

# Movements and Survival of Molt Migrant Canada Geese From Southern Michigan

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**ABSTRACT** We studied movements and survival of 250 female giant Canada geese (*Branta canadensis maxima*) marked during incubation with either satellite-monitored platform transmitting terminals or very high frequency radiotransmitters at 27 capture areas in southern Michigan, USA, in 2000–2003. We destroyed nests of 168 radiomarked females by removing eggs after day 14 of incubation, and we left nests of 82 incubating hens undisturbed after capture and marking. Of females whose nests we experimentally destroyed, 80% subsequently migrated from breeding areas to molt remiges in Canada. Among 82 nests left undisturbed, 37 failed due to natural causes and 51% of those females departed. Migration incidence of birds that nested in urban parks was low (23%) compared with migration incidence of birds that nested in other classes of land use (87%). Departure of females from their breeding areas began during the second and third weeks of May, and most females departed during the last week of May and first week of June. Based on apparent molting locations of 227 marked geese, birds either made long-distance migratory movements >900 km, between latitudes 51° and 64° N, or they remained on breeding areas. Molting locations for 132 migratory geese indicated 4 primary destinations in Canada: Western Ungava Peninsula and offshore islands, Cape Henrietta Maria, Northeast James Bay and offshore islands, and Belcher Islands, Hudson Bay, Canada. Following molt of remiges, Canada geese began to return to their former nesting areas from 20 August through 3 September, with 37% arriving on or before 15 September and 75% arriving on or before 1 October. Migration routes of geese returning to spring breeding areas were relatively indirect compared with direct routes taken to molting sites. Although overall survival from May through November was 0.81 (95% CI: 0.74–0.88), survival of migratory geese marked on breeding sites where birds could be hunted was low (0.60; 95% CI: 0.42–0.75) compared with high survival of birds that remained resident where hunting was restricted (0.93; 95% CI: 0.84–0.97). Nest destruction can induce molt migration, increase hunting mortality of geese returning from molting areas, and reduce human–goose conflicts, but managers also should consider potential impacts of increasing numbers of molt migrants on populations of subarctic nesting Canada geese. (JOURNAL OF WILDLIFE MANAGEMENT 72(2):449–462; 2008)

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Canada geese (*Branta canadensis*) are managed with goals to conserve their diversity and to maintain populations at levels that are ecologically and socially desirable. Although Canada geese are probably now more abundant in North America than at any previous time, status varies among 20 recognized management populations (Moser and Caswell 2004). Over the past 3 decades, rapid growth of Canada goose populations nesting within temperate regions of North America has resulted in new management challenges, including increased human–goose conflicts (Rusch et al. 1995, Ankney 1996, Moser and Caswell 2004, United States Department of the Interior 2005).

Although traditional Mississippi Flyway (MF) Canada goose population management focused on protecting subarctic-nesting interior Canada geese (*Branta canadensis interior*) from excessive harvest, management over the past 2 decades has focused more on controlling growth of the Mississippi Flyway giant Canada goose population (MFGP; Leafloor et al. 2004). The MFGP recovered from near extinction to a spring population of >1.6 million birds by 2002 and has since remained near this level (Hanson 1965, Mississippi Flyway Council 2006). Because MFGP geese are sympatric with arctic and subarctic nesting Canada geese during some traditional fall and winter hunting seasons,

regulatory strategies were developed to focus harvest on MFGP. Although regulations such as early and late hunting seasons were successful in increasing MFGP harvest and avoiding excessive harvest of nontarget populations, giant Canada goose numbers continued to increase in the MF (Leafloor et al. 2004). Effects of special early season harvest on annual survival of MFGP during 1982–1999 varied among MF states, and they were confounded by changes in regular season harvest regulations to protect interior Canada geese (Sheaffer et al. 2005).

Many MF states initiated nonhunting control methods such as nest destruction to manage human–goose conflicts and MFGP population growth near urban centers, and 38,555 nests were destroyed during 1995–2005 within the United States Fish and Wildlife Service's Region 3, which included about 6,800 nests destroyed in Michigan, USA (S. Wilds, United States Fish and Wildlife Service, unpublished data). Subadult and failed-nesting adult Canada geese are known to undergo molt migration (Kuyt 1966, Salomonsen 1968, Zicus 1981a, Lawrence et al. 1998, Abraham et al. 1999), and these flights can range from short, <150-km localized movements, to movements >3,000 km (Dimmick 1968, Krohn and Bizeau 1979). Incidence of molt migration among unsuccessful nesting MFGP Canada geese from Illinois and Wisconsin, USA, ranged from 90% to 96% (Zicus 1981a, Lawrence et al. 1998). Although molt migration is relatively unstudied in MFGP Canada geese

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nesting in urban settings, nest destruction may increase numbers of giant Canada geese molting on arctic and subarctic nesting areas, upwardly biasing estimates of breeding population size of subarctic nesting geese and increasing competition for forage between giant and interior Canada geese (Abraham et al. 1999). Reducing reproduction is generally considered inefficient in controlling population growth of long-lived geese compared with reducing adult survival (Schmutz et al. 1997, Coluccy et al. 2004); however, molt migrant Canada geese may have reduced survival compared with birds remaining on breeding areas (Ogilvie 1978, Lawrence et al. 1998). Thus, nest destruction may indirectly increase adult mortality via induced molt migration, although this survival hypothesis has not been tested for MFGP Canada geese.

Early Canada goose hunting seasons in the MF are generally 1–15 September, and they are designed to harvest giant Canada geese before interior Canada geese become abundant in the United States later in the fall. Understanding migration chronology of molt migrant giant Canada geese is important to evaluate the extent to which hunting seasons target population segments and other subspecies. For example, Zicus (1981a) reported that >75% of molt migrant Canada geese returned to Crex Meadows, Wisconsin, USA, by the time of first major migration of interior Canada geese to the area.

Although molt migration in Canada geese has been well documented, locations of molting areas and timing of movements have not been described completely due to the difficulty of monitoring long-distance bird movements using leg bands, neck collars, or very high frequency (VHF) radiotransmitters (Mykut et al. 2004). We used a combination of satellite-monitored platform transmitting terminals (PTTs) and VHF radiotransmitters to study molt migration. Our objectives were to estimate molt migration incidence, describe timing and locations of movements, and compare survival and harvest rates of nonmigrant and molt migrant Canada geese nesting in a variety of southern Michigan habitats.

## STUDY AREA

The study area encompassed 21 counties in southern Michigan and 27 capture areas were distributed across this area, including major metropolitan areas and adjoining agricultural and residential lands (Fig. 1). This area was characterized by rolling hills and flat lake plains that have been greatly modified by agriculture and urban development (Albert 1995). Capture areas were distributed over 11 southeastern and south-central Michigan counties from 2000 to 2003 that included major metropolitan areas of Detroit, Pontiac, Ann Arbor, and Lansing and adjoining agricultural and residential lands. We also captured geese in an additional 10 counties in southwestern Michigan from Muskegon south to Centerville during 2002 and 2003 (Fig. 1). Capture areas were 25 km<sup>2</sup>, and we radiomarked geese at 13, 15, 25, and 23 capture areas during each year 2000–2003, respectively, so that spatial distribution of marked

geese was representative of Canada goose distribution in southern Michigan.

## METHODS

### Capturing Geese and Destroying Nests

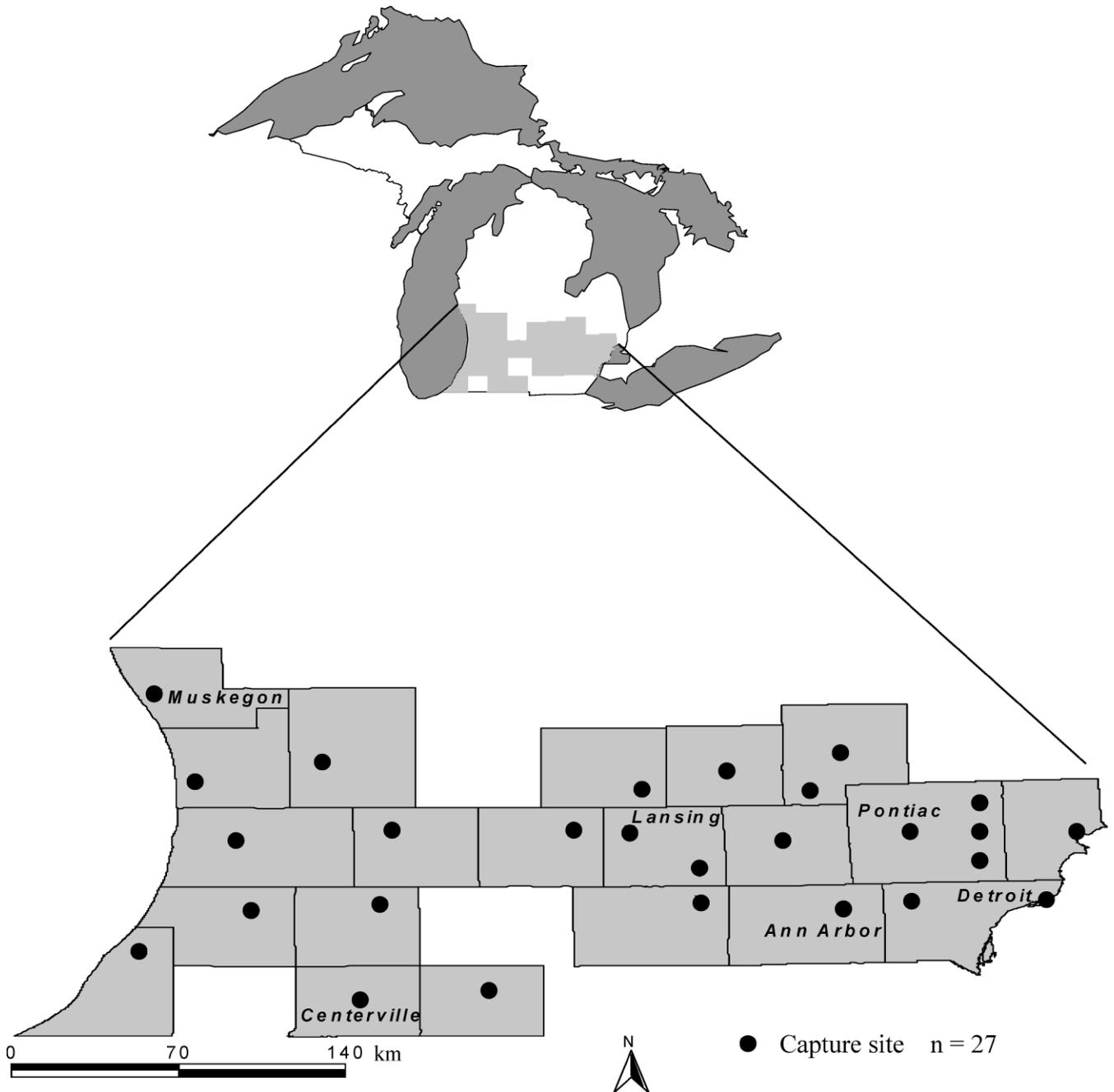
We located active goose nests during the day by scouting capture areas from the ground during April and May 2000–2003. We captured geese on nests primarily at night using a night-lighting technique and landing net as described by Mykut et al. (2004). We also used landing nets for capturing geese during daylight hours when incubating females would remain on nests long enough for capture. Upon capture, we quickly secured birds to prevent wing injuries and damage to eggs.

At each capture area in 2000–2002, we attempted to capture 5 incubating female geese within 5 km of each other, and we marked one goose with a PTT and 4 more geese with VHF radiotransmitters. We randomly assigned transmitter types to females within capture areas. Females marked with a PTT and  $\geq 2$  randomly selected females with VHF radios from each capture area made up a treatment group in which we induced nest failure by removing all eggs from the nests. Other females with VHF radios made up a control group in which we left nests undisturbed after capture. We induced nest failure at time of capture if embryos were near the midpoint of incubation (i.e.,  $\geq 14$  days; Kossack 1950, Cooper 1978). We measured embryo age by opening one egg in a nest and comparing development with reference photographs of known-age embryos. Afterward, we killed embryos by decapitation as recommended by the Michigan State University, All University Committee on Animal Use and Care (AUF 01/03-002-00). If  $\geq 1$  embryo was <14 days of age, we left the remainder of the clutch in the nest and removed eggs at a later date to discourage re-nesting (Smith et al. 1999). We revisited nests of females in the control group after the nesting season, and we determined fate based on presence or absence of eggshell and membrane fragments and their characteristics (Klett et al. 1986). We also visually confirmed presence of goslings with marked adults. During 2003, we used only PTTs, and we destroyed all nests of marked geese.

We used rocket nets to capture geese and make use of additional VHF radiotransmitters that we did not deploy during the 2000 and 2001 nesting seasons. We used rocket nets to capture flocks of 10–15 geese that we presumed to be engaging in premolt migration behavior in mid- to late May. We avoided sites used by larger flocks. We attracted geese to specific areas by baiting with whole corn (*Zea mays*) 2–3 days before launching rocket nets.

### Telemetry Equipment

The PTTs and VHF radiotransmitters were manufactured by Telonics, Inc. (Mesa, AZ), and we attached them to green neckbands with white alphanumeric codes; neckbands were the same as those used by the Michigan Department of Natural Resources for other goose studies. Neckbands were made from Romark® (Spinner Plastics, Springfield, IL) plastic tubes (7.0–7.6 cm wide, 5.0 cm diam, and 0.2 cm



**Figure 1.** Michigan, USA, study area showing 21 counties and specific sites where we captured and marked nesting female Canada geese with either platform transmitting terminals or very high frequency radiotransmitters, 2000–2003. We show approximate locations of 6 Michigan cities for reference.

thick, with a 2.5-cm overlap of the tube ends). Labels affixed to each transmitter during 2000–2002 had a please advise message and offered a US\$100 reward to increase probability of reporting recovered transmitters. Mean mass of PTTs and VHF radiotransmitters was 71 g and 82 g, respectively, representing <3% of goose body mass. We attached the antenna of VHF units directly to the neckband surface. It was necessary to have an external antenna protruding from PTTs for them to function properly. The PTTs had expected battery life of 360 hours, which was distributed over 4 monitoring periods. The duty cycle was designed to maximize battery life for approximately 11

months over the 4 periods. The PTTs were active for 6 hours every 8 days from April through mid-May, every 4 days from mid-May through October, every 14 days from November through December, and every 8 days from January through early March. Mykut et al. (2004) evaluated and reported on PTT performance.

We received satellite location estimates from the Argos System (Service Argos 1996). Location classes were assigned by Argos based on estimated accuracy and number of transmissions received from a PTT during a selected overpass (Harris et al. 1990). We received data as 2 locations from each individual PTT message, and we

removed the biologically implausible location from the pair as described by Britten et al. (1999) and Malecki et al. (2001); when multiple daily locations were available, we used locations with the highest accuracy rating to represent a bird's location for that day.

The VHF radiotransmitters had an expected battery life of 14 months and transmitted a pulsed signal that increased in rate to indicate mortality after 4 hours of no movement. The VHF units had effective ground and aerial ranges of 3 km and 16 km, respectively, based on field testing before and after deployment. We conducted aerial searches for geese marked with VHF radiotransmitters with directional antennas mounted to the wing struts of a Cessna 206 (Cessna Aircraft Company, Wichita, KS) aircraft flown at altitudes of 833–1,170 m. We conducted ground searches with omnidirectional antennas.

### VHF Monitoring

We conducted ground searches for VHF-marked geese beginning in early May, and we searched for all frequencies every 3–4 days through October 2000–2003. We reduced ground searches to once weekly from November through March. We focused ground searches within 8-km radii of capture sites because Zicus (1981*b*) found that movement of pairs after hatch ranged from 0.7 km to 8.4 km, and nonproductive Canada geese that did not molt migrate were often associated with broods. Brood-rearing Canada geese in southern Michigan remained within 10 km of banding sites throughout summer and early fall (Flegler 1989).

We conducted aerial searches during 2000–2003 with fixed-wing aircraft to supplement ground searches, and we spaced transects (approx. 9 km) to cover the entire study area based on aerial detection ranges of VHF transmitters. One exception was air space over Detroit, Michigan, where we were regularly denied access. We increased intensity of ground searches over this area to increase probability of detecting VHF-marked birds. We conducted aerial searches once every 2 weeks during mid-May through June (4 flights/yr) and again from September through mid-November (4 flights/yr). We assumed VHF-marked geese that we did not locate on breeding areas during ground and aerial searches from June through mid-July migrated from the study area, because we observed no VHF radiofailures among geese with broods, and we readily detected these birds during telemetry monitoring flights. We flew an average of 5,000 km each year during July 2000–2002 while conducting aerial searches of subarctic molting habitats to locate birds marked with VHF transmitters. We established primary search zones for probable VHF-marked molt migrants using PTT location estimates as reference points; secondary search zones were areas searched en route to primary search zones, but they had a low probability of VHF radiotransmitter detection based on PTT location data (Mykut et al. 2004). We searched all primary and secondary zones, excluding the Belcher Islands, Hudson Bay, Canada, and primary zone north of 59° N latitude, by flying one transect directly over the coastline. We searched the Belcher Islands by flying 4 transects spaced 22 km apart, and we searched the north-

ernmost primary search zone by flying 3 transects spaced 25 km apart. We used a panel-mounted aviation global positioning system receiver to determine location coordinates of VHF-marked birds detected on northern molting grounds.

### Data Analysis

Females that did not successfully nest included those whose nests we experimentally destroyed and those in the control group whose nests were destroyed by predators or other causes after capture and marking. We modeled probability of molt migration for unsuccessful nesting females using logistic regression with explanatory categorical variables of year, land use, nest treatment (experimental nest destruction or control), and transmitter type (VHF or PTT). We assigned breeding areas to 1 of 4 land use categories, including urban parks, urban commercial or industrial, suburban, and rural. We classified PTT-marked geese as migratory when they departed breeding areas; we considered VHF-marked geese migratory if we could not detect them on breeding areas during the last 2 weeks of June. We included transmitter type as an explanatory variable to account for potential effects of different monitoring capabilities and schedules on estimates of migration incidence. We first considered models containing all combinations of land use, nest treatment, and year. We then added transmitter type to our global model and to the most parsimonious model among those without transmitter type. We implemented this analysis using the Genmod procedure in SAS (SAS Institute, Cary, NC) using the logit link function (SAS Institute 1997). We ranked 9 candidate models using information-theoretic methods, and we estimated model weights based on Akaike's Information Criterion adjusted for small sample size (Burnham and Anderson 2002). We calculated model-based estimates of migration probability and confidence intervals for all combinations of land use, nest treatment, and transmitter type by model averaging all models (Burnham and Anderson 2002). Confidence intervals were back-transformed logit-based intervals as suggested by Burnham and Anderson (2002).

We determined apparent molt sites for PTT-marked geese using groups of location estimates from mid-July through mid-August, corresponding to the period when geese were flightless on molting areas. We represented each bird's molting site based on the location within the group that had the best Argos assigned accuracy rating. We designated locations where we detected VHF-marked birds on northern aerial searches during late July as apparent molt sites.

We modeled survival of geese captured on nests, and we marked with VHF transmitters using Cox proportional hazards analysis implemented using the PHREG procedure in SAS. Our global model contained the 3 explanatory variables, migration status (migratory or resident), hunting restrictions (present or absent), and year (2000–2002), and we assessed model fit using a goodness-of-fit test and determined expected numbers of mortalities as described by Parzen and Lipsitz (1999). Migratory birds included those

**Table 1.** Number of Canada geese marked in southern Michigan, USA, with either platform transmitting terminals (PTT) or very high frequency (VHF) radiotransmitters, April–May, 2000–2003. We captured female geese on nests and either destroyed nests during incubation (treatment) or left nests undisturbed (control). We also captured other geese away from nests (non-nesting). We classified PTT-marked geese as migratory when they departed breeding areas; we considered VHF-marked geese migratory if we could not detect them on breeding areas during the last 2 weeks of June.

Treatment group	Yr	Geese marked		Nests hatched	Geese migrated
		PTT	VHF		
Nest destroyed	2000	15	12	0	18
	2001	25	21	0	36
	2002	31	41	1	59
	2003	23	0	0	22
Control nest	2000	0	21	10	5
	2001	0	29	17	7
	2002	0	32	18	7
Non-nesting	2000	0	10	—	9
	2001	0	2	—	2
Combined	2000–2003	94	168	46	165

that departed breeding areas during May or June, whereas we found resident birds on breeding areas during July and August. We defined hunting restrictions based on legality of hunting within 1 km of nest (i.e., capture) locations. Hunting restrictions included local ordinances prohibiting firearm discharge or the feasibility of legally hunting with firearms based on the distance from nests to residential and commercial buildings. We used model averaging to estimate end point survival for 4 goose groups defined by all combinations of migration status and hunting restrictions. We also estimated baseline survival functions for these groups using the product-limit method and tested for equality of survival distributions using a log-rank test (Kaplan and Meier 1958, Pollock et al. 1989). We restricted our survival analysis to VHF-marked geese because of limitations imposed by PTT longevity in some years (Mykut et al. 2004). We censored migratory birds that we did not find during July aerial searches and birds with which we lost contact during September–November. We estimated harvest rates from direct hunter recoveries (recovered the first hunting season after marking) of radiomarked geese assuming \$100 reward was incentive enough for all harvested birds to be reported (Nichols et al. 1991).

## RESULTS

We captured and marked 94 adult female geese with PTTs and marked an additional 168 birds with VHF radiotransmitters during the 4 years of study (Table 1). We captured 12 non-nesting geese using rocket nets, whereas we captured the remaining 250 geese on nests. The only death immediately after marking was a rocket-netted female found dead near the capture area 2 days after capture in 2000.

Mean clutch size for all years within incubated nests was 5.6 ( $n = 245$ ;  $SD = 1.4$ ) and ranged from 4.8 eggs ( $n = 23$ ;  $SD = 1.2$ ) in 2003 to 5.8 eggs ( $n = 102$ ;  $SD = 1.3$ ) in 2002. Over all years, 55% of 82 nesting females in the control

group hatched  $\geq 1$  young ( $\bar{x} = 4.5$  young hatched/successful F;  $SD = 2.2$ ) and success ranged from 48% in 2000 to 59% in 2001 (Table 1). One of 168 females in the experimental nest destruction group hatched 4 young resulting from a re-nesting attempt.

Although PTTs were designed to transmit for 11 months, realized operational life in the field was considerably shorter and varied by year (Mykut et al. 2004). The PTT performance was highest in 2003, with an average of 85% ( $n = 20$ ,  $SD = 9\%$ ) of expected battery life. There was no evidence that VHF radiotransmitters malfunctioned during the study based on performance of 36 units attached to geese that hatched young. We regularly detected and observed these individuals during telemetry searches on the Michigan study area from May through October. We classified 86 VHF-marked geese as molt migrants, and we detected 58 of these birds in the primary search zone in Canada (documented molting locations); we located 73%, 62%, and 68% of the 86 geese classified as molt migrants in the primary search zones during 2000, 2001, and 2002, respectively, whereas the remaining birds went undetected (Mykut et al. 2004). Among 28 VHF-marked presumed molt migrants not located in Canada, we confirmed radiofunction for 20 birds (19 when they returned in fall and one mortality detected outside of the breeding area). We could not confirm radiofunction for the remaining 8 VHF-marked geese classified as molt migrants because we did not detect their radios after nesting.

About 76% of 201 females in both treatment groups that lost nests and survived through April moved off breeding areas. About 80% ( $n = 168$ ) of females in the experimental nest destruction group departed (Table 1). One of 45 females that hatched eggs and 11 of 12 birds marked off nests left breeding areas. We observed shortly after hatch without young the one bird that hatched young and departed. The global logistic regression model (containing all explanatory variables) predicting migration probability among geese that lost nests fit the data, and there was no evidence of overdispersion ( $\chi^2 = 23.98$ ,  $df = 28$ ,  $\bar{c} = 0.86$ ). The top-ranked model including nest treatment and land use received more than twice as much support (Akaike wt [ $w_i$ ] = 0.517) as any other model; the second-ranked model with only land use also had considerable support from the data ( $w_i = 0.228$ ) as did the model including transmitter type with treatment and land use ( $w_i = 0.180$ ; Table 2). Migration probabilities estimated by averaging all models indicated  $<27\%$  of females with failed nests in urban parks migrated, whereas  $>65\%$  of females with failed nests in other land uses migrated (Fig. 2). Migration probabilities among females in the experimental nest destruction group were 4–75% times greater (depending on land use) than estimates for control females that lost nests to other causes, but the nest treatment effect was small relative to model selection and sampling variation as 95% confidence intervals broadly overlapped (Fig. 2). Migration probabilities estimated for geese marked with PTTs and VHF radio-

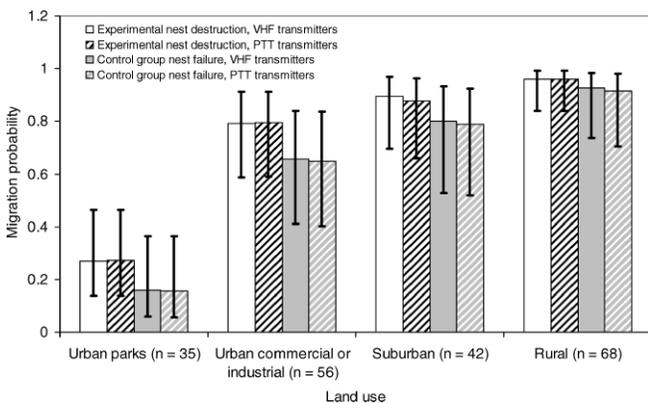
**Table 2.** Candidate logistic regression models considered for predicting probability of molt migration among unsuccessful nesting female Canada geese marked with either platform transmitting terminals (PTT) or very high frequency (VHF) radiotransmitters in southern Michigan, USA, 2000–2003. For each model, we report log-likelihood [ $\log(L)$ ], number of parameters ( $K$ ), small sample Akaike's Information Criterion ( $AIC_c$ ), difference in  $AIC_c$  relative to smallest  $AIC_c$  in the model set ( $\Delta_i$ ), and  $AIC_c$  weight ( $w_i$ ).

Model	Variables included <sup>a</sup>	$\log(L)$	$K$	$AIC_c$	$\Delta_i$	$w_i$
1	Land use, treatment	-74.92	5	160.09	0.00	0.517
2	Land use	-76.78	4	161.73	1.64	0.228
3	Land use, treatment, transmitter	-74.92	6	162.21	2.11	0.180
4	Land use, treatment, yr	-74.30	8	165.27	5.18	0.039
5	Land use, yr	-75.88	7	166.27	6.18	0.024
6	Land use, treatment, yr, transmitter	-74.29	9	167.42	7.33	0.013
7	Treatment, yr	-100.60	5	211.46	51.36	<0.001
8	Treatment	-104.17	2	212.38	52.29	<0.001
9	Yr	-104.90	4	217.96	57.87	<0.001

<sup>a</sup> Land use = predominant land use of breeding areas among 4 categories, treatment = nests experimentally destroyed by researchers vs. control nests destroyed by other causes, transmitter = PTT vs. VHF transmitter. All models include an intercept.

transmitters differed by <2% within combinations of land use and nest treatment (Fig. 2).

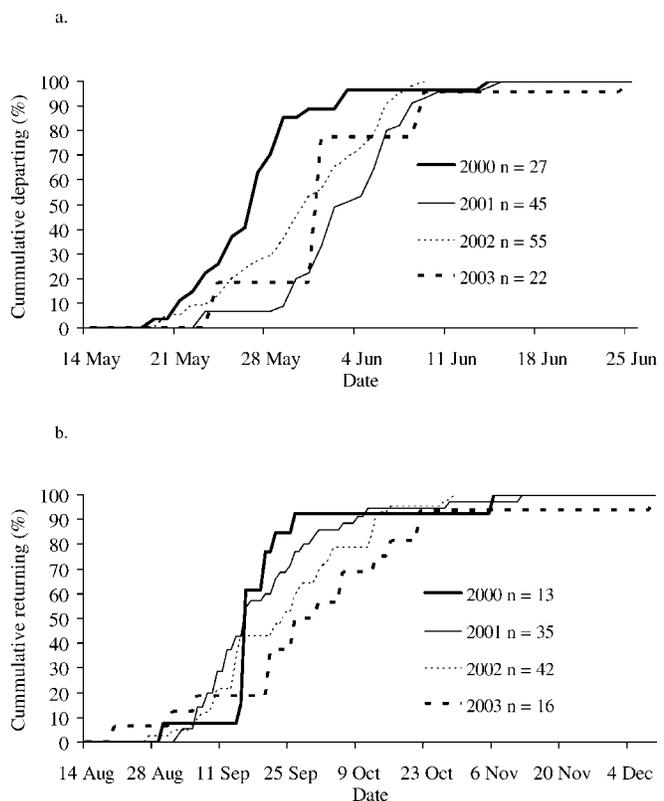
Although female departure from breeding areas began during the second and third weeks of May, most geese departed during the last week of May and first week of June (Fig. 3). Mean departure dates ranged from 28 May ( $n = 27$ ; SD = 4.6 days) during 2000 to 2 June ( $n = 45$ ; SD = 4.8 days) during 2001. Although we found variation in departure dates among years ( $F_{3,142} = 7.2$ ;  $P < 0.001$ ), variation in departure dates associated with transmitter types was small ( $F_{1,142} = 0.14$ ;  $P = 0.71$ ). Differences in mean departure dates of PTT- and VHF-marked geese ranged from 2 days to 3 days, depending on year. Departure was complete by mid-June in most years, except 2003 when one bird departed during the last week of June (Fig. 3). A subsample of 65 migrating geese marked with PTTs provided enough locations to resolve timing of movements near James Bay, Ontario, Canada; the earliest migrating birds reached Southern James Bay Population (SJBP) interior Canada goose breeding areas (50°N) by 23 May



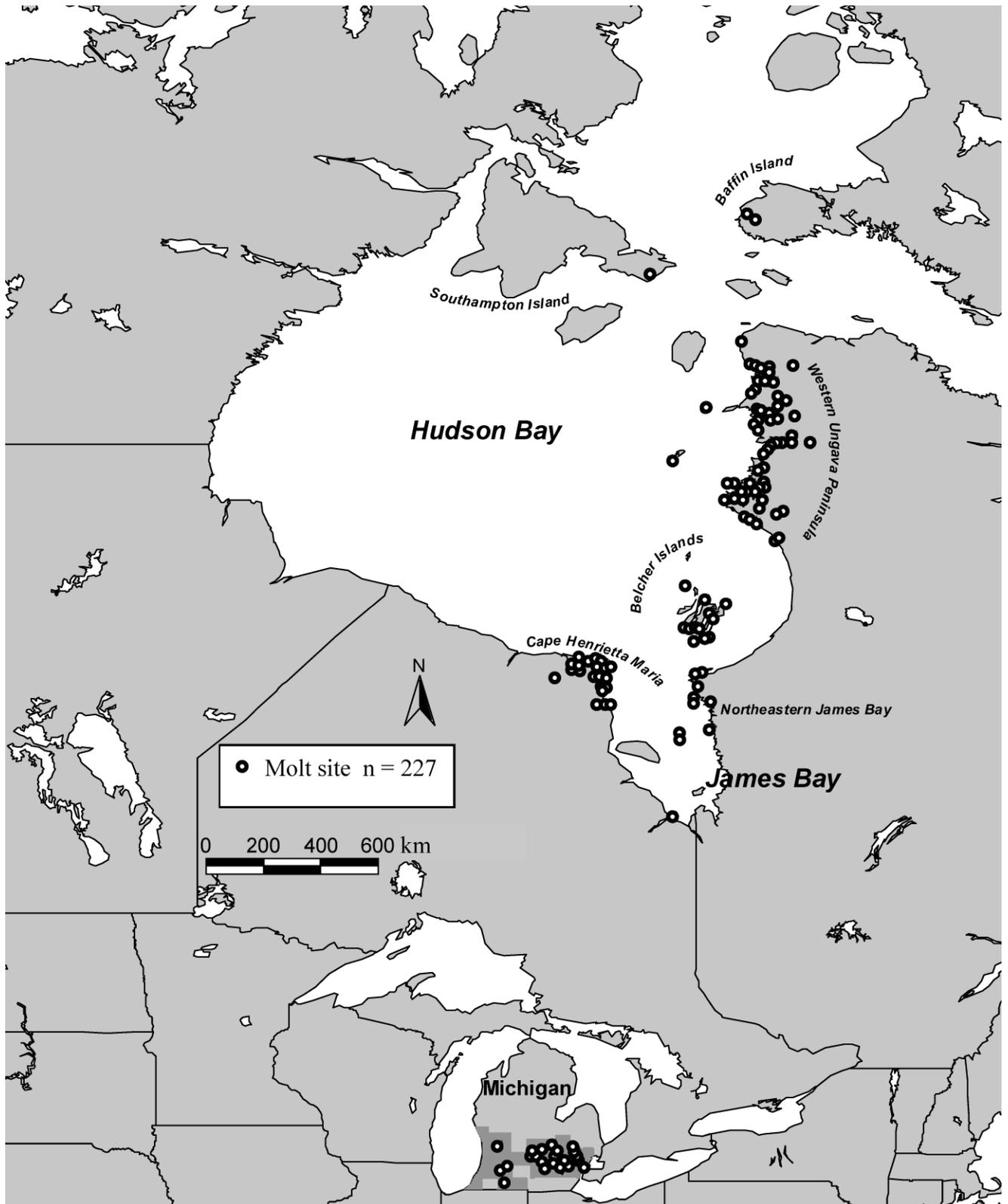
**Figure 2.** Molt migration probabilities and 95% confidence intervals for unsuccessful nesting female Canada geese marked with either platform transmitting terminals (PTT) or very high frequency (VHF) radiotransmitters in southern Michigan, USA, 2000–2003. We estimated molt migration probabilities by averaging estimates from 9 logistic regression models we fit to data from birds whose nests we destroyed during incubation (experimental nest destruction) or for geese that lost nests for other reasons (control group nest failure). We categorized dominant land use at goose breeding (capture) areas.

and 95% were at or north of this latitude by 11 June. The earliest migrating bird from a subsample of 41 PTT-marked geese to reach 58°N did so by 6 June and 92% that eventually made it north of this latitude did so by 25 June.

Based on molting location estimates for 227 marked geese, birds either made long-distance migratory movements >900 km, between latitudes 51°N and 64°N, or they remained on breeding areas (Fig. 4). Molting locations for 132 migratory geese indicated 4 primary Canadian destinations, Western Ungava Peninsula and offshore islands (53%), Cape Henrietta Maria (25%), Northeast James Bay and offshore islands (10.6%), and Belcher Islands (9.1%), accounted for



**Figure 3.** Departure dates of molt migrating female Canada geese from southern Michigan, USA, breeding areas to molting locations (a) and return dates of molt migrant geese to breeding areas (b), 2000–2003.

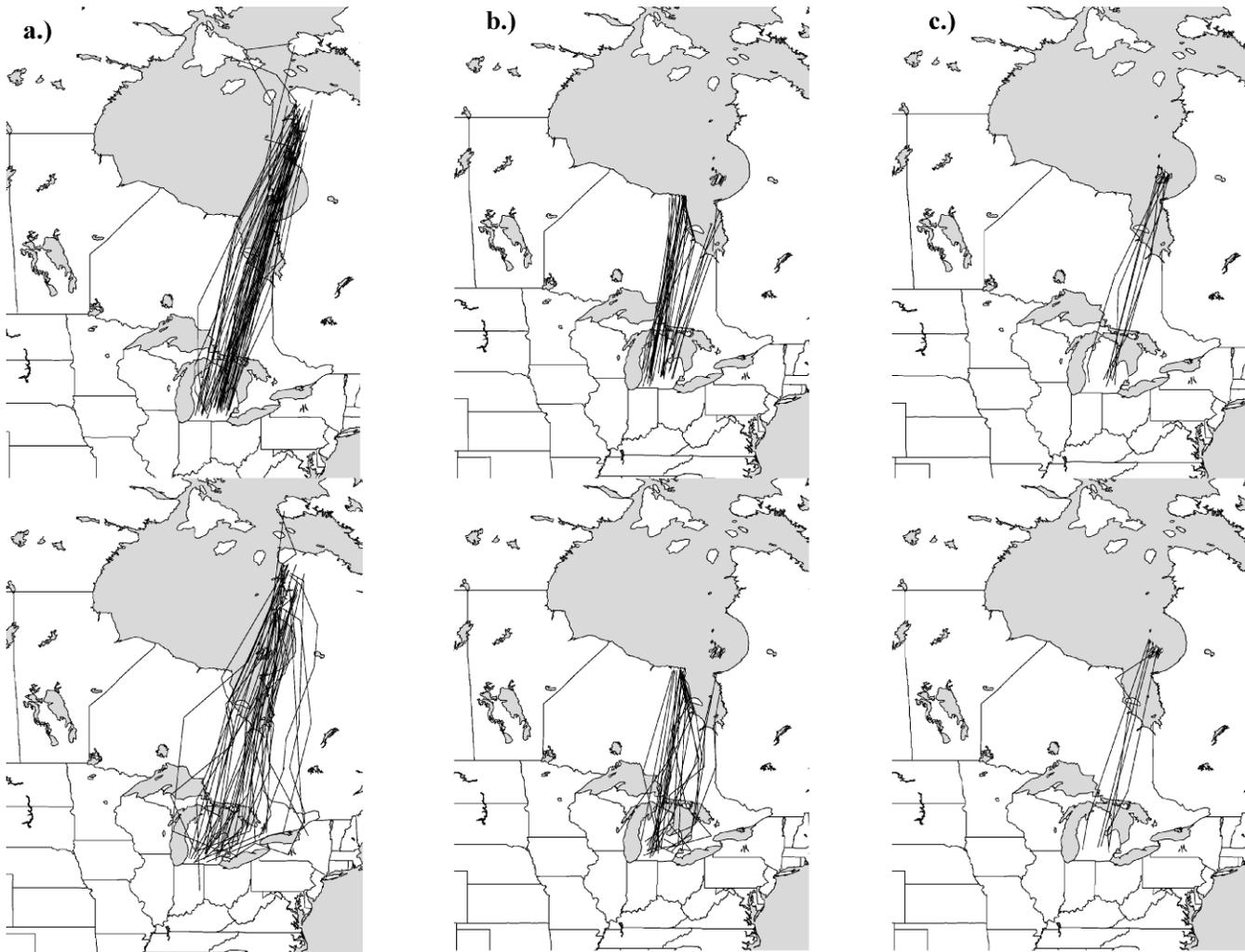


**Figure 4.** Molting locations of female Canada geese marked in southern Michigan, USA, with either platform transmitting terminals ( $n = 74$ ) or very high frequency radiotransmitters ( $n = 153$ ), 2000–2003.

all but 3 (2.3%) molting sites among migratory birds. The 2 longest migrations were birds in different years that flew to the Fox Peninsula of Baffin Island, Nunavut, Canada. After being marked in successive years, 9 birds migrated, and

distances between molting locations for the same bird ranged from 35 km to 410 km ( $\bar{x} = 154$  km).

Migration routes to molting sites were generally straight and directionally similar (north-northeasterly) regardless of



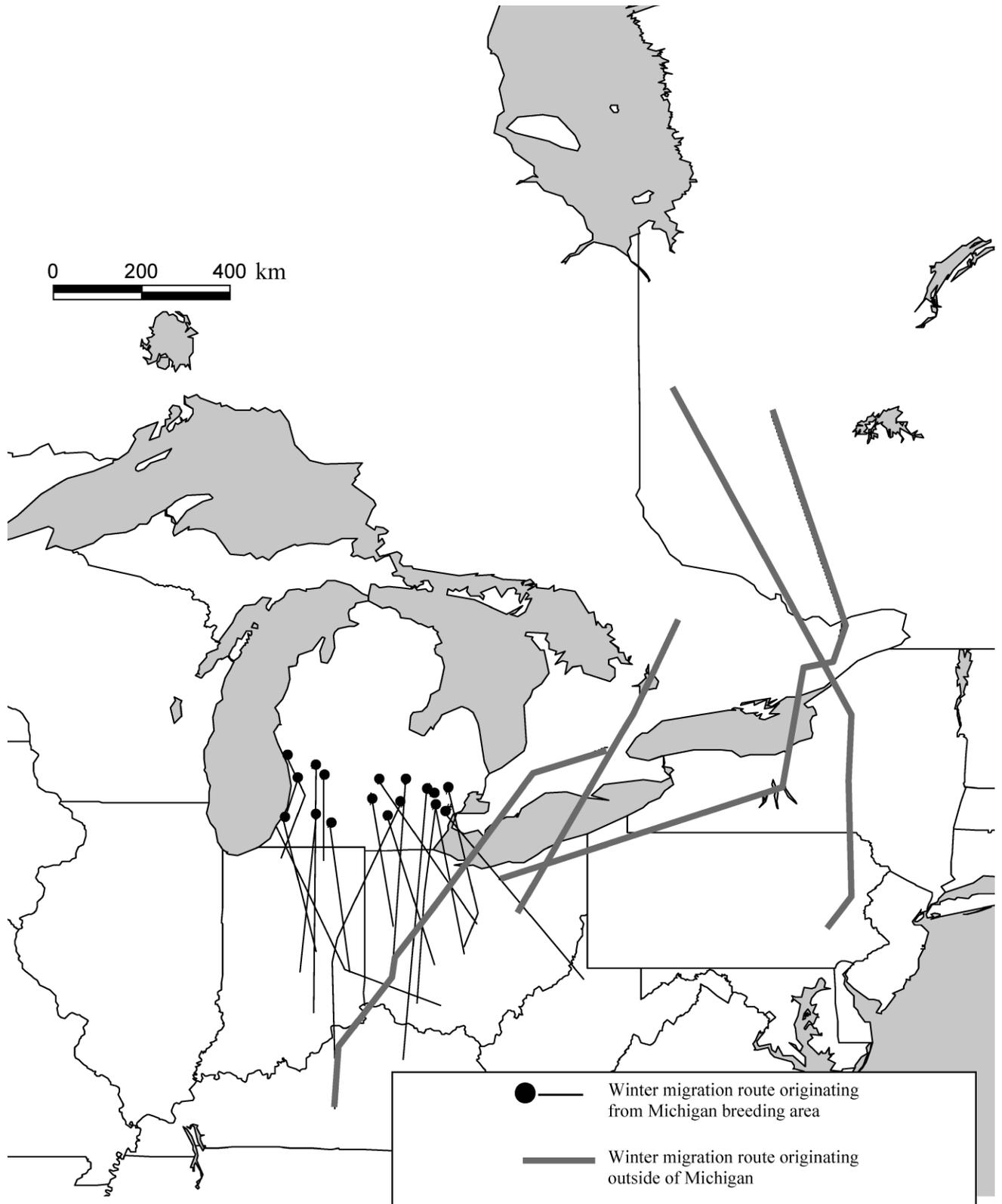
**Figure 5.** Migration routes of female Canada geese marked in southern Michigan, USA, with platform transmitting terminals to (top) and from (bottom) their subarctic molt sites, 2000–2003 in the (a) western Ungava Peninsula, (b) James Bay, and (c) Belcher Islands, Canada.

destination (Fig. 5). With few exceptions, migrating geese stopped near or flew directly over James Bay in route to final destinations. Geographic distribution of molting sites among migratory geese differed by region of origin within Michigan. About 54% of 37 geese that migrated from southwestern Michigan molted near Cape Henrietta Maria, whereas 10% of 49 birds originating from southeastern Michigan and 19% of 43 birds originating from south-central Michigan migrated to this area. Of geese migrating from southeastern, south-central, and southwestern Michigan, 61%, 58%, and 40%, respectively, molted near the Western Ungava Peninsula.

Migratory birds began returning to breeding areas from 20 August through 3 September, depending on year (Fig. 3). Mean return dates ranged from 20 September ( $n = 35$ ;  $SD = 15$  days) during 2001 to 2 October ( $n = 16$ ;  $SD = 25$  days) during 2003. There was no evidence that return dates varied among years ( $F_{3,99} = 1.3$ ;  $P = 0.27$ ) or between transmitter types ( $F_{1,99} = 0.02$ ;  $P = 0.90$ ). Differences in mean return dates of PTT- and VHF-marked geese ranged from 0 days to 5 days, depending on year. With years combined, 37% (95% CI: 28–46%) of returning birds arrived on or before

15 September and 75% (95% CI: 67%–84%) returned on or before 1 October. Migration routes of geese returning to Michigan were relatively indirect compared to direct routes taken to molting sites (Fig. 5). Among birds molting in Western Ungava Peninsula, there was use of a more easterly return route through southern Ontario and even New York, USA, of birds eventually returning to Michigan.

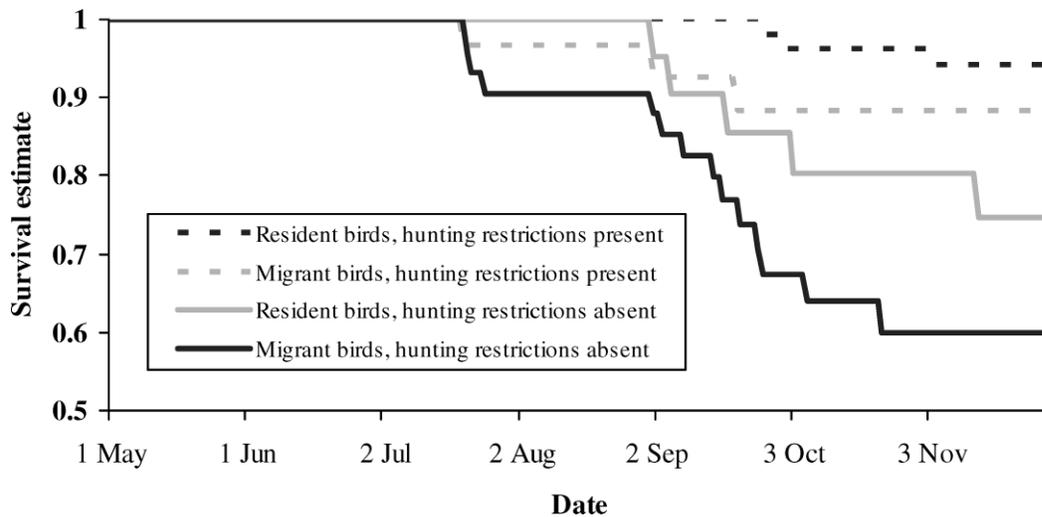
The PTTs were designed to provide location data from spring through early winter each year, but we obtained no data on winter movements until 2002. The PTTs functioned long enough to document winter movements for 3 and 18 birds during the winters of 2002–2003 and 2003–2004, respectively (Fig. 6). During 2003–2004, 74% of females returned to the area near their breeding sites before making migratory movements. By the third week of September, half of the females were near the breeding site, with most returning by early November, although one female did not return to the area near her breeding site until early December. Movement south began in early December, and half of the females had moved by late December. The final movement occurred in mid-January, and all birds stayed at their winter locations until mid-February when



**Figure 6.** Winter (Dec–Jan) movements of Canada geese marked with platform transmitting terminals on southern Michigan, USA, breeding areas, 2002–2003 and 2003–2004. Included are birds that began winter movements either from Michigan breeding areas (solid lines) or from outside Michigan (dashed lines).

movement back to the Michigan breeding sites began. We located most females, including birds that had not visited their breeding area in the previous fall, at breeding sites by mid-March.

During the study 71 birds marked with transmitters died, 50 (70.4%) of which were recovered and reported by hunters, but only 27 harvested birds were direct recoveries. Two migrant birds were shot and reported by subsistence



**Figure 7.** Survival (May–Nov; Kaplan–Meier estimator) of nesting female Canada geese marked with very high frequency radiotransmitters on southern Michigan, USA, breeding areas for 4 groups defined by molt migration status and hunting restrictions within 1 km of nest sites, 2000–2002.

hunters in northern Ontario during summer. We received mortality signals from another 21 birds, but we recovered carcasses or determined cause of death for only 10 of these birds. Our survival analysis included 165 female geese marked with VHF transmitters; 25 of these birds died, 50 birds were censored, and the remaining 90 birds survived the May–November period. We documented mortalities first among migrant birds during July, whereas mortality events among resident birds did not begin until opening day of special early Canada goose seasons on 1 September (Fig. 7). Overall survival from May through November based on Kaplan–Meier estimates was 0.81 (95% CI: 0.74–0.88), but survival distributions differed among goose groups defined by migration status and presence or absence of hunting restrictions near nest sites ( $\chi^2 = 18.5$ ,  $df = 3$ ,  $P < 0.001$ ).

The global Cox proportional hazards model (containing all explanatory variables) predicting survival fit the data, and there was no evidence of overdispersion ( $\chi^2 = 1.52$ ,  $df = 2$ ,  $\bar{c} = 0.76$ ). The top-ranked model included hunting restrictions and migration status and received >1.9 times as much support ( $w_i = 0.517$ ) as any other model; the second-ranked model containing only the hunting restriction explanatory variable also had considerable support ( $w_i = 0.270$ ) as did the model including year in addition to

hunting restriction and migration status ( $w_i = 0.132$ ; Table 3). Model averaged survival estimates differed from Kaplan–Meier estimates by <2%, and they varied among groups defined by migration status and presence or absence of hunting restrictions (Fig. 7; Table 4). Survival of resident and molt migrant geese marked in areas with hunting restrictions (i.e., urban refuges) was 25% and 46% higher, respectively, than survival of resident and molt migrant geese from areas without hunting restrictions (Table 4). Survival of resident geese in areas with hunting restrictions was 55% higher than survival of molt migrant geese originating from areas where hunting was not restricted (Table 4). Resident geese marked in areas where hunting was not restricted had intermediate survival (0.74; 95% CI: 0.52–0.88) as did migrant geese from areas with hunting restrictions (0.88; 95% CI: 0.72–0.96). Our overall estimate of harvest rate was 0.11 (95% CI: 0.07–0.16). Harvest rates ranged from 0.01 (95% CI: 0.00–0.04) among resident birds marked in areas where hunting was restricted to 0.19 (95% CI: 0.04–0.33) among resident birds from areas where hunting was not restricted (Table 4). Survival and harvest rate estimates among the 4 groups defined by migration and hunting status were negatively correlated ( $r = -0.81$ ).

**Table 3.** Candidate Cox proportional hazards models considered for predicting survival (May–Nov) of adult female Canada geese marked with very high frequency radiotransmitters in southern Michigan, USA, 2000–2002. For each model, we report log-likelihood [ $\log(L)$ ], number of parameters ( $K$ ), small sample Akaike’s Information Criterion ( $AIC_c$ ), difference in  $AIC_c$  relative to smallest  $AIC_c$  in the model set ( $\Delta_i$ ), and  $AIC_c$  weight ( $w_i$ ).

Model	Variables included <sup>a</sup>	$\log(L)$	$K$	$AIC_c$	$\Delta_i$	$w_i$
1	Migration, hunt	-110.65	2	225.73	0.00	0.517
2	Hunt	-112.32	1	226.65	1.30	0.270
3	Migration, hunt, yr	-109.93	4	228.10	2.73	0.132
4	Hunt, yr	-111.67	3	229.49	4.12	0.066
5	Migration	-115.44	1	232.91	7.54	0.012
6	Migration, yr	-114.90	3	235.80	10.58	0.005
7	Yr	-119.14	2	242.29	16.99	<0.001

<sup>a</sup> Migration = molt migrated vs. remained on breeding area, hunt = presence vs. absence of hunting restrictions within 1 km of nest (capture) sites.

**Table 4.** Estimates of survival (May–Nov), harvest rate (May–Jan), and 95% confidence intervals for nonmigratory and molt migrant adult female Canada geese captured in areas of southern Michigan, USA, with and without hunting restrictions, 2000–2002. We estimated survival by averaging estimates from 7 Cox proportional hazards models for geese marked with very high frequency radiotransmitters. We estimated harvest rates from direct recoveries of all geese marked with neck collars supporting either platform transmitting terminals or very high frequency radiotransmitters and labeled with US\$100 reward incentives.

Parameter	Hunting restrictions	Migration status							
		Nonmigratory				Molt migrants			
		<i>n</i>	Estimate	Lower CI	Upper CI	<i>n</i>	Estimate	Lower CI	Upper CI
Survival	Present	55	0.93	0.84	0.97	31	0.88	0.72	0.96
	Absent	25	0.74	0.52	0.88	54	0.60	0.42	0.75
Harvest rate	Present	67	0.01	0.00	0.04	47	0.11	0.02	0.20
	Absent	27	0.19	0.04	0.33	95	0.17	0.09	0.24

## DISCUSSION

Previous estimates of migration incidence among failed nesting MFGP Canada geese ranged from 92% at Crex Meadows to 96% in west-central Illinois (Zicus 1981a, Lawrence et al. 1998). Although our estimate of 76% is lower than previous estimates, we collected our data over a variety of land uses where estimates of migration incidence varied from 16% to 93%. Our estimates of migration incidence for rural and suburban areas (89–93%) were similar to estimates from Wisconsin and Illinois, and variation in migration behavior among groups of geese nesting under different environmental or social conditions may explain differences among studies. Incidence of migration was low for both treatment and control birds nesting in urban parks. Although we have no data to support a particular mechanism causing differential migration, there are several factors that could be contributing to low migration incidence in urban parks. Urban parks typically have large expanses of fertilized and mowed grass near water, which is ideal brood habitat. Also, geese are generally protected in parks and are sometimes fed by park visitors. Canada geese can reach high densities under these conditions and nest in proximity to conspecifics. We believe that the combination of space, protection, and abundant food resources support high goose densities, which could reduce molt migration tendencies in subadult and adult geese.

Differences in migration incidence between unsuccessful nesting geese from our treatment (destroyed nests) and control (other nest loss) groups may be a result of timing of nest loss. All geese in our treatment group lost nests after about 14 days of incubation, whereas nest losses among control birds were distributed throughout the nesting cycle, including the laying stage. Although we only documented one renesting attempt, birds that lose nests during laying or early incubation stages may attempt renesting as opposed to migrating. It is possible that we did not detect some renesting attempts after initial nests failed during laying or early incubation.

Although we did not design our study to estimate migration incidence among subadult MFGP, researchers in Wisconsin and Illinois reported a range of 88–97% of

subadults and 50–63% of the spring population molt migrated from their study areas (Zicus 1981a, Lawrence et al. 1998). We estimate that about 55% of the spring population migrated assuming 1) 45% of adult geese were unproductive, 2) about 36% of Michigan's spring Canada goose population was composed of subadults (Coluccy et al. 2004), and 3) migration incidence of subadult geese was similar to other studies. Spring Canada goose population estimates in Michigan ranged from 152,000 to 196,000 birds during our study, which could have resulted in molt migrations of 84,000 to 108,000 geese into subarctic breeding habitats of interior Canada geese (D. R. Luukkonen, Michigan Department of Natural Resources, unpublished data). Spring 2006 MFGP was estimated to consist of about 1.7 million birds, so if incidence of molt migration is about 55% across the MFGP breeding range, then >900,000 MFGP Canada geese would have participated in this migration (Mississippi Flyway Council 2006).

Our movement data demonstrate that molt migrant MFGP Canada geese were sympatric with interior Canada geese and cackling geese (*Branta hutchinsii*) on breeding grounds in both Mississippi and Atlantic flyways. Molting locations of MFGP Canada geese from Michigan included breeding areas defined for SJB, Mississippi Valley Population (MVP), and Atlantic Population (AP) interior Canada geese and cackling geese affiliated with the Tall Grass Prairie Population (Hindman et al. 2004, Leafloor et al. 2004). The west coast of James Bay and south coast of Hudson Bay are known locations for molting MFGP Canada geese, and our study extends the known molting locations for MFGP east and north, including the east coast of James Bay, Belcher Islands, western Ungava Peninsula, Southampton Island, and Baffin Island (Abraham et al. 1999).

Although molt migrant geese from Michigan clustered in 4 areas of Hudson and James Bay, molting location varied with longitude of breeding location origin. Destinations of geese migrating from southwestern Michigan were more closely affiliated with Cape Henrietta Maria compared with birds originating from south-central and southeastern Michigan that were distributed more easterly and affiliated with western Ungava Peninsula. Although researchers

studying molt migration in more westerly MFGP breeding areas could not track departing geese to molting locations, distributions of band recoveries and neck collar observations from birds marked in Minnesota, USA, and Wisconsin suggested a more westerly path to molting locations compared with migratory routes taken by birds from Michigan. Abraham et al. (1999) suggested an easterly migration to Hudson Bay, Ontario, and James Bay and a westerly route to Hudson Bay, Manitoba. Our data support the easterly migration route from southern Michigan, extending northeasterly between the eastern end of Lake Superior and west coast of Georgian Bay, Lake Huron, Ontario, to more northerly molting destinations. Migration routes used by geese returning from Canada to southern Michigan were less direct than northward routes as birds traveled farther east of longitudes used by geese during north migration. Geese migrating north have limited time to reach destinations before they become flightless, and this is not a constraint on birds migrating south in late summer and early fall. It is possible that some birds fail to reach intended molting destinations because of the progression of flight feather loss. For example, Cape Henrietta Maria, Northeast James Bay, and Belcher Islands molting sites were along migratory routes used by birds eventually reaching West Ungava Peninsula.

Presence of molt migrant MFGP Canada geese can upwardly bias population estimates of interior Canada geese derived from spring aerial surveys, and our data confirm that current MVP and SJBP survey dates (mid- to late May) effectively exclude most molt migrants from Michigan (Abraham et al. 1999, Abraham and Warr 2003). Surveys for AP Canada geese have been flown later (mid- to late Jun), and, consistent with our data on migration timing, observers have noted likely molt migrant flocks of Canada geese moving north along the Hudson Bay coast near Povungnituk, Quebec, Canada, during the survey period (Harvey and Rodrigue 2006). Estimating indicated breeding pairs from counts of pairs and singles may reduce influence of molt migrants, but we have no data on flock size of molt migrants departing Michigan.

Timing of fall return of molt migrant MFGP to Michigan was similar to timing reported for Wisconsin, except there was less annual variation in arrival times of geese between the 2 years of study in Wisconsin (Zicus 1981a). Annual variation among fall return times of molt migrants to Michigan may be related to variation in spring phenology reported within subarctic Canada goose nesting areas. For example, nesting effort of SJBP Canada geese was late during 2003 compared with other years during our study (Walton and Abraham 2003).

Our data on survival and harvest rate suggest that Canada geese in Michigan were not uniformly vulnerable to harvest. Survival of adult Canada geese is high in the absence of hunting (Rexstad 1992), and urban settings acted as refuges such that survival of geese marked on urban breeding areas was increased compared with geese marked on breeding areas where hunting was not restricted by local firearm

discharge ordinance or safety zones. Geese that participated in molt migrations were exposed to subsistence harvest during summer, but our data were inadequate to characterize harvest of birds migrating south of Michigan during winter. Estimates of harvest rates were similar between resident and migrant birds, but our assumption of 100% reporting of harvested geese may have been violated by incomplete reporting of marked birds by subsistence hunters. Although our survival estimates were supportive of an effect of reduced survival among molt migrants compared with resident birds, we recommend additional studies to estimate the magnitude of this effect over the entire range of MFGP Canada geese and over the entire year. Our limited winter movement data suggest that after returning to breeding areas, some geese depart Michigan coincident with freezing of open water and when snow depths inhibit access to food. Geese breeding in urban Michigan settings may become vulnerable to harvest during winter movements.

Future research should consider potential impacts of molt migration on demographics of Canada geese. Existing population models for MFGP Canada geese assume no correlations among vital rates (Coluccy et al. 2004). Survival differences between molt migrant and resident MFGP could lead to positive correlations between adult survival and reproduction because a smaller proportion of the breeding population will migrate in years when nest success is high. The importance of this effect will vary among land uses because incidence of migration was low in urban parks and survival differences were less in birds that originated from areas with hunting restrictions. Differential survival of molt migrants versus residents also has implications for estimating relative effects of management options such as egg and nest destruction versus adult harvesting on modeled population growth. We recommend additional research to assess impacts of nest destruction and subsequent molt migration on MFGP demographics.

Early Canada goose seasons can effectively target harvest of MFGP Canada geese before interior Canada geese arrive on MFGP breeding grounds, but many molt migrant geese have not returned from molting areas by the close of the season (15 Sep in southern MI). Traditional United States hunting season frameworks allowed regular Canada goose seasons in the MF to begin in late September or early October, but during our study, Michigan used earlier regular season opening dates to affect additional harvest on MFGP Canada geese breeding in Michigan. Because peak migration of MVP and SJBP into southern Michigan usually occurs after 1 October, there is potential to extend early seasons or use regular seasons during the period 16 September–1 October to direct additional harvest at MFGP Canada geese (Luukkonen and Soulliere 2004). Southern Ontario, Canada, is another important harvest area for MFGP Canada geese from the eastern portion of their range and we expect migration timing is similar in Michigan and southern Ontario such that our recommended season dates could be used there.

## MANAGEMENT IMPLICATIONS

Although molt migration of geese away from nest destruction treatment areas may help reduce local human–goose conflicts temporarily (i.e., Jun–Aug), nest destruction will have greatest impacts on goose abundance in areas where molt migrant and nonmigrant geese can be exposed to additional hunting mortality. Special early Canada goose seasons typically end 15 September in the MF, before most molt migrants have returned to Michigan. Thus, early seasons will largely target successfully breeding adult MFGP Canada geese and their young, whereas approximately two-thirds of molt migrants are not vulnerable. Modification of regular Canada goose season timing offers one potential way of exposing molt migrant Canada geese to additional harvest (Luukkonen and Soulliere 2004). However, in urban settings it is sometimes illegal, unsafe, or impractical to hunt geese, and alternative methods may be required to resolve conflicts between geese and people. Because MFGP Canada geese provide substantial benefits to people interested in harvesting or viewing geese, managers should consider the possibility that increasing MFGP goose harvest rates over large areas may reduce goose abundance below desirable levels in some areas. For example, high harvest rates of geese in rural settings could lead to changes in distribution of birds such that geese remain most abundant in urban areas where recreational hunting is restricted, but conflicts with people are common. We share concern expressed over potential for competition between molt migrant MFGP and interior Canada geese, and we recommend assessment of the capabilities of subarctic habitats to support increasing influxes of molt migrant Canada geese (Abraham et al. 1999). Finally, management of Canada goose populations in the Mississippi Flyway should be coordinated and strive to maintain populations at desirable levels across their breeding range.

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