	42.723	83.259	55.900	79.500	1485.18
166.395	2001	42.427	83.428	56.833	79.833	1620.74
165.665	2001	42.790	84.399	58.333	77.783	1786.83
166.285	2001	42.567	83.841	58.383	77.983	1806.08
166.475	2001	42.790	84.399	58.600	77.467	1824.93
166.495	2001	42.475	83.155	58.550	76.767	1853.45
166.225	2001	42.722	83.242	59.133	77.600	1867.28
166.235	2001	42.385	84.369	58.967	78.133	1895.23
166.425	2001	42.674	84.666	59.433	77.567	1928.47
166.115	2001	42.475	83.155	60.200	76.450	2024.92
166.215	2001	42.431	83.430	60.333	77.550	2031.33
166.165	2001	42.426	83.434	61.333	77.283	2138.52
166.175	2001	42.813	84.348	61.717	77.800	2149.87
166.385	2001	42.475	83.155	62.217	78.117	2230.23
13713	2001	42.981	83.746	51.405	80.242	979.05
13733	2001	42.524	84.358	54.096	82.263	1373.51
13732	2001	42.688	84.512	55.070	82.716	1380.53
13724	2001	42.929	84.003	56.180	78.895	1518.73
13718	2001	42.433	83.478	56.204	78.805	1562.92
25086	2001	42.475	83.155	58.243	77.678	1800.78
13725	2001	42.657	83.936	59.109	78.228	1875.63
13724	2001	42.475	83.155	59.024	76.946	1895.11
13722	2001	42.674	84.666	60.924	76.722	2100.89

Appendix B (cont'd).

Frequency/PTT ID	Year	Lat1[a]	Lon1[b]	Lat2[c]	Lon2[d]	Distance Flown (km)
13731	2001	42.787	83.287	61.615	77.170	2137.31
13729	2001	42.813	84.348	61.608	77.432	2141.99
13721	2001	42.705	84.479	61.352	76.587	2144.15
13730	2001	42.637	83.202	shot during migration north		

[a] – Latitude of breeding site
[b] – Longitude of breeding site
[c] – Latitude of molt site
[d] – Longitude of molt site

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