

**NESTING AND BROOD-REARING ECOLOGY OF
RESIDENT CANADA GEESE IN NEW JERSEY**

by

Katherine B. Guerena

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment
of the requirements for the degree of Master of Science in Wildlife Ecology

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Katherine B. Guerena

Approved: _____
Christopher K. Williams, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: _____
Douglas W. Tallamy, Ph.D.
Chair of the Department of Entomology and Wildlife Ecology

Approved: _____
Robin W. Morgan, Ph.D.
Dean of the College of Agriculture and Natural Resources

Approved: _____
Charles G. Riordan, Ph.D.
Vice Provost for Graduate and Professional Education

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ABSTRACT

The Atlantic Flyway Resident Population (AFRP) of Canada geese (*Branta canadensis*) in New Jersey has grown so considerably during the last thirty years that it is now considered a nuisance in urban areas (United States Fish and Wildlife Service 2003). New Jersey is also the most densely human populated state in the nation, with intensive urbanization of agricultural and natural lands. Development of corporate parks and urban areas with manicured lawns and artificial ponds offer ideal nesting habitat for AFRP geese, with limited pressure from hunting or natural predators. As a result, spatial heterogeneity in reproduction and survival must be taken into account in managing the population. My objectives for this study were to 1) identify the spatial scale/s at which land use features influence nest site selection and nest success, 2) estimate nesting parameters across three decades and identify variables that influence productivity, and 3) estimate pre-fledged gosling survival from hatch until summer molt banding efforts, in order to assist in developing a spatially-explicit population model for AFRP geese in New Jersey.

I conducted a two-year (2009–2010) nesting ecology study of AFRP Canada geese, and compared it to data collected in New Jersey from 1985–1989 and 1995–1997.

Nest searches were conducted on 250 1-km² plots throughout the state, and 309 nests were monitored through hatch to determine the fate. I ran a spatial correlation analysis of land use composition to nest success during 2009–2010 to identify spatial scales at which geese respond to their environment for nest site selection and nest success. All significant spatial scales were at or below 2250m for the five classified land use types. Geese responded to human dominated land uses at a smaller scale than land uses with low human density. Mean clutch size at hatch in 2009–2010 was 4.66 eggs (SE $\pm$ 0.12 eggs) and 4.76 eggs (SE $\pm$ 0.16 eggs), respectively. Mean hatchability in 2009–2010 was 0.86 (SE $\pm$ 0.02) and 0.81 (SE $\pm$ 0.02), respectively. I estimated nest success at 0.44 (SE $\pm$ 0.05) in 2009 and 0.41 (SE $\pm$ 0.05) in 2010. Variables important to nest success from 1985–1989 were the age of the nest, year, extreme high temperature, nest density, rural residential land use at the landscape scale, commercial at the site level, and daily precipitation. Variables important to nest success for 1995–1997 were the age of the nest, date of nest initiation, year, physiographic stratum, extreme high temperature, rural residential land use at the landscape level, and agricultural land use at the site level. Variables important to nest success for 2009–2010 were the age of the nest and date of nest initiation. Nest success decreased during the duration of the study, likely due to an increase in reproductive control efforts.

Additionally, I conducted a two-year (2009–2010) gosling survival study from hatch until annual banding efforts in late-June at 12 known nesting and brood rearing sites. To estimate gosling survival, I used 1) mark-recapture of web tagged goslings to

estimate partial brood loss, 2) radio-collared breeding adults to estimate total brood loss, and 3) observations of broods associated with marked adults and color-marked broods to quantify mortality during the first two weeks after hatch. The proportion of breeding adults that experienced total brood loss was 0.316. The remaining proportion of breeding adults was subject to partial brood loss (0.684), which was estimated at 0.465 ($SE \pm 0.026$) for 56 days. The overall survival estimate for 56 days after hatch was 0.318 ($SE \pm 0.018$). Select environmental and density-dependent variables were used to build candidate models to identify sources of variation in partial brood loss. The number of broods at the site was negatively related to brood survival. The percent agriculture within 215 m was positively related to brood survival.

Managers are encouraged to consider scale-dependent relationships in identifying habitat-wildlife relationships, and if population control of AFRP Canada geese is of primary interest, then focus on habitat management at the local scale will most likely have the largest influence. Developing productivity trends should assist in understanding the dynamics of recruitment as a function of population size, spatial distribution, and human influence. I recommend that managers consider land use and human development as important features in identifying the driving forces of productivity in AFRP Canada geese.

Chapter 1

SPATIALLY-EXPLICIT HABITAT EFFECTS ON NEST SITE SELECTION AND NEST SUCCESS OF ATLANTIC FLYWAY RESIDENT CANADA GEESE

Introduction

New Jersey is the most densely human-populated state in the nation, with more than 460 people/ km² in 2009 (United States Census Bureau 2011). The resultant demand for housing, recreation areas, roads, and corporate parks with manicured open lawns and artificial water sources has reduced the amount of suitable habitat for many wildlife species, but has created increased urban/suburban nesting and brood rearing habitat for Atlantic Flyway Resident Population (AFRP) Canada geese (*Branta canadensis*). A secondary impact of land use shifts has decreased the amount of land suitable for hunter harvest, limiting the major mortality factor of fledged AFRP geese (Smith et al. 1999, Atlantic Flyway Council 2011). Consequently, these conditions have allowed the AFRP to increase to approximately 106,000 birds in 2000, and a current estimated population of 70,000 in 2011 (New Jersey Division of Fish and Wildlife, unpublished data).

Because human-manipulated landscapes may have influenced recent growth of the AFRP, direct measurement of its influence on recruitment and annual survival is critical. Pastor et al. (1997) argued that in order to better understand relationships between habitat and productivity and inform management control efforts, a need exists to

identify the site and landscape scales at which wildlife interact with their environment. Furthermore, there has been increased recognition that we must consider bird responses to habitat types at varying or multiple spatial scales (Roland and Taylor 1997, Holland et al. 2004, Holland et al. 2005). To date, several research efforts have been made to determine the primary spatially explicit landscape variables that influence the selection of waterbird nest locations and nest success (e.g. sandhill cranes [*Grus Canadensis*, Baker et al. 1995], mallards [*Anas platyrhynchos*, Zicus et al. 2006], and common loons, [*Gavia immer*, Kuhn et al. 2011]).

Although Messmer (2010) found that habitat associations of breeding pair temperate-nesting Canada geese could be influenced by spatial scales, previous research has primarily focused on the effects of simple habitat attributes of Canada goose nesting ecology. For example, nest survival has been found to be positively influenced by increased commercial, urban, or residential development (Hilley 1976, Ankney 1996, Owen et al. 1998, Smith et al. 1999, Paine et al. 2003) due to removal of forested/natural areas, filling of natural water bodies, installation of sod lawns and manmade ponds with drainage, and reduced predators (Gosser et al. 1997). In contrast, positive correlations associated with managed ecosystems may be dampened by implementation of reproductive control programs available to the public by United States Fish and Wildlife Service, United States Department of Agriculture, and companies specializing in population control techniques. Lastly, natural lands such as forest, shrub, and wetlands may have a negative correlation with nest survival due to an increase in terrestrial predator habitat and tidal flooding in some areas (Wolf 1955, Batt et al. 1992).

To maintain efficient management of a growing nuisance population such as with AFRP geese, it is important to understand spatially explicit habitat effects on their nesting ecology. Because the direction and magnitude of associations between habitats and animals may vary across the landscape, this study investigates both site scale and multiple landscape scale habitat associations on the nest site selection and nest success of AFRP Canada geese in New Jersey.

Study Area

Nest searches were conducted on 250 randomly located 1-km² plots, stratified among five physiographic strata within New Jersey, USA, during 2009–2010 nesting seasons. The five primary physiographic strata covered within these plots include Ridge and Valley, Highlands, Northern Piedmont, Coastal Plain, and Salt Marsh habitats (Fig. 1.1). The Ridge and Valley region is composed of forest-covered ridges and river valleys, providing breeding waterfowl habitat primarily along rivers, freshwater wetlands and farm ponds and streams associated with agricultural areas. The Highlands region has recently experienced tremendous human development; however, this stratum offers breeding waterfowl habitat primarily in areas dominated by freshwater wetlands, rivers, farm ponds, and reservoirs. Northern Piedmont is a sediment-filled rift basin bound by the Blue Ridge Mountains and the eastern side of the Appalachians. Low rolling hills and poorly drained soil hold natural streams and water bodies proving beneficial for waterfowl. While part of the Coastal Plain offers moist, poorly drained soil, much of this stratum in New Jersey consists of sandy, infertile soil. Primary breeding waterfowl habitat includes palustrine wetlands and manmade sandwash ponds. The salt marsh

region is tidal wetland primarily consisting of cordgrass (*Spartina* spp.), and offers both wintering and breeding habitat for many waterbirds. This stratum is located along the tributaries of the Atlantic coast and Delaware Bay.

The 250-plot study area has been used by New Jersey Division of Fish and Wildlife (NJDFW) staff as part of the Atlantic Flyway Breeding Waterfowl Survey (AFBWS) since the survey was initiated in 1996 (Heusmann and Sauer 1997, Heusmann and Sauer 2000). The average distance between plots was 4.72 km. For the purpose of selecting nesting locations, I considered these plots to be independent of each other. All plots contain habitat adequate for waterfowl, with at least one body of water (e.g. stream, retention pond, lake, wetland, or reservoir).

Methods

I conducted nest searches on all plots from 15 March–10 May 2009–2010. Of the 250 plots, 181 of these had geese observed during at least one of the three prior AFBWS years (2006–2008), and were searched 3 times during the laying and incubation period. The 69 plots where geese had not historically been observed were searched once by NJDFW biologists during the annual AFBWS from 15 April–10 May. I recorded the location and monitored weekly of any discovered nests through hatch to determine whether the nests were successful. Nest success is conventionally defined as the hatch of at least one egg (Mayfield 1961). I determined the nest fate by either observing: 1) goslings within the nest bowl, 2) eggshells with intact membranes in the nest bowl, and/or 3) goslings associated with the adult near the nest. I assumed that the use of apparent nest success is representative of actual nest success across the population.

To explain how nest presence/selection and success could have been influenced by site and landscape scale habitat variables, I quantified habitat available to geese at multiple spatial scales. I reclassified 22 land cover categories within the 2005 National Oceanic and Atmospheric Administration Coastal Change and Analysis Program (NOAA C-CAP; Dobson et al. 1995) land cover dataset into 5 habitat types including Urban/Suburban, Rural, Agriculture, Natural, and Water (Table 1.1). This reclassification was performed to minimize the number of explanatory variables but allow for biological reasoning behind each correlation analysis. To quantify the relationships between site scale habitat composition on nest site selection and nest success, I measured the percentage of the 5 habitat types with a 250 m buffer (Messmer 2010) around the center of each plot and around each nest location, respectively, using geographic information system (GIS) software.

To determine the appropriate landscape scale habitat correlations to nest site selection, I measured the percentage of the habitat types within a series of buffers at spatial scales ranging from a radius of 0.25 km –16 km at 250 m increments around each location (using ESRI ArcMap 9.2.x, Fig. 1.2). I minimized the site scale effect on the landscape scale analyses by removing the 250 m radius site scale buffer from each landscape scale buffer (Messmer 2010). Some plots held multiple nests, but only the presence of a randomly determined single nest was used in the analysis to avoid pseudoreplication. To determine the landscape scale that most influenced nest site selection and nest success, I performed a correlation analyses between the 5 habitat types at landscape scales from 0.25–16 km and nest site selection and success (PROC CORR,

SAS). I used an initial bootstrapping to obtain Spearman's Rank correlation coefficients on 10,000 random samples of 10 points at least 32 km apart for each buffer distance (Holland et al. 2004). The correlation of the proportion of land cover types to nest occupancy and nest success resulted in r-values for each habitat category at all tested spatial scales. I used a Student's t-test ($\alpha = 0.05$) to identify ranges of spatial scales that were statistically similar to the range that exhibited the strongest correlation (Duren 2010). The smallest radius within that range was used as the scale for determining the landscape scale that was most influential.

In the initial analyses for nest success and nest occupancy, all significant scales were below 3 km. Because spatial scales were dominated by local scales, I reran the aforementioned analyses with the 2007 New Jersey Land Use/Land Cover (NJ-LULC; NJ OIT 2010) dataset because of its increased specificity. In 15 cases, nests with spatial scales extending into bordering states were then removed from the dataset so that all further analyses could utilize the NJ-LULC dataset. The NJ-LULC dataset was reclassified from the original 84 categories into 6 land use/land cover types that both corresponded with the NOAA C-CAP dataset but also allowed for the separation of Urban/Suburban habitat into Urban/Suburban Residential and Commercial/Industrial categories (Table 1.2). I tested spatial scales ranged from 0.25–3 km, including the 0.25 km site scale in order to better explain spatial interactions between site and landscape scales. I ran a series of correlation analyses on the fate of a bootstrapped sample of 278 nests with the 6 habitat types to determine the most significant spatial scale for each

habitat. Spearman's Rank correlations were graphed with spatial scales ranging from 0.25–3 km radii.

Results

During 15 March–10 May 2009–2010, state biologists and technicians surveyed 250 plots, and determined the fate of 293 AFRP Canada goose nests in all five physiographic strata. Of these, 163 nests (55.6%) were successful during the 2-year study. Eighty-two out of 250 plots occupied ≥ 1 nest. For nest site selection, selected spatial scales for each NJ-LULC type ranged from 500–1000 m (Fig. 1.3a). For nest success, the spatial scales for each NJ-LULC type ranged from 500–2250 m (Fig. 1.3b).

The proportion of Commercial/Industrial land use ranged from 7.2–8.3% around plot centers and between 8.7–11.2% around nest sites. At the site level, nest site selection was positively correlated with Commercial/Industrial land use ($r = 0.285$; Fig. 1.3ai). At a landscape scale, Commercial/Industrial land use was most correlated at a 500 m scale ($r = 0.262$; Fig. 1.3bi) and decreased as the spatial scale increased beyond this point. Corresponding to the relationships observed in nest site selection, nest success was most positively correlated at the site scale ($r = 0.115$; Fig. 1.3bi) and landscape scale of 500 m ($r = 0.119$) and then decreased toward 0 as the spatial scale increased beyond 1000 m.

The proportion of Urban/Suburban Residential land use ranged from 10.0–12.6% around plot centers and from 9.7–12.6% around nest sites. At the site level (250 m), nest site selection was positively correlated with Urban/Suburban Residential land ($r = 0.286$; Fig. 1.3aⁱⁱ), which, in turn, positively affected nest success ($r = 0.062$, Fig. 1.3bⁱⁱ). At a landscape scale, nest site selection was positively correlated with Urban/Suburban

Residential land within 500 m ($r = 0.215$). However, Canada geese nest site selection was less influenced by increasing amounts of Urban/Suburban Residential habitat at broader scales. Nest success was most correlated at 750–1000 m scales ($r = 0.082$ – 0.084) and correlations with habitat availability decreased toward 0 as the spatial scale increased beyond this point.

The proportion of Rural Residential land ranged from 11.1–12.2% around plot centers and from 11.8–12.8% around nest sites. At the site level, nest site selection was positively correlated with Rural Residential land ($r = 0.106$; Fig. 1.3aⁱⁱⁱ). At a landscape scale, nest site selection was positively correlated with Rural Residential land at the 750 m scale ($r = 0.115$), but remained between 0.087–0.129 through a spatial scale of 3 km. Interestingly, nest success was least correlated with Rural Residential at the site level ($r = 0.027$); however, correlations improved substantially at the landscape scale of 1000 m scales ($r = 0.116$; Fig. 1.3bⁱⁱⁱ).

The proportion of Agricultural land use ranged from 12.7–15.1% around plot centers and 6.8–9.9% around nest sites. At a site scale, nest site selection was negatively correlated with Agricultural land use ($r = -0.037$; Fig. 1.3a^{iv}). However, at increasing landscape scales, the presence of agriculture improved nest site selection and was most correlated with a positive nest site selection when available within a 1000 m scale ($r = 0.098$). The correlation coefficient remained between 0.070 and 0.105 through a spatial scale of 3 km. Despite the negative correlation between nest site selection and presence of agriculture at the site scale, nest success was positive ($r = 0.130$, Fig. 1.3b^{iv}) and remained at a similar correlation out to a landscape scale of 2250 m ($r = 0.124$).

The proportion of Natural habitat ranged from 45.8–47.5% around plot centers and between 38.5–41.1% around nest sites. Natural habitat was negatively correlated with nest site selection both at the site scale ($r = -0.049$; Fig. 1.3av) and landscape scales ($r = -0.079$ – -0.108). While this negative correlation with nest site selection at the site scale also translated into a negative correlation with nest success ($r = -0.076$, Fig. 1.3bv), Natural habitat became positively correlated with nest success when present at increasingly larger spatial scales peaking at 2250–2500 m scale ($r = 0.059$ – 0.073).

Lastly, the proportion of Water ranged from 7.3–8.3% around plot centers and from 7.2–16.7% around nest sites. At the site scale, the percent Water was positively correlated with nest site selection ($r = 0.169$; Fig. 1.3avi), and while the correlation with Water improved at the 500–1000 m scale ($r = 0.208$), it decreased toward 0 as spatial scales increased beyond this point. Despite the positive correlation with water for nest site selection, nest success was negatively correlated with the percent water at both the site scale ($r = -0.037$, Fig. 1.3bvi) and increasingly at a landscape scale of 1000 m ($r = -0.161$). The correlation coefficient remained between -0.126 and -0.178 beyond 1000 m through 3 km.

Discussion

The investigation of habitat-animal associations relies on our ability to understand the scale at which wildlife respond to and interact with their environment (Pastor et al. 1997). Spatial scales may vary drastically between species and populations, particularly with variation in mobility, resource requirements, and population size. A generalist species such as a temperate-nesting Canada goose, with fewer resource requirements

influencing the selection of a nest site, might be expected to respond differently than a species requiring more specific resources during nesting, such as a sandhill crane (Baker et al 1995). Variation might also be expected between study areas containing differing land uses or habitats. For example, a temperate-nesting Canada goose might respond to its environment at a smaller spatial scale than a sub-arctic nesting Canada goose, due to the difference in availability of nesting resources and environmental influences such as timing of snowmelt or seasonal flooding. Our study is among the first to explore how a human-dominated landscape influences both nest site selection and nest success in resident Canada geese.

Theoretical hierarchical decisions made by a breeding goose are likely influenced by an array of variables, including landscape scale attributes, site scale characteristics such as the presence of water corridors and/or increased visibility to defend against predators, and biological and ecological considerations such as female philopatry (Johnson 1980, Batt et al. 1992, Jones 2001) and resource acquisition (Hostetler 1999). From an evolutionary perspective, it should also be considered that habitat features might influence nest site selection and nest success similarly (Pulliam 1988), as geese are a highly adaptive and productive species. Although female philopatry may have a substantial influence on nest site selection (Batt et al. 1992), behavioral plasticity in nest site selection has been seen in response to previously failed breeding attempts (Brakhage 1965, Hanson 1965, Anderson 1996, Gosser and Conover 1999). This study demonstrates that the relationships between nest site selection and nest success in human-dominated

landscapes are often variable, and the magnitude and direction of correlations are not necessarily linked.

We found that site-scale characteristics were important for nest site selection in Urban Residential and Commercial/Industrial areas. Our results also indicate that land use influences on nest site selection are at a relatively small scale (≤ 1000 m), in comparison with the year-round mean home range of resident geese at ~ 25 km² (Groepper et al. 2008). Site-scale elements were also important to nest success in Commercial/Industrial and Agricultural areas. These results are consistent with the results of prior studies of resident geese (Smith et al. 1999, Cline et al. 2004), in that nest success is often higher in urban and commercial/industrial areas. We also found that human-dominated land uses such as Commercial/Industrial and Urban Residential were related to nest success on a smaller scale (500 m–750 m) than that of land uses that generally lacked human presence (Agricultural and Natural areas; 2250 m). Rural Residential land use was related to nest success at a moderate scale (1000 m); areas in which humans are present at a low density.

Urban and Commercial/Industrial land uses had a stronger relationship with nest site selection than nest success. Although we expected nest success to be positively correlated with increased urban land, weakening of the correlation between these land uses and nest success may be due to anthropogenic impacts in success through implementation of reproductive control programs in these areas. A key benefit of nesting in Commercial/Industrial areas is the continual growth and mowing of lawns, making available key nutrients for developing goslings during brood rearing (Batt et al. 1992).

Additionally, a decrease in predator habitat and low resource competition (Cline et al. 2004) has been shown to influence nest site selection. In studying urban influences on nesting of western burrowing owls (*Athene cunicularia hypugaea*), Botelho and Arrowood (1996) suggested that moderate levels of urbanization provide more food and protection from predators than nearby undeveloped areas. However, at high levels of urban development, this protection may be offset by other anthropogenic impediments.

Rural Residential land use offers many attributes of an ideal nest site for resident geese (e.g. food, water, shelter, protection from predators) at multiple spatial scales. Avoidance of human development by predators and the presence of small ponds could be interpreted at a smaller scale, while ample brood rearing habitat may also be appealing within 1–2 km. Conversely, a reproductive control program offered by US Fish and Wildlife Service allowing private landowners to control nests on their property has become widely used in these areas. Our results reflect this reduction in nest success, possibly creating an ecological trap in which nest site attributes are attractive, but geese are subject to infertility during the nesting period.

The site scale benefits of Agricultural land on nesting geese are not as transparent as those of the landscape scale, which might include increased food availability during brood rearing (Batt et al. 1992), presence of wetlands associated with farmland, or distance to wintering area. Accordingly, our data shows that geese respond to Agricultural land use at a larger scale in selecting a nest site than urban land uses.

Although Natural land was negatively related to nest success at the site scale, nest success became positively related to the proportion of Natural lands at increasing

landscape scales. These results are consistent with prior literature that natural lands have lower survival than that of urban land (Smith et al. 1999). Bowman and Harris (1980) suggest that nesting success reduces in habitats where spatial heterogeneity is decreased (e.g. transitioning to uniform natural lands), due to decreasing foraging efficiency by predators.

Like most waterfowl, resident geese prefer nest sites within several meters of a water body (Hanson 1965), offering protection from terrestrial predators during incubation and brood-rearing (Batt et al. 1992). Carbaugh et al. (2010) showed that geese selected nest sites on larger bodies of water more often, which may offer a larger foraging base and a greater ability to escape from predators. However, our data shows that an increase in the proportion of water across spatial scales was correlated with a decrease in nest site selection beyond 750 m. Large scale effects of water such as heavy precipitation during April and May, as well as spring tides, may cause flooding in areas dominated by water. Additionally, this may be reflecting differences in other features associated with water bodies, such as an attraction of predators to water sources, or a decrease in available brood rearing habitat with an increase in water.

Densely urbanized land use may not be as desirable for nest site selection beyond a site scale, as seen in this study. Although it has been noted in prior literature that urban areas are associated with decreased predation and hunting pressure (Gosser et al. 1997, Atlantic Flyway Council 2011), increased urbanization at a landscape level may lack the resources necessary for producing young. They may also be more prone to water level fluctuations, given the high percentage of surfaces with impermeable cover. Although

resident Canada geese likely endure less competition for resources than migratory goose species (Atlantic Flyway Council 2011), the potential for human disturbance may influence the decision to nest in a human-dominated landscape.

Management Implications

It is important to understand spatially explicit goose-habitat dynamics in order to direct control efforts in the most economically and ecologically efficient manner and to better understand the factors that drive population growth in AFRP Canada geese. Although we used a detailed state-specific land use/land cover dataset in our final analyses, national land cover datasets can be used in areas where state information is not available. We used the NOAA C-CAP dataset during initial analyses in order to allow for an investigation of spatial scales as broad as 16km around a nest. Never-the-less, our results showed that geese related to land use at much smaller scales, allowing us to utilize a more detailed dataset and focus management recommendations at a local scale.

Our results show that spatial scales at which nest success is highest correlated associated are smaller in urban land uses than rural, agricultural, and natural land uses. We suggest that managers utilize these spatial scales in identifying the effect of landscape scale habitat variables on nest success. Managers are encouraged to consider scale-dependent relationships in identifying habitat-wildlife relationships, and if population control of AFRP Canada geese is of primary interest, then focus on habitat management at the local scale will most likely have the largest influence.

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Table 1.1. Original and reclassified land use/land cover types based on National Oceanic and Atmospheric Administration Coastal Change and Analysis Program (NOAA C-CAP) land cover dataset to model Canada goose nest success and nest occupancy in New Jersey, USA, from 15 March – 15 June 2009–2010.

Category	Original CCAP Land Cover Type (and associated code)	% of New Jersey
Urban/Suburban	Developed, High Intensity (2)	12.4
	Developed, Medium Intensity (3)	
	Developed, Open Space (5)	
Rural Agriculture	Developed, Low Intensity (4)	9.0
	Cultivated (6)	17.5
	Pasture/Hay (7)	
Natural	Deciduous Forest (9)	47.1
	Evergreen Forest (10)	
	Mixed Forest (11)	
	Wetland, Palustrine Forested (13)	
	Wetland, Palustrine Scrub/Shrub (14)	
	Wetland, Palustrine Emergent (15)	
	Wetland, Palustrine Aquatic Bed (22)	
	Wetland, Estuarine Forested (16)	
	Wetland, Estuarine Scrub/Shrub (17)	
	Wetland, Estuarine Emergent (18)	
	Wetland, Estuarine Aquatic Bed (23)	
Water	Open Water (21)	11.9
Other	Other Land	2.1

Table 1.2. Original and reclassified land use/land cover types based on New Jersey Land Use/Land Cover (NJ LULC) dataset to model Canada goose nest success and nest occupancy in New Jersey, USA, from 15 Mar – 15 June 2009–2010.

Category	Original NJ-LULC Type (and associated code)	% of New Jersey
Urban/Suburban Residential	Residential, High Density Or Multiple Dwelling (1110) Residential, Single Unit, Medium Density (1120) Mixed Residential (1150) Recreational Land (1800)	11.1
Rural Residential	Residential, Single Unit, Low Density (1130) Residential, Rural, Single Unit (1140)	8.8
Commercial/Industrial	Commercial/Services (1200) No Longer Military (1214) Industrial (1300) Industrial And Commercial Complexes (1500) Military Installations (1211) Mixed Urban Or Built-Up Land (1600) Other Urban Or Built-Up Land (1700) Cemetery (1710) Upland Rights-Of-Way Developed (1462) Upland Rights-Of-Way Undeveloped (1463) Transportation/Communication/Utilities (1400) Major Roadway (1410) Mixed Transportation Corridor Overlap Area (1411) Bridge Over Water (1419) Railroads (1420) Airport Facilities (1440) Storm Water Basin (1499)	8.0
Agriculture	Cropland And Pastureland (2100) Former Agricultural Wetland (Becoming	10.4

Natural	Shrubby, Not Built-Up) (2150)	46.9
	Orchards/Vineyards/Nurseries/Horticultural Areas (2200)	
	Confined Feeding Operations (2300)	
	Other Agriculture (2400)	
	Deciduous Forest (10–50% Crown Closure) (4110)	
	Deciduous Forest (>50% Crown Closure) (4120)	
	Coniferous Forest (10–50% Crown Closure) (4210)	
	Coniferous Forest (>50% Crown Closure) (4220)	
	Plantation (4230)	
	Mixed Forest (>50% Coniferous With 10–50% Crown Closure) (4311)	
	Mixed Forest (>50% Coniferous With >50% Crown Closure) (4312)	
	Mixed Forest (>50% Deciduous With 10–50% Crown Closure) (4321)	
	Mixed Forest (>50% Deciduous With >50% Crown Closure) (4322)	
	Old Field (< 25% Brush Covered) (4410)	
	Phragmites Dominate Old Field (4411)	
	Deciduous Brush/Shrubland (4420)	
	Coniferous Brush/Shrubland (4430)	
	Mixed Deciduous/Coniferous Brush/Shrubland (4440)	
	Severe Burned Upland Vegetation (4500)	
	Saline Marsh (Low Marsh) (6111)	
	Saline Marsh (High Marsh) (6112)	
	Fresh Water Tidal Marshes (6120)	
	Vegetated Dune Communities (6130)	
	Phragmites Dominate Coastal Wetlands (6141)	
	Deciduous Wooded Wetlands (6210)	
	Coniferous Wooded Wetlands (6220)	
	Atlantic White Cedar Wetlands (6221)	
	Deciduous Scrub/Shrub Wetlands (6231)	
	Coniferous Scrub/Shrub Wetlands (6232)	
	Mixed Scrub/Shrub Wetlands (Deciduous Dom.) (6233)	

	Mixed Scrub/Shrub Wetlands (Coniferous Dom.) (6234)	
	Herbaceous Wetlands (6240)	
	Phragmites Dominate Interior Wetlands (6241)	
	Mixed Wooded Wetlands (Deciduous Dom.) (6251)	
	Mixed Wooded Wetlands (Coniferous Dom.) (6252)	
	Unvegetated Flats (6290)	
	Wetland Rights-Of-Way (1461)	
	Cemetery On Wetland (1711)	
	Phragmites Dominate Urban Area (1741)	
	Managed Wetland In Maintained Lawn Greenspace (1750)	
	Disturbed Wetlands (Modified) (7430)	
	Severe Burned Wetland Vegetation (6500)	
	Agricultural Wetlands (Modified) (2140)	
	Managed Wetland In Built-Up Maintained Recreational Area (1850)	
Water	Natural Lakes (5200)	14.8
	Artificial Lakes (5300)	
	Tidal Rivers, Inland Bays, And Other Tidal Waters (5410)	
	Open Tidal Bays (5411)	
	Dredged Lagoon (5420)	
	Atlantic Ocean (5430)	
	Streams And Canals (5100)	
	Exposed Flats (5190)	

Figure 1.1. Locations of all survey plots within five physiographic strata in New Jersey, USA, from 15 March–3 June 2009–2010.

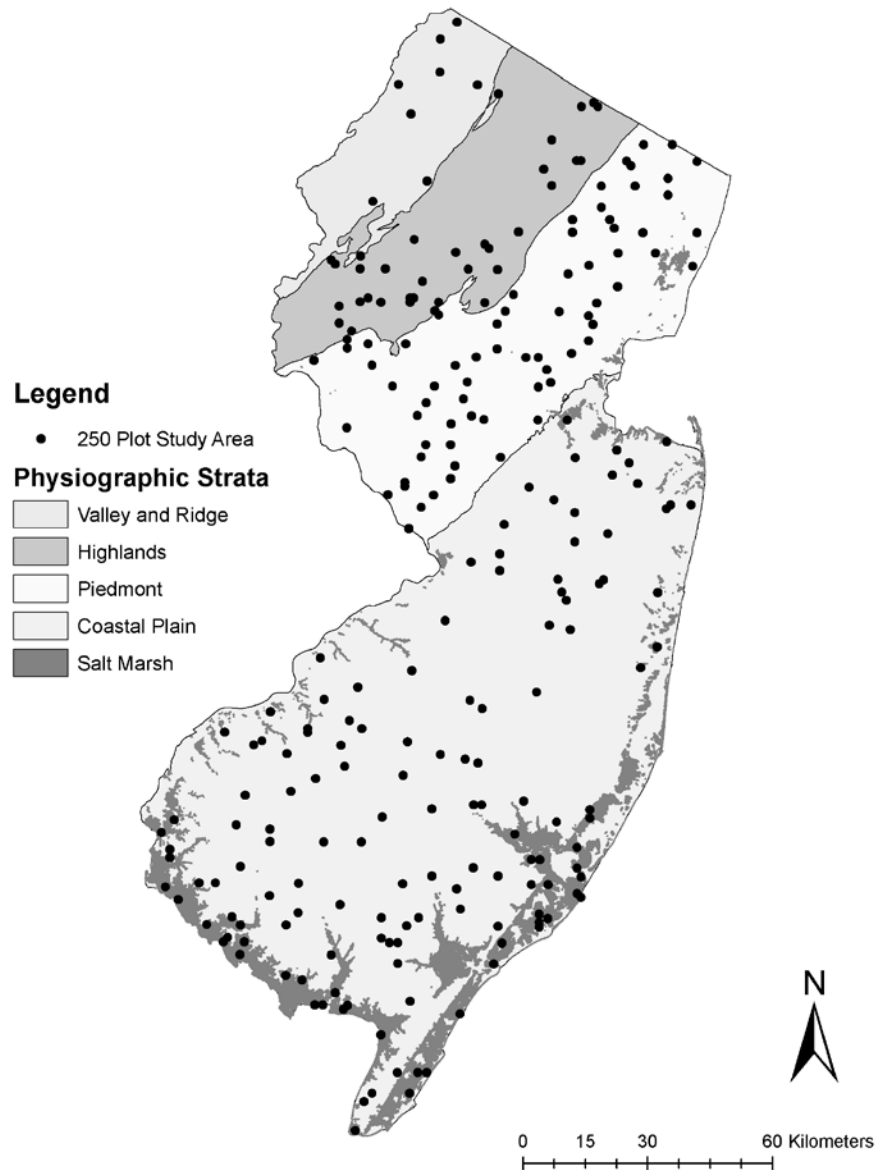


Figure 1.2. Example of spatial scales ranging from 0.25–3 km surrounding a Canada goose plot center in Ocean County, New Jersey, USA.



Figure 1.3. Mean $\pm$ standard error of Spearman's Rank Correlation Coefficient between explanatory habitat variables measured within buffers of 0.25 to 3 km in 250m increments around each plot center and nest site, and Canada goose (a) nest site selection, and (b) nest success in New Jersey, USA, 2009–2010. Mean proportion of habitat variables measured at each spatial scale are depicted in grey. Black points indicate distances statistically similar to the buffer distance with the strongest correlation. Arrows indicate distance used.

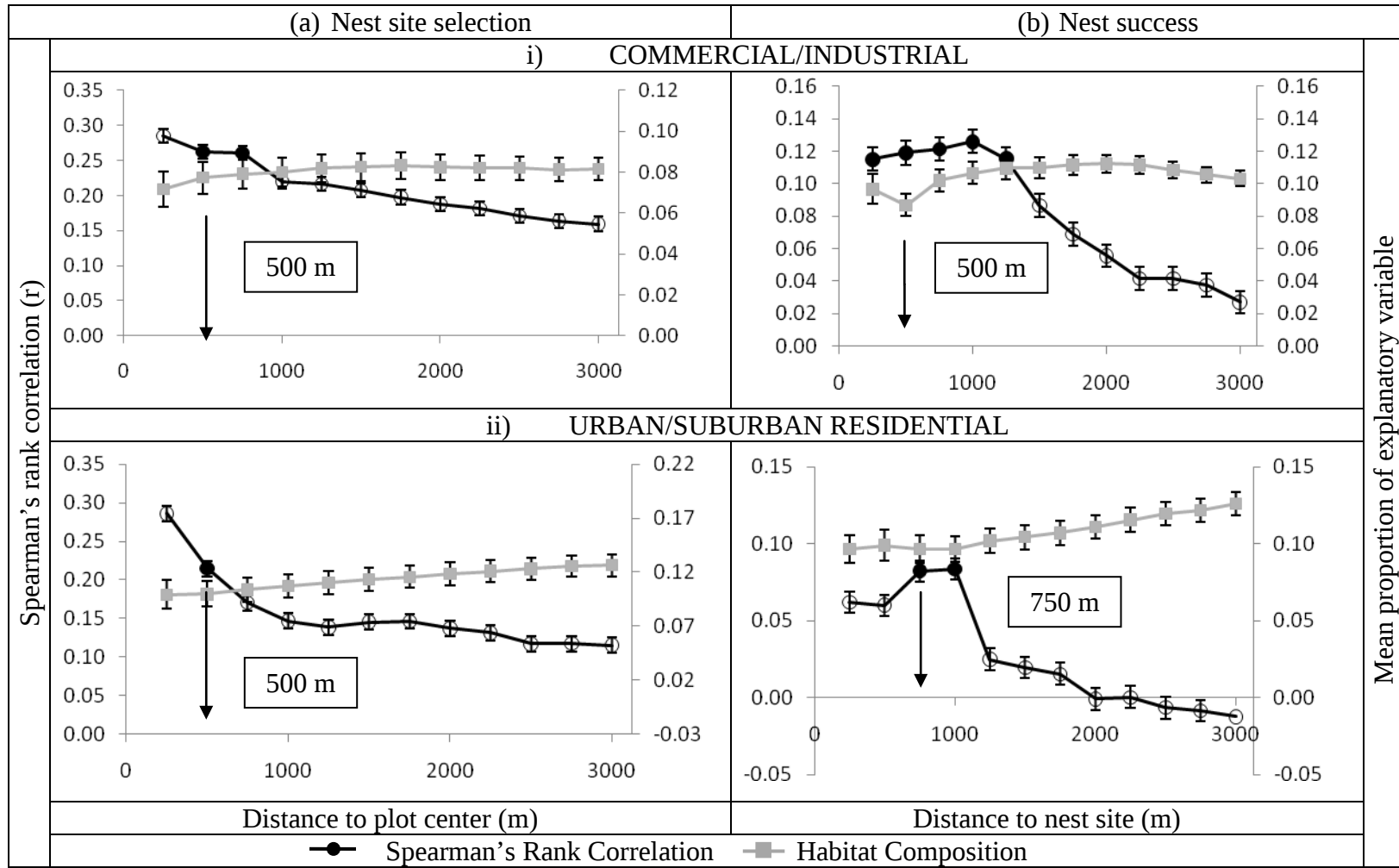


Figure 1.3, *cont.*

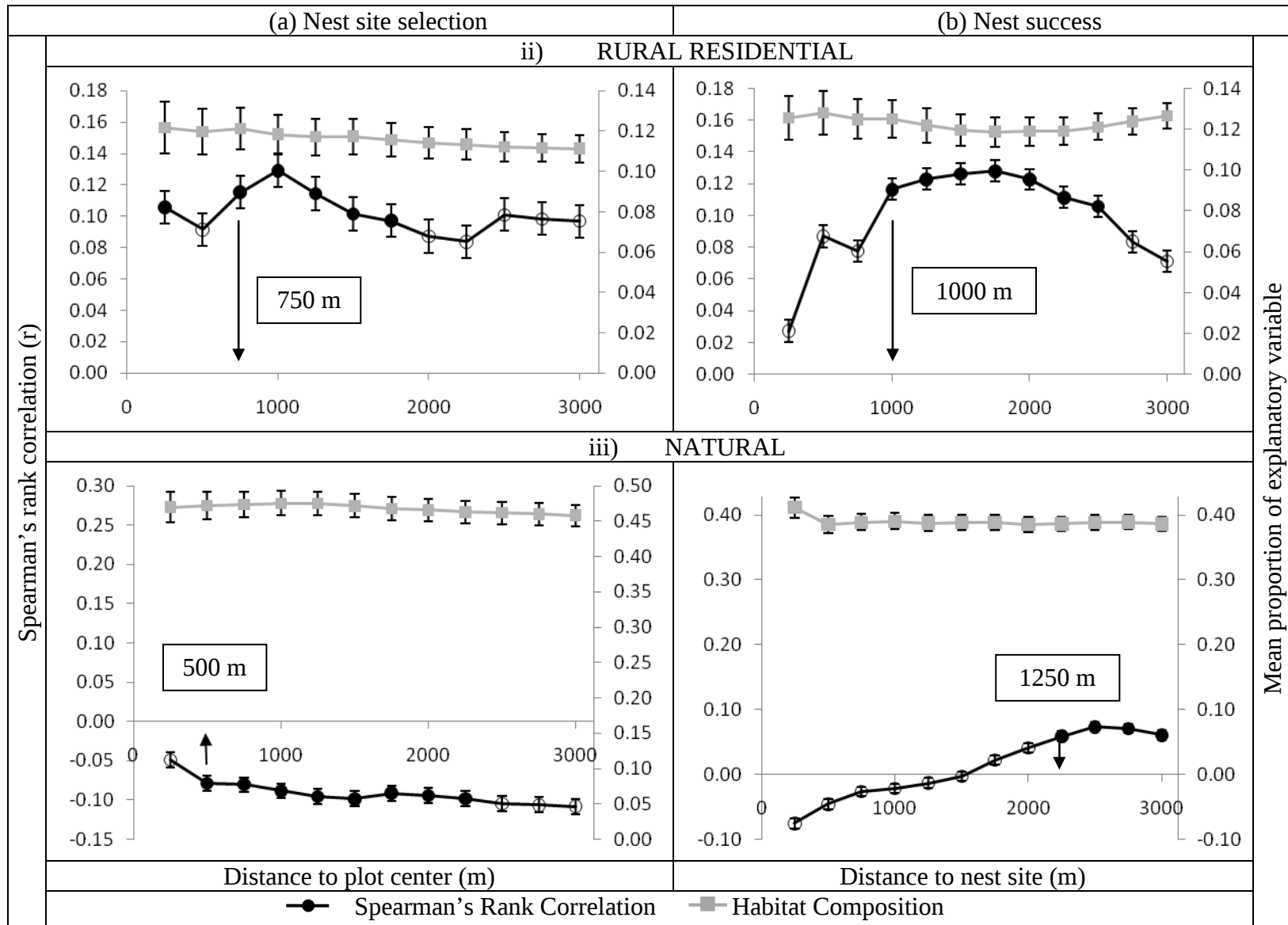
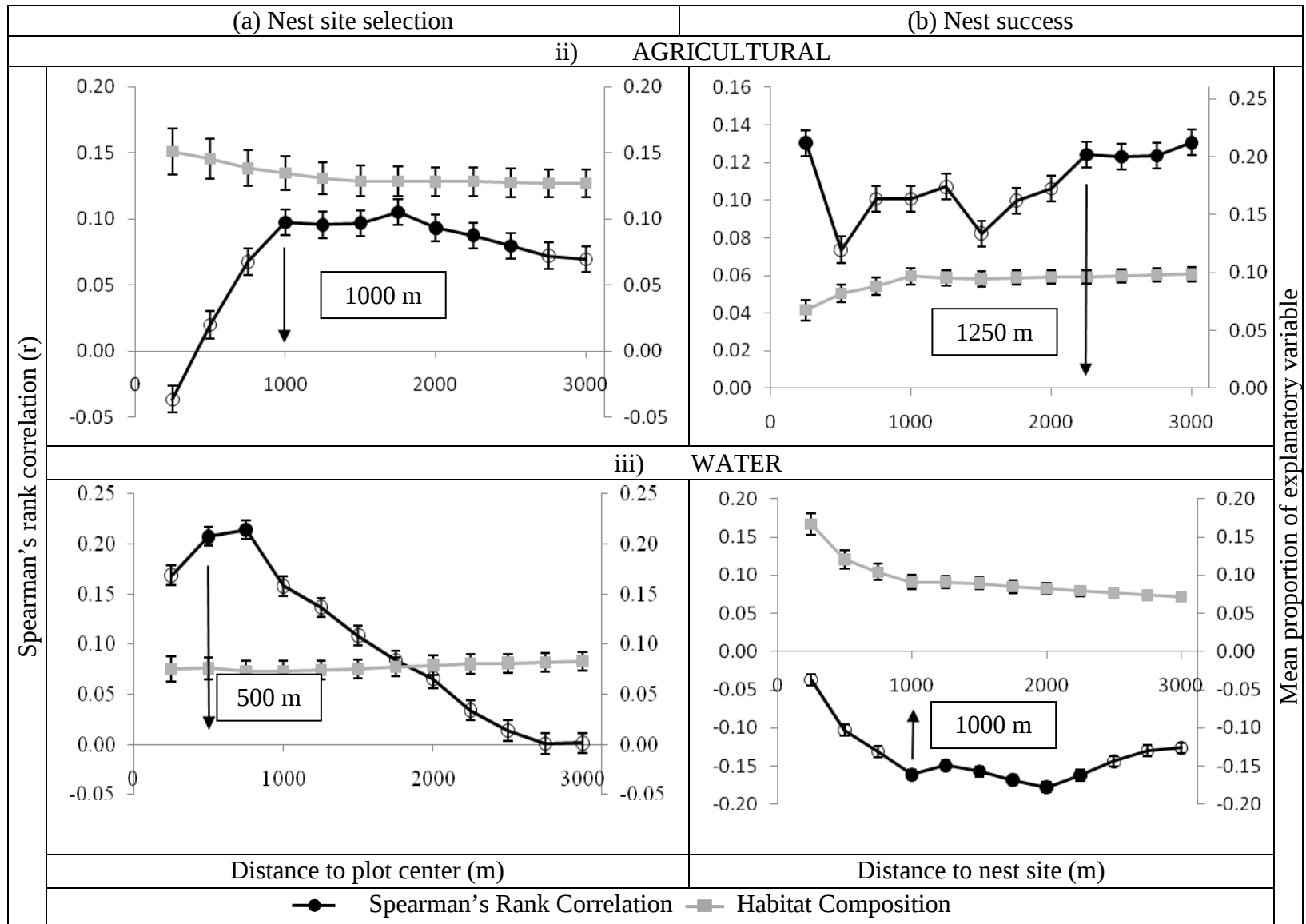


Figure 1.3, *cont.*



Chapter 2

NESTING ECOLOGY OF ATLANTIC FLYWAY RESIDENT POPULATION CANADA GEESE IN NEW JERSEY

Introduction

The establishment of Atlantic Flyway Resident Population (AFRP) Canada geese (*Branta canadensis*) has been so successful during the last 75 years that these populations are now viewed as a nuisance species in urban areas (United States Fish and Wildlife Service 2003). New Jersey supports the highest density of AFRP Canada geese in the eastern United States at 4.97 birds/km² (Bucknall 2004), with a current estimated population of over 70,000 individuals in 2011 (Fig. 2.1; New Jersey Division of Fish and Wildlife, unpublished data). New Jersey is also the most densely human-populated state in the nation, with over 460 people/km² in 2010 (United States Census Bureau 2011). The resultant demand for housing, recreation areas, roads, and other development activities has reduced the amount of suitable habitat for many wildlife species, but created increased urban/suburban nesting habitat for AFRP Canada geese (Atlantic Flyway Council 2011). Specifically, the expansion of corporate parks, golf courses, and recreational areas with manicured open lawns and artificial water sources has created an ideal habitat for the nesting and brood rearing of AFRP geese. Between 1986–2007,

urban land use has increased by 27%, at the expense of 24% of the state's agricultural land and 7% of forested land (New Jersey Department of Environmental Protection 2010).

A rising incidence of conflict between AFRP Canada geese and farmers, airport operations, governmental park systems, private landowners, and local businesses substantiates the call for population control of the species for the purpose of public health and safety (Conover and Chasko 1985, Smith et al. 1999). Management of the species involves a balance of population control through hunter harvest, culling programs, and reproductive control options. Although all three management techniques are actively implemented, emphasis is placed on hunter harvest as a primary control effort because it accounts for the majority of annual mortality (United States Fish and Wildlife Service 2002). While the annual harvest goal to maintain a stable population is ~30% (Atlantic Flyway Council 2011), current harvest rates of $\leq 15\%$ are being accomplished (United States Fish and Wildlife Service 2002). Complicating this disparity, increasing development of urban areas has also decreased the amount of land suitable for hunter harvest.

Human intervention of goose productivity through reproductive control has been increasing during the last two decades (United States Fish and Wildlife Service 2002), and is implemented by egg treatment and sterilization techniques. Summer mortality for adult geese is primarily due to culling programs. Reproductive control and summer culling are not adequately effective as solitary control practices (Allan et al. 1995); however, an integrated management plan using these techniques has been shown to be a

cost-effective way of directly reducing local goose populations (Keefe 1996) when carried out in high-density nesting and brood-rearing areas such as government-owned lands and islands in lakes/reservoirs (Atlantic Flyway Council 2011). The efficacy of control techniques is crucial to its validity, since summer culling has been shown to be particularly controversial in public opinion (United States Fish and Wildlife Service 2004).

There is not currently a population model designed for management of AFRP Canada geese to evaluate the effectiveness of these different management techniques. However, population models have been developed for other populations of Canada geese. To assist with harvest management of migratory Atlantic Population (AP) geese in the Atlantic Flyway, an age-based population model incorporating harvest has been proposed for use by managers (Hauser et al 2007). In this model, a constant reproductive and survival parameter exists during the first year $R_t S_t^{(0)}$. Their estimate of $R_t S_t^{(0)}$ is a function of R_t , which is composed of several nesting constants such as timing of the snow melt and a productivity rate, and $S_t^{(0)}$, which represents juvenile survival during the first year.

While productivity in migratory geese is primarily driven by meteorological effects such as snow melt (Sheaffer and Malecki 1996), resident populations in temperate regions such as New Jersey are not subject to the harsh breeding conditions of the sub-arctic, and are therefore impacted by other random and/or density-dependent factors. Natural mortalities of viable eggs and hatched birds during the nesting and brood-rearing stages likely drive summer mortalities. Nest predation, leaving partial clutches or empty nest bowls, may lead to the abandonment of a nest, eventual renesting, or cause the adult

birds to join the non-breeding population (Nichols et al. 2004). Hatchability and nest success has also been shown to be negatively related to both nest density (Ewaschuk and Boag 1972, Hanson 1997), and precipitation causing flooding of waterfowl nest sites (Hilden 1964, Joyner 1977). Additionally, the breeding age and experience of adult birds has been shown to affect nest site selection, and ultimately nest success (Raveling 1981, Hardy and Tacha 1989). Habitat availability and changes in land use may affect the ability to locate a nest site in the spring, and eventually the success of the nest.

To address some of the reproductive limitations on resident Canada geese, Coluccy et al. (2004) developed a stage-based matrix population model for Giant Canada geese in Missouri. A main objective of this model was to understand the relationships between vital rates and population growth rates. Unlike most sub-arctic nesting goose populations, precocious breeding has been documented for temperate nesting geese as young as 1 year old (Hall and McGilvrey 1971, MacInnes and Dunn 1988, Drobney et al. 1999). Coluccy et al. (2004) accounted for heterogeneity in productivity across age classes by utilizing an age-based nesting rate, clutch size, nest success, hatchability, and gosling survival. Although this population model is helpful in evaluating control efforts for Giant Canada geese in Missouri, a habitat-sensitive population model is still necessary to identify the driving forces of population growth in areas of increased human development.

To account for these variations in productivity of resident geese, a need exists to develop a model for AFRP Canada goose populations that is more sensitive to habitat, environmental and/or density-dependent parameters. Evaluating spatially-explicit

productivity parameters of AFRP Canada geese will assist with improved model design and enhanced measurement of the efficacy of current control practices against population growth. To accomplish this goal, this study evaluated the nesting ecology of AFRP Canada geese in New Jersey from both prior research (1985–1989, and 1995–1997) as well as current investigation (2009–2010) to determine the driving forces of productivity. Specifically, I (1) documented clutch size, hatchability, and nest success, (2) evaluated the effects of land use, nest density, and meteorological effects on nest success, and (3) compared 10 years of nesting data spanning the last 25 years for the purpose of developing long-term productivity trends in New Jersey.

Study Area

Nesting ecology data was collected within 250 randomly located 1-km² plots, stratified by physiographic stratum in New Jersey, which were designated by the Atlantic Flyway Breeding Waterfowl Survey (AFBWS; Heusmann and Sauer 1997, Heusmann and Sauer 2000). The five physiographic strata covered within these plots include Ridge and Valley, Highlands, Northern Piedmont, Coastal Plain, and Salt Marsh habitats (Fig. 2.2). The Ridge and Valley region is composed of forest-covered ridges and river valleys, providing breeding waterfowl habitat primarily along rivers, freshwater wetlands and farm ponds and streams associated with agricultural areas. The Highlands region has recently experienced tremendous human development; however, this stratum offers breeding waterfowl habitat primarily in areas dominated by freshwater wetlands, rivers, farm ponds, and reservoirs. Northern Piedmont is a sediment-filled rift basin bound by the Blue Ridge Mountains and the eastern side of the Appalachians. Low rolling hills and

poorly drained soil hold natural streams and water bodies proving beneficial for waterfowl. While part of the Coastal Plain offers moist, poorly drained soil, much of this stratum in New Jersey consists of sandy, infertile soil. Primary breeding waterfowl habitat includes palustrine wetlands and manmade sand wash ponds. The salt marsh region is tidal wetland primarily consisting of cordgrass (*Spartina* spp.), and offers both wintering and breeding habitat for many waterbirds. This stratum is located along the tributaries of the Atlantic coast and Delaware Bay.

These plots have been used by New Jersey Division of Fish and Wildlife (NJDFW) staff as part of the Atlantic Flyway Breeding Waterfowl Survey (AFBWS) since the survey was initiated in 1996 (Heusmann and Sauer 1997, Heusmann and Sauer 2000). The average distance between plots was 4.72 km (SE $\pm$ 0.18 km). For the purpose of selecting nesting locations, these plots were independent of each other. All plots contained potential waterfowl habitat, with at least one body of water (e.g. stream, retention pond, lake, or reservoir).

Methods

Population Model

In modifying the Hauser et al. (2007) and Collucy et al. (2004) population models, the productivity parameter of F_i is expanded to incorporate a series of biological variables:

$$F_i = A_i \times C \times H \times S_N \times S_G \times S_J \quad \text{Equation 2.1}$$

where F_i is productivity parameter, A_i is age-specific nesting rate, C is clutch size at hatch, H is hatchability, S_N is the nest success rate, S_G is pre-fledge gosling survival, and S_J is post-fledge juvenile survival through 1yr. Additionally, select environmental and density-dependent variables need to be evaluated, including physiographic stratum, landscape and site scale habitat composition, nest density, and meteorological effects (Fig. 2.3).

To address these needs, I collected nesting ecology data during the spring of 2009–2010 and compared it to data collected in New Jersey from 1985–1989 and 1995–1997. Neither age-specific nesting rates nor nest success rates were addressed in this study; therefore, age-independent fecundity, F , was used as a proxy for age-dependent fecundity, F_i . Pre-fledged gosling survival, S_G , was addressed in a separate study in New Jersey during 2009–2010 (see Chapter 3).

Field Methods

A nesting ecology study was conducted by NJDFW during 1985–1989, and 1995–1997. The first 6 years of the study were performed prior to the initiation of the AFBWS plot system in 1996. During this time, nest searching was conducted statewide and effort was allocated in rough proportion to the number of AFRP geese found in each area of New Jersey. Nests were monitored weekly through hatch to determine nest fate and clutch loss. Band resighting was conducted on all banded adults associated with a nest. Hand-drawn maps identifying nest locations allowed me to obtain GPS coordinates for most nests. Site-specific geographic coordinates were assigned to nests without hand-drawn maps using available nest site data and observer notes for the purpose of

addressing trends in nest success as a function of surrounding land use. During 1996–1997, nests were located and monitored through hatch within the 250 plot study area.

With the assistance of NJDFW, I conducted new nest searches of the 250 plots during the laying period from 9 March–10 May 2009–2010. The chronology of nest searches was based on ~~prior~~ nest initiation data from 1996–1997. Nest searches were conducted during daylight hours between 0800–1700, in order to reduce abandonment and the interruption of laying (Gloutney et al. 1993). The frequency of nest searches was based on whether a nest, pair, lone goose, or group of geese was observed on the plot during the prior 3 years of the AFBWS. Of the 250 plots, nesting geese had not historically been observed on 69 plots. These plots were searched during the 2009 and 2010 AFBWS between mid-April to early May to assure no nesting activity was present. Any nests discovered within the 69 plots during the AFBWS were reported immediately for further nest monitoring.

Once nests were located, I aged embryos utilizing both field candler (modified from Weller 1956, Cooper and Batt 1972) and egg floating (United States Department of Agriculture 2009) techniques to estimate the incubation stage and hatch date. Results from both methods were averaged to gain the most accurate estimate of hatch date (Reiter and Anderson 2008). I also recorded clutch size, egg loss, predator identification (Rearden 1951, Sargeant et al. 1998), and adult behavior. The nesting parameters addressed by this study include mean clutch size, nest survival, mean hatchability (the number of eggs that hatch within a clutch), mean nest initiation, and mean hatch dates.

Clutch size was defined as the number of eggs present in the clutch on the visit prior to hatch, and only included nests that hatched ≥ 1 egg. For renesting pairs, each attempt was calculated as a separate clutch. Any change in the number of eggs within each clutch was recorded during each visit, along with any associated evidence of the cause of egg loss (Sargeant et al. 1998). I used a Univariate Analysis of Variance (ANOVA) with Tukey's post hoc tests ($\alpha = 0.05$) to test for differences in mean clutch size among years.

The viability of each egg is important to the overall estimation of productivity. This number was calculated by dividing the number of unhatched eggs by the total clutch size of only successful nests. Hatchability of successful nests was equivalent to the hatchability under natural conditions. Human-induced infertility (addling, oiling, or puncturing eggs) was likely applied to all eggs within a clutch, causing total nest failure and was instead included in the estimate of nest survival. I used an ANOVA with Tukey's post hoc tests ($\alpha = 0.05$) to compare differences in hatchability between 1996, 1997, 2009, and 2010. Data from 1985–1989 and 1995 was not used due to a lack of data collected during the hatch period.

I calculated the age distribution of nesting adults by age class and sex using band resighting data from 1985–1989. Nest density was calculated by physiographic stratum during study years that used the AFBWS plot system. The number of nests was divided by the number of 1-km² plots within each stratum.

An accurate estimate of nest survival is important in understanding the dynamics of a population. An apparent nest survival estimate is simply a proportion of the number

of successful nests within the total number of nests discovered. However, this method can overestimate survival because it assumes that survival is constant throughout the entire nesting process. The Mayfield nest survival model (Mayfield 1961, Mayfield 1975) avoids the assumption that nests must be monitored from initiation by estimating the daily probability of nest failure as a function of the observed period. However, the Mayfield model assumes that survival is constant across the nesting period, and that the timing of nest failure occurs halfway between nest discovery and the nest visit when failure was observed. Etterson offered an alternative model based on the Markov principle that the status of the nest is solely based on the events of the prior day (Etterson and Bennett 2005, Etterson 2007). Variables can be a combination of categorical or continuous, and can be inputted using an excel spreadsheet to a MS-DOS user interface with minimal further programming requirements. I selected the Markov chain model to determine factors that influenced nest failure, which allows for variation in the exposure period and does not require a known failure date. Trends in nest success between 1985–2010 were calculated using linear regression ($\alpha = 0.05$).

Nests that hatched at least one egg were classified as successful (Mayfield 1961, Johnson et al. 1992, Bruggink et al. 1994). An unsuccessful nest was recorded as either infertile, abandoned, flooded, predated, unknown, or a specified combination of the above. Human-induced reproductive control, such as egg addling or oiling, was observed throughout the study and was included as “infertile/dead”, due to the difficulty in distinguishing an addled egg from a naturally infertile or dead egg. I defined the exposure

period as the complete day of the first visit through the full day prior to the next visit, in order to minimize bias due to evaluating duplicate exposure days.

Only nests that were observed in an active state for >1 d were included in this calculation (i.e. the discovery of a hatched or abandoned nest was ignored). Nest success was defined as the probability of a nest surviving the laying and incubation periods (S_N). The nesting period was defined by the sum of the laying and the incubation periods. I *a priori* estimated the laying period for this study using an average initial clutch size of 5 eggs (Cooper 1978, Rummel 1979, Huskey et al. 1998, Peters et al. 2004, New Jersey Division of Fish and Wildlife, unpublished data) and the laying rate of 1.5 d/egg laid (Kossack 1950). The incubation period used for this study was 28 d (Collias and Jahn 1959). I assumed that incubation began the day that the last egg within the clutch was laid.

Predictive Nest Survival Models

I modeled nest survival to better understand the parameters influencing variation in productivity. The covariates that were used in candidate models included decade, year, week of nest initiation (day the first egg was laid in or near the nest bowl), age of the nest within the nesting period, physiographic stratum, number of nests per site (1985–1989) or nest density (2009–2010), % extreme daily high temperature, daily precipitation, and 5 landscape-scale and 5 site-scale habitat variables. I did not address observer effect during this study due to the lack of observer data for some years and because observer effect was likely confounded with regional observer assignments, and thus would have natural variation in nest survival associated with each region/observer. Furthermore, I did not

include the age of breeding adults in candidate models for nest survival due to the small sample size of banded birds within the study area.

Two meteorological variables, extreme high temperature and daily precipitation, were selected to identify key stochastic components that may influence survival. Extreme high temperatures may be important in that incubating females may take extended recesses during this time to keep the clutch from overheating. Although extreme low temperatures or late snowmelt may hinder productivity in sub-arctic nesting geese (Hauser et al. 2007), this is not likely to affect temperate-nesting populations.

Precipitation may cause flooding of the nest bowl, hinder the ability of the female to properly incubate the clutch, or inversely cause an increase in productivity due to further isolation from terrestrial predators. Daily surface data was downloaded from the National Climate Data Center website. I selected seven weather stations that collected data spanning the entire study length (1985–2010). I ran a proximity analysis within ArcMap 9.2.x (ESRI 2009) to find the nearest weather station to each nest, with a mean distance of 26.2 km (SE $\pm$ 0.3 km). In order to identify the effect of extreme temperature conditions during the nesting period, a measurement of the percent away from the daily normal high temperature was calculated using the equation:

$$T_{Extreme} (\%) = \frac{T_{Actual} - T_{Normal}}{T_{Normal}} \quad \text{Equation 2.2}$$

where $T_{Extreme}$ was the percent difference of the actual daily high temperature from the normal daily high temperature, T_{Actual} was the actual daily high temperature, and T_{Normal} was the normal daily high temperature recorded at the weather station. $T_{Extreme}$ was then averaged across each exposure period.

Due to heterogeneity in study area among years, nest density could not be defined across all years. For study years from 1985–1989, the number of nests per site was used as a proxy for nest density in nest survival models. For data from 2009–2010, I defined nest density as the number of nests per 1-km² plot. Since data from 1995 was prior to the plot study area, I did not include nest density as a variable in nest survival models for the 1990's. I also did not include nest density as a variable in nest survival models for the combined dataset from 1985–2010.

I analyzed surrounding land use and land cover in ArcMap 9.2.x (ESRI 2009) using 1986, 1995/97, and 2007 New Jersey Land Use/Land Cover (NJ LULC; NJDEP 1998, 2000, 2010) datasets for each study season. The 1986 NJ LULC dataset was used to estimate habitat composition around nesting locations from 1985–1989. The 1995/97 NJ LULC dataset was used for nesting data from 1995–1997. The 2007 NJ LULC dataset was used for nesting data from 2009–2010. A buffer area of 250 m² was used to calculate nest site-scale characteristics (Messmer 2010). Biologically significant landscape spatial scales were calculated for each land use type through a series of correlations (Chapter 1, Figure 1.3). In order to allow for multiple habitat-bird interaction hypotheses, I reclassified land use types within the New Jersey LULC dataset into five categories: Urban Residential, Rural Residential, Commercial/Industrial, Agricultural, and Natural (forest, shrub, and wetlands). Water was not included as a general land use covariate in nest survival models, but specific components of Water such as palustrine and estuarine wetlands were inherently represented in Natural land use.

I tested candidate models for the three decades separately to identify uniquely important variables, and also for the entire dataset to determine the overarching important variables across the study period. I limited the total number of the candidate models for each analysis to 70 in an iterative step-wise manner according to the following criteria:

- All covariates were used at least once. Some covariates were used more than others because they frequently appeared in high-ranking models. Covariates that consistently appeared in low-ranking models were used less often. Additional covariates were individually added to high-ranking models to determine their effect on the model.
- Each model included 1–3 landscape scale and 1–3 site scale habitat covariates. I selected a maximum of six habitat variables to prevent the development of highly complex models.
- Covariates that were highly correlated ($|r| \geq 0.75$) were not used in the same model.
- Covariates that did not improve the log-likelihood estimate of the model by a value of > 2 were removed (Burnham and Anderson 2002, Arnold 2010).
- Within the set of candidate models, I also included a global model of all covariates, a global model of all landscape scale habitat and non-habitat covariates, a global model of all site scale habitat and non-habitat covariates, and a null model in which survival was held constant.

Model selection was based on the Akaike Information Criterion (AIC; Akaike 1973) values testing for fit and simplicity, and a bias correction term was added for small sample size (AICc).

Statewide Productivity Indices

NJDFW calculates an annual statewide population index of Canada geese by extrapolating from survey plots to the total area of the state using standard methodology established by the Atlantic Flyway Council (Heusmann and Sauer 1997, Heusmann and Sauer 2000). I calculated an index of the number of nests within the state by extrapolating the number of nests within the study area to the total area of the state, following this previously established methodology. I estimated the number of young produced per pair for each year from 1996–1997 and 2009–2010 using an iteration of Equation 2.1, whereby I multiplied the mean clutch size, mean hatchability, and mean nest success. Data from 1985–1989 and 1995 did not utilize a plot study area; therefore, statewide estimates were not extrapolated from these years. I estimated the total number of young produced statewide each year by multiplying the number of young produced per pair by the estimated number of nests within the state. Lastly, I evaluated the accuracy of estimating annual productivity using observed breeding pairs during the AFBWS by dividing the number of nests discovered on each plot during nest searches by the total number of indicated pairs observed within each plot during the AFBWS for each year, and averaging this value across plots.

Results

During the 2009 and 2010 nesting seasons, I located and monitored 309 Canada goose nests through hatch. Of these, 268 nests had a known fate and were observed in an active state for >1 d. The mean initiation date across all years was 31 March (SE $\pm$ 0.3 d; Appendix A). The annual mean hatch date across all years ranged from 3 May– 9 May, with an overall mean of 5 May (Appendix B). I observed 2 peaks in hatching frequency during 2009 and 2010. In 2009, two peaks occurred on 3 May and 7 May. In 2010, the two peaks occurred on 1 May and 10 May.

The mean clutch size for all years was 4.74 eggs (SE $\pm$ 0.04 eggs). Ninety-two percent of variance was within years ($F_{(9, 1768)} = 15.35$, $P < 0.01$). However, mean clutch size during 1986 was significantly different from all other years (Tukey's posthoc tests, $P < 0.05$). Mean clutch size during 1989 was also significantly different from that of 1987 and 1995. The mean hatchability of successful nests in 1996 was 0.85 (SE $\pm$ 0.03). In 1997, mean hatchability was 0.92 (SE $\pm$ 0.02). In 2009, mean hatchability was 0.86 (SE $\pm$ 0.02). In 2010, the hatchability was 0.81 (SE $\pm$ 0.02). The mean hatchability for all years was 0.84 (SE $\pm$ 0.02). Ninety-seven percent of variance was within years ($F_{(3, 312)} = 3.83$, $P = 0.01$). However, hatchability in 1997 was significantly different from that in 2010 (Tukey's posthoc tests, $P < 0.05$).

Nest density was 0.53 nests/km² (SE $\pm$ 0.14 nests/km²) in 1996, 0.40 nests/km² (SE $\pm$ 0.10 nests/km²) in 1997, 0.62 nests/km² (SE $\pm$ 0.12 nests/km²) in 2009, and 0.62 nests/km² (SE $\pm$ 0.11 nests/km²) in 2010 (Table 2.2). The age distribution of banded breeding adults during 1985–1989 was composed of 1.2% 1+ year old birds, 18.0% 2+

year old birds, 34.9 % 3+ year old birds, 23.5% 4+ year old birds, 12.5% 5+ year old birds, 6.4% 6+ year old birds, 1.5% 7+ year old birds, 0.9% 8+ year old birds, 0.9% 9+ year old birds, and 0.3% 10+ year old birds (Appendix C).

An evaluation of egg loss was conducted at each nest site from 2009–2010, for both partial and full clutch losses. Primary causes of known failure were predation and dead or infertile eggs. Of the 224 occurrences of egg loss, 38% were by predation, 33% were by infertility or natural egg death, 15% were from an unknown cause, 10% were due to abandonment, and 4% were due to flooding. Of the 86 occurrences of egg loss due to predators, 36% were caused by red fox (*Vulpes vulpes*), 29% were caused by an unknown predator, 14% were caused by skunk (*Mephitis mephitis*), 8% were caused by raccoon (*Procyon lotor*), 6% were caused by an unknown mammal, 6% were caused by an avian predator, and 1% were caused by river otter (*Lontra canadensis*).

Mean habitat composition within 250 m of the nests during all study years consisted of 12.6% Urban Residential (SE $\pm$ 0.3%), 7.0% Rural Residential (SE $\pm$ 0.2%), 16.3% Commercial/Industrial (SE $\pm$ 0.3%), 34.6% Natural (SE $\pm$ 0.4%), 9.8% Agriculture (SE $\pm$ 0.3%), and 19.7% other land use (SE $\pm$ 0.5%). The selected landscape scales that were most correlated with nest success were 500 m for Commercial/Industrial (composing 8.7% of the habitat within the distance band), 750 m for Urban Residential (composing 9.7%), 1000 m for Rural Residential (composing 12.0%), 2250 m for Agriculture (composing 9.6%), and 2250 m for Natural (composing 38.6%). Mean extreme high temperature across all exposure periods was +0.019 °C (SE $\pm$ 0.001 °C). Mean daily precipitation across all exposure periods was 0.1 cm (SE $\pm$ < 0.001 cm).

Modeling Nest Survival

During the 10 study years, 1967 nests with a known fate and at least one exposure period were used to estimate nest survival (Mayfield 1961). There were 4,221 exposure periods between nest visits, totaling 35,364 exposure days. Of the 4,221 exposure periods, 3,732 of these exposures ended in an active nest, while 489 exposures ended in failure. The estimated length of the nesting period based on mean clutch size was 35 days ($SE \pm 0.06$ days).

The most parsimonious model for data from 1985–1989 included age of the nest within the nesting period, year, extreme high temperature, number of nests at the site, daily precipitation, percent Rural Residential at the 1000 m landscape level, and Commercial/Industrial at the site level, with a weight of 0.92 (Table 2.3a). Estimated nest success for this period was 0.512 ($SE \pm 0.057$). The age of the nest within the nesting period, extreme high temperature and precipitation were positively related to nest success. Nest density was negatively related to nest success. At the landscape level, nest survival was positively related to Rural Residential land use. At the site level, nest survival was positively related to Commercial/Industrial land use.

The most parsimonious model for data from 1995–1997 included age of the nest, week of nest initiation, year, physiographic stratum, extreme high temperature, percent Agriculture at the site level, and percent Rural Residential at the 1000 m landscape level, with a weight of 0.85 (Table 2.3b). Estimated nest success for this period was 0.422 ($SE \pm 0.102$). Age of the nest within the nesting period was positively related to nest survival. Week of nest initiation and extreme high temperature were negatively related to nest

survival. At the landscape level, nest survival was negatively related to percent Rural Residential land use. At the site level, nest survival was negatively related to percent Agricultural land use.

The most parsimonious model for data from 2009–2010 included age of the nest and week of nest initiation, with a weight of 0.97 (Table 2.3c). Age of the nest was positively related to nest survival. Week of nest initiation was negatively related to nest survival. Estimated nest success for this period through model averaging was 0.403 (SE $\pm$ 0.041).

The most parsimonious model for nesting data from all study years (1985–2010) included age of the nest, week of nest initiation, year, extreme high temperature, Commercial/Industrial and Urban Residential land uses at the site level and Urban Residential land use at the 750 m landscape level, with a weight of 0.96 (Table 2.3d). Estimated nest success for the entire study was 0.491 (SE $\pm$ 0.045). Age of the nest, extreme high temperature, Commercial/Industrial at the site scale and Urban Residential at the landscape scale were positively related to nest survival. Week of nest initiation and Urban Residential land use at the site scale were negatively related to nest survival. The linear regression of year on nest success from 1985–2010 was significant ($r^2=0.465$, $P=0.03$; Fig. 2.4).

Statewide Productivity Indices

The New Jersey portion of the AFBWS was conducted within the study area in conjunction with this project between about 15 April–12 May of 1996–1997, 2009–2010. In 1996, NJDFW biologists estimated 22,871 Canada goose pairs (CV=0.13) and 69,549

total Canada geese in New Jersey (CV=0.13). In 1997, biologists estimated 23,091 Canada goose pairs (CV=0.15) and 85,338 total Canada geese (CV=0.27). In 2009, biologists estimated 29,916 Canada goose pairs (CV=0.13) and 92,913 total Canada geese (CV=0.13). In 2010, biologists estimated 27,329 Canada goose pairs (CV = 0.12) and 76,190 total Canada geese (CV = 0.14). The estimated proportion of indicated goose pairs with nests was 0.375 (1996), 0.276 (1997), 0.372 (2009), and 0.412 (2010).

The statewide estimated number of young produced per nest during 1996–1997, and 2009–2010 was 2.14, 3.24, 1.76, and 1.58, respectively (Table 2.2). The index of the number of young produced statewide in 1996, 1997, 2009, and 2010 based on the statewide estimated number of nests was 24,061, 30,265, 21,294, and 18,966, respectively.

Discussion

The New Jersey population of resident Canada geese has experienced a tremendous increase, from ~ 29,000 geese in 1990 to over 106,000 in 2000. This growth was likely due to a combination of factors, including a lack of hunting pressure in urban areas (Smith et al. 1999, Atlantic Flyway Council 2011) during the first half of the decade, and a hunting moratorium in response to a dramatic decrease in the migratory Atlantic Population between 1995–1999. Population growth of resident geese slowed during the early 2000's, and has since seen a considerable decrease during the last 5 years from ~104,000 to ~70,000 birds, particularly due to the implementation of special early and late hunting seasons targeting resident birds, as well as reproductive control programs. Paired with the heterogeneity in changing land use across the state, these

variables have provided a complex narrative of habitat-animal relationships over this time. Our research tracks the key components of variation in productivity during a period of fluctuation in the resident goose population, as well as increased urbanization of the landscape.

The substantial increase in the AFRP goose population (Serie and Cruz 1997) coincided with intensive urbanization of former forested and agricultural areas. The increase in human-manipulated habitat has offered abundant resources to this highly adaptive population. Between 1986–1995, over 130,000 acres of New Jersey were converted from agriculture, forest, and wetlands to urban areas (NJDEP 2000). Our data supported past research in highlighting both commercial/industrial and urban land uses as important factors in nest survival (Cline et al. 2004). During the late 1980's, Commercial/Industrial land use at the site scale and Rural Residential at the landscape scale were positively related to nest success. Reproductive control was not yet a common practice, and manicured lawns and ponds associated with rural development likely created ideal nesting habitat for resident geese. However, once control techniques were more widely accepted during the peak of population growth, it is likely that landowners intervened, as seen in the leading model for 1995–1997. Farm ponds in rural areas, although attractive to geese, were possibly controlled during the nesting season to prevent property damage. Nest success further decreased in 2009–2010, likely due to increased reproductive control efforts from both public and private sectors (United States Fish and Wildlife Service, unpublished data). The number of permits issued to New Jersey applicants by the United States Fish and Wildlife Service to allow goose nest removal

increased from 3 to 219 between 1993–2011 (Atlantic Flyway Council 2011), with a maximum of 972 nests in 2010. Additionally, United States Department of Agriculture/Wildlife Services has controlled an increasing number of nests in urban areas annually, from 353 to 890 nests in 2007–2010 (*personal communication*, W. Anderson, US Department of Agriculture).

In addition to changing land use, nest density was also an important factor influencing nest survival during the 1980's. High-density nesting locations were often found within corporate parks and golf courses during this time, and our data showed that the number of nests present at a site was negatively related to nest success. Other studies have shown that density can play a role in nest survival in large-bodied waterfowl, primarily through competition for nest sites and resources during nesting (Hanson 1997, Nummi and Saari 2003), as well as predator influence (Ewaschuk and Boag 1972). Nest density increased only slightly from 1996–1997 to 2009–2010, likely due to difference in the direction of population growth between these two periods. Although density-dependence may have played a role in nest survival during the 1990's as the population was increasing, we were unable to account for this variation in our models due to differences in the study areas between 1995 and 1996–1997.

Nest age and date were two variables that we consistently found important to nest survival across decades. Nest survival has been shown to be lower during the laying period in precocial birds (Klett and Johnson 1982, Grand 1995, Garrettson and Rohwer 2001, Grand et al. 2006), due to a shift in behavior among nesting females that occurs near the transition between laying and incubation periods. Seasonal variation in nest

survival has also been found in prior studies (Klett and Johnson 1982, Lepage et al. 1999). Additionally, older, more experienced birds tend to initiate nests earlier in the season and are more successful breeders (Brakhage 1965, Akesson and Raveling 1984).

Annual production of sub-arctic nesting geese is highly dependent on meteorological events (Sheaffer and Malecki 1996). However, temperate-nesting geese do not face these severe weather conditions, and are likely controlled by other non-meteorological factors. Meteorological variables played an interesting role in our leading models across decades. During the 1980's, extreme high temperature and precipitation were both important variables positively influencing nest survival. However, data from 1995–1997 showed that extreme high temperature had a negative influence on nest survival. The effect of warmer-than-normal temperature can be beneficial to thermoregulation of eggs early in the season (Hawkins 1986). However, extremely warm temperatures can also allow incubating females to leave the nest for longer recesses, leaving her clutch unprotected against predators (Cooper 1978). Increased daily precipitation has the potential to cause flooding, but can also produce additional wetland habitat for nesting (Batt et al. 1992), increase nest attentiveness (Caldwell and Cornwell 1975, Hawkins 1986) and create physical barriers around nests to protect against predators (Johnson et al. 1989).

Nest phenology in New Jersey was similar to other studies of resident Canada geese (Rummel 1979, Huskey et al. 1998, Jacobs and Dunn 2004). I observed two peaks in hatch each year, which may be explained by a combination of renesting attempts by pairs that lost their nests early in the nesting cycle (Cooper 1978) and late nesting

attempts by inexperienced breeders (Jacobs and Dunn 2004). Hatchability did not differ among years, and was comparable to previous literature on AFRP geese (Jacobs and Dunn 2004). Clutch size differed significantly between several years; however, much of the variation was found within years. Mean clutch size is similar to previous literature on AFRP geese in the mid-Atlantic (Rummel 1979, Huskey et al. 1998).

The spatial distribution of breeding birds observed during the AFBWS in New Jersey changed during this study, with an increase in the proportion of nests discovered in the Coastal Plain region from 22.7% to 52.7%, and a decrease in nests discovered in the Piedmont region from 41.4% to 26.9% from 1996–2010. It is unknown whether this shift was through movement or fluctuation within separate subpopulations.

The proportion of breeding pairs with nests varied by year, but highlights an important concept in the natural history of this population. Although some geese may begin pairing behaviors at 1 year of age, many of these birds are simply “going through the motions”, before nesting begins at 2 or 3 years of age. Supporting this, Coluccy et al. (2004) recently estimated nesting rates for 1-yr old Giant Canada geese at 3.9%, 2-yr old birds at 33.6%, 3-yr old birds at 71.0%, 4-yr old birds at 93.0%, 5-yr old birds at 97.5%, and 6+ yr old birds with roughly 100% propensity to breed (2001, unpublished data *in* Coluccy et al. 2004). Further, adult survival is notably higher in urban areas (Balkcom 2010, Huang 2010), resulting in older, more experienced breeders producing full clutches with more goslings recruited into the population each year (Batt et al. 1992), leading to spatial heterogeneity in productivity in addition to survival. Consequently, the use of indicated pair counts uniformly applied across all habitat types may bias annual

production estimates. Further research is required to evaluate the relationship between pairing, age demographics, and propensity to breed in order to quantify this behavior.

Several observations of breeding yearling geese in New Jersey may lead researchers to include a fecundity loop for 1yr and 2yr old birds in the population model that accounts for the heterogeneity in age demographics between urban and rural AFRP geese. It is possible that young breeding birds are inexperienced unsuccessful nesters, or are the offspring of older, more successful adults that breed earlier in the season, and are consequently from more productive “stock”. Additionally, reproductive decline in older birds due to senescence may play a role in urban areas, but has not yet been studied. Further research in age-based productivity may be necessary to account for these variations.

Although the occurrence of molt migration in the AFRP is not as extensive as in the Mississippi Flyway Giant Population (Nichols et al. 2004), artificial reduction in nest survival through reproductive control has the potential to increase the incidence of molt migration to shared staging/brood-rearing grounds with migratory populations. This may cause temporary negative effects on the migratory population due to increased competition for resources (Hill et al. 2003). However, as resident populations are reduced over multiple generations, interspecific competition should ultimately decrease on both sub-arctic breeding and temperate wintering grounds. Targeting urban areas for reproductive control efforts, in addition to continued support of increased hunting pressure, should be promoted to reduce the AFRP Canada goose population while potentially improving sub-arctic nesting migratory populations. Additional research

should quantify the immediate and lagged impact of AFRP molt migration on productivity of migratory populations.

Management Implications

Documenting factors that affect nest survival is an important component of the monitoring of populations during the implementation phase of population control program. Data from this study should assist in the development of a more comprehensive population model for AFRP Canada geese in New Jersey and the Atlantic Flyway. Developing productivity trends should assist in understanding the dynamics of recruitment as a function of population size, spatial distribution, and human influence.

This study identifies key variables influencing nest success during the increase and subsequent decrease of the population over 25 years. Managers are encouraged to examine these variables while taking into account the current growth status of the population. In regions where reproductive control programs have not yet been implemented, urban development should be targeted. Because AFRP productivity appears to be differentially influenced between urban and rural areas, I recommend that managers consider land use and human development as important features in identifying specific management plans to improve efficiency.

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Table 2.1. List of covariates used to build candidate models for nest survival of Canada geese in New Jersey, USA, 1985–2010. Variable subscripts denote measurement scale; site = S, landscape = L.

Covariate Type	Covariate name	Code	Mean (+/- SE)
Temporal	Decade	DECADE	
	Year	YEAR	
	Week of Nest Initiation	INITWEEK	5 April (0.02)
	Age of Nest	AGE	
Spatial	Physiographic Stratum	PHYSIO	
	# Nests Per Site	DENSITY	
	Nest Density	DENS	
Meteorological	% Extreme daily high temperature	HITEMP	0.034 (0.002)
	Daily precipitation	PRECIP	0.059 (0.002)
Habitat Composition	Urban Residential _S	URBAN _S	0.126 (0.003)
	Rural Residential _S	RURAL _S	0.070 (0.002)
	Commercial/Industrial _S	COM/IND _S	0.163 (0.003)
	Agricultural _S	AG _S	0.098 (0.003)
	Natural _S	NATURAL _S	0.346 (0.004)
	Urban Residential _L	URBAN _L	0.142 (0.003)
	Rural Residential _L	RURAL _L	0.107 (0.002)
	Commercial/Industrial _L	COM/IND _L	0.140 (0.003)
	Agricultural _L	AG _L	0.140 (0.002)
	Natural _L	NATURAL _L	0.397 (0.003)

Table 2.2. Recruitment parameters during nesting seasons of 1985–1989, 1995–1997, and 2009–2010 in New Jersey, USA. I report clutch size at hatch (CSH), nest success (S_N), and hatchability (H). Statewide production indices include the number of nests, the number of young produced per nest/breeding pair, and the statewide number of young produced through hatch. Data from 1985–1989 and 1995 did not utilize a plot study area; therefore, statewide estimates were not extrapolated from these years.

SAMPLE											STATEWIDE INDICES	
Year	# nests	Nest Density (# nests/km ²)		CSH		S_N		H		Young produced per nest	# nests	Statewide production
		mean	SE	mean	SE	mean	SE	mean	SE			
1985	252	-	-	4.86	0.10	0.56	0.04	-	-	-	-	-
1986	280	-	-	3.37	0.16	0.80	0.03	-	-	-	-	-
1987	151	-	-	5.21	0.12	0.61	0.05	-	-	-	-	-
1988	292	-	-	4.94	0.10	0.80	0.03	-	-	-	-	-
1989	245	-	-	4.54	0.12	0.67	0.04	-	-	-	-	-
1995	280	-	-	5.11	0.10	0.52	0.04	-	-	-	-	-
1996	144	0.53	0.14	4.91	0.16	0.52	0.06	0.84	0.03	2.14	11219	24061
1997	120	0.40	0.10	4.63	0.16	0.76	0.05	0.92	0.02	3.24	9349	30265
2009	155	0.62	0.12	4.66	0.12	0.44	0.05	0.86	0.02	1.76	12076	21294
2010	154	0.62	0.11	4.76	0.16	0.41	0.05	0.81	0.02	1.58	11998	18966

Table 2.3. Summary of model-selection procedure examining variables affecting the probability of nest survival of AFRP Canada geese in Jersey, USA from 1985–1989. I report Akaike’s Information Criterion (AICc) of the top-ranked model, the relative difference in AIC values compared to the top-ranked model (Δ AIC), the AIC model weight (W), and the number of parameters in the model (K). Variables are described in Table 1. Variable subscripts denote measurement scale; site = S, landscape = L.

(a) 1985–1989

Model	ΔAIC	Weight	K	Rank
AGE, YEAR, HITEMP, DENSITY, RURAL _L , COM/IND _S , PRECIP	0	0.92	11	1
AGE, YEAR, HITEMP, DENSITY, RURAL _L , COM/IND _S	3.03	0.04	10	2
GLOBAL MODEL _L	4	0.02	19	3
AGE, YEAR, HITEMP, DENSITY, RURAL _L , NATURAL _L	4.27	0.01	10	4
AGE, YEAR, HITEMP, DENSITY, RURAL _L , PRECIP	6.47	0	10	5
AGE, YEAR, HITEMP, DENSITY, RURAL _L	7.24	0	9	6
AGE, YEAR, HITEMP, DENSITY, RURAL _L , URBAN _L	7.71	0	10	7
AGE, YEAR, HITEMP, DENSITY, COM/IND _S	8.03	0	9	8
AGE, YEAR, HITEMP, DENSITY, RURAL _L , COM/IND _S , PHYSIO	8.78	0	14	9
AGE, YEAR, HITEMP, DENSITY, RURAL _L , INITWEEK	8.99	0	10	10
NULL MODEL	109.59	0	1	60
GLOBAL MODEL _S	2350.15	0	19	61
GLOBAL MODEL	2358.16	0	23	62

AIC value of top model = 1453.43

Table 2.3, *cont.*

(b) 1995–1997

Model	ΔAIC	Weight	K	Rank
AGE, INITWEEK, YEAR, PHYSIO, RURAL _L , HITEMP, AG _S	0	0.85	11	1
AGE, INITWEEK, YEAR, PHYSIO, RURAL _L , HITEMP	2.04	0.11	10	2
AGE, INITWEEK, YEAR, PHYSIO, RURAL _L , AG _S	3.56	0.02	10	3
AGE, INITWEEK, YEAR, PHYSIO, RURAL _L , URBANRES _L	5.24	0	10	4
AGE, INITWEEK, YEAR, PHYSIO, RURAL _L	6.01	0	9	5
AGE, INITWEEK, YEAR, PHYSIO, AG _S	6.93	0	9	6
AGE, INITWEEK, YEAR, PHYSIO, HITEMP	7.07	0	9	7
GLOBAL MODEL	7.68	0	21	8
GLOBAL MODEL _L	7.79	0	16	9
AGE, INITWEEK, YEAR, PHYSIO, URBAN _L	8.26	0	9	10
GLOBAL MODEL _S	9.64	0	16	13
NULL MODEL	81.01	0	1	59

AIC value of top model = 688.32

(c) 2009–2010

Model	ΔAIC	Weight	K	Rank
INITWEEK, AGE	0	0.97	3	1
INITWEEK, HITEMP	4.87	0.01	3	2
INITWEEK	5.23	0.01	2	3
INITWEEK, AG _S	5.38	0	3	4
INITWEEK, RURAL _L	6.23	0	3	5
INITWEEK, RURAL _S	6.23	0	3	6
INITWEEK, PRECIP	6.86	0	3	7
INITWEEK, AG _L	6.88	0	3	8
INITWEEK, YEAR	6.92	0	3	9
INITWEEK, COM/IND _L	7.02	0	3	10
GLOBAL MODEL _L	11.75	0	16	17
GLOBAL MODEL _S	13.14	0	16	18
GLOBAL MODEL	16.93	0	22	19
NULL MODEL	29.78	0	1	20

AIC value of top model = 546.98

Table 2.3, *cont.*

(d) All Years (1985–1989, 1995–1997, 2009–2010)

Model	ΔAIC	Weight	K	Rank
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , HITEMP, URBAN _L	0	0.96	16	1
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , HITEMP	3.13	0.04	15	2
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , URBANSUB _L	7.05	0	15	3
GLOBAL MODEL	7.44	0	31	4
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , COM/IND _L	9.7	0	15	5
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s	10.7	0	14	6
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , PRECIP	11.38	0	15	7
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , AG _L	12.17	0	15	8
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , RURAL _s	12.33	0	15	9
AGE, YEAR, INITWEEK, COM/IND _s , URBAN _s , AG _s	12.41	0	15	10
GLOBAL MODEL _L	12.46	0	26	11
GLOBAL MODEL _s	12.66	0	26	15
NULL MODEL	196.15	0	1	57

AIC value of top model = 2754.99

Figure 2.1. Estimate of the breeding population of AFRP Canada geese in New Jersey from 1989–2010 (New Jersey Division of Fish and Wildlife, unpublished data). Error bars denote the coefficients of variation of each estimate.

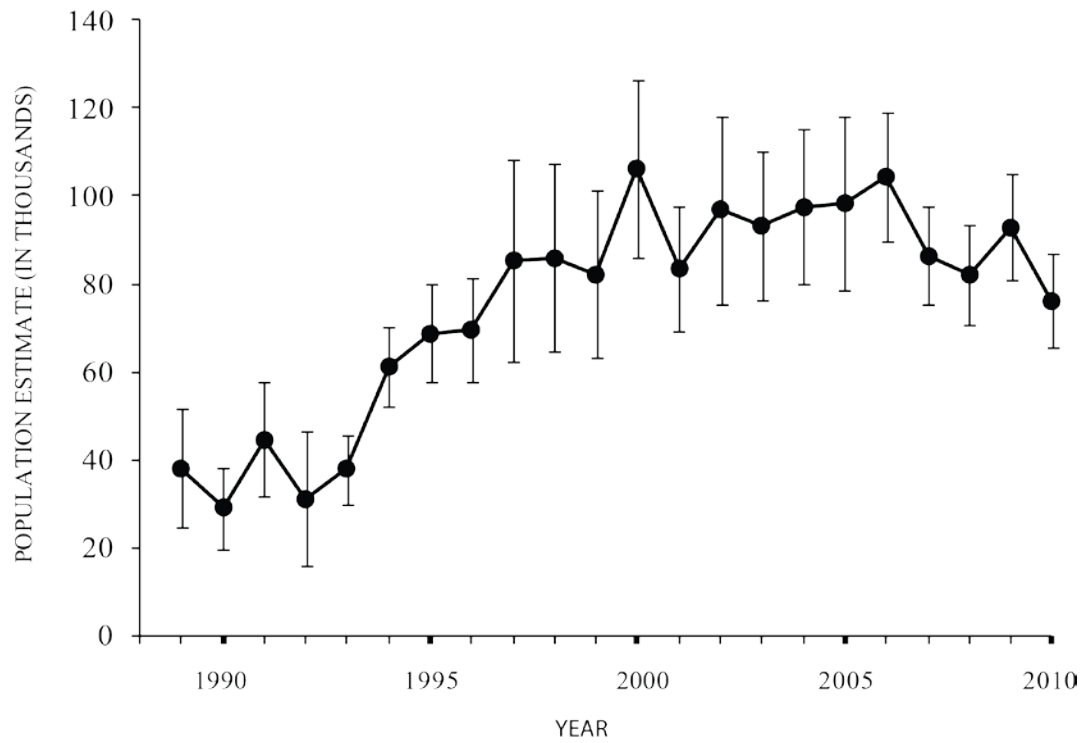


Figure 2.2. Proposed population model for Atlantic Flyway Resident Population Canada geese, modified from the AP Canada goose model proposed by Hauser et al. (2007), and the Giant Canada goose model proposed by Collucy et al. (2004) for the Missouri population. F_i is the age-specific fecundity parameter, A_i is age-specific nesting rate, C is clutch size, H is hatchability, S_N is nest success rate, and S_G is pre-fledge gosling survival rate. The survival parameter, P_i , is based on three age stages; juvenile is from fledge to 1yr, sub-adult is from 1 to 2yr, and adult is annual survival following 2yr. Additionally, select environmental and density-dependent variables are considered in the estimates of nest and pre-fledge gosling survival.

$$F_i = A_i \times C \times H \times S_{N(i)} \times S_G \times S_J$$

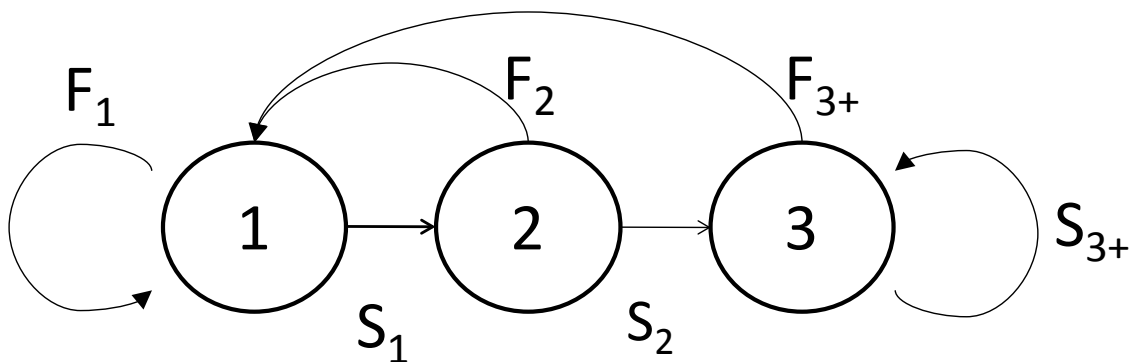
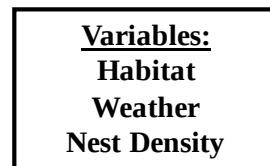


Figure 2.3. Two-hundred fifty randomly placed 1-km² plot study area, stratified by five physiographic strata in New Jersey, USA.

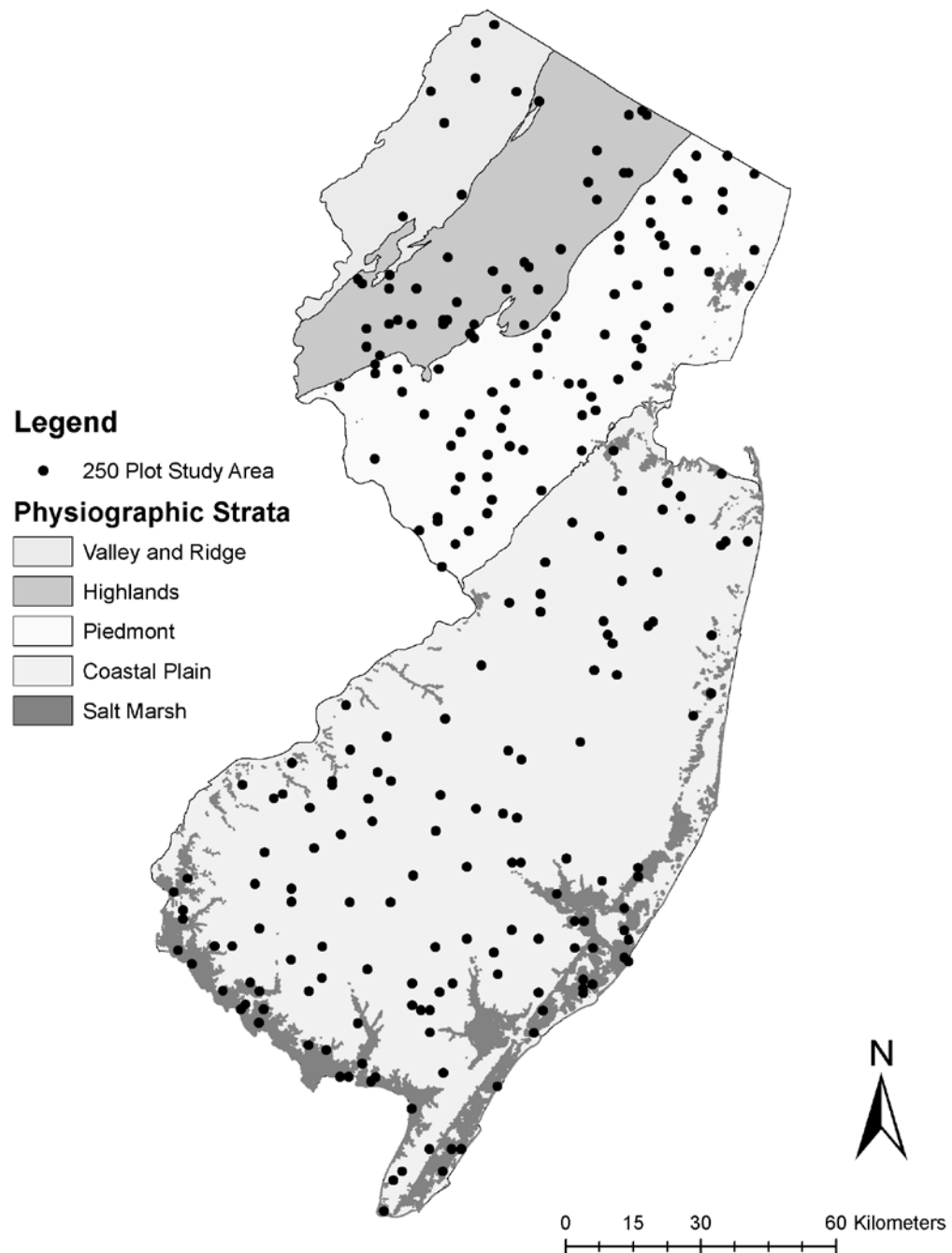
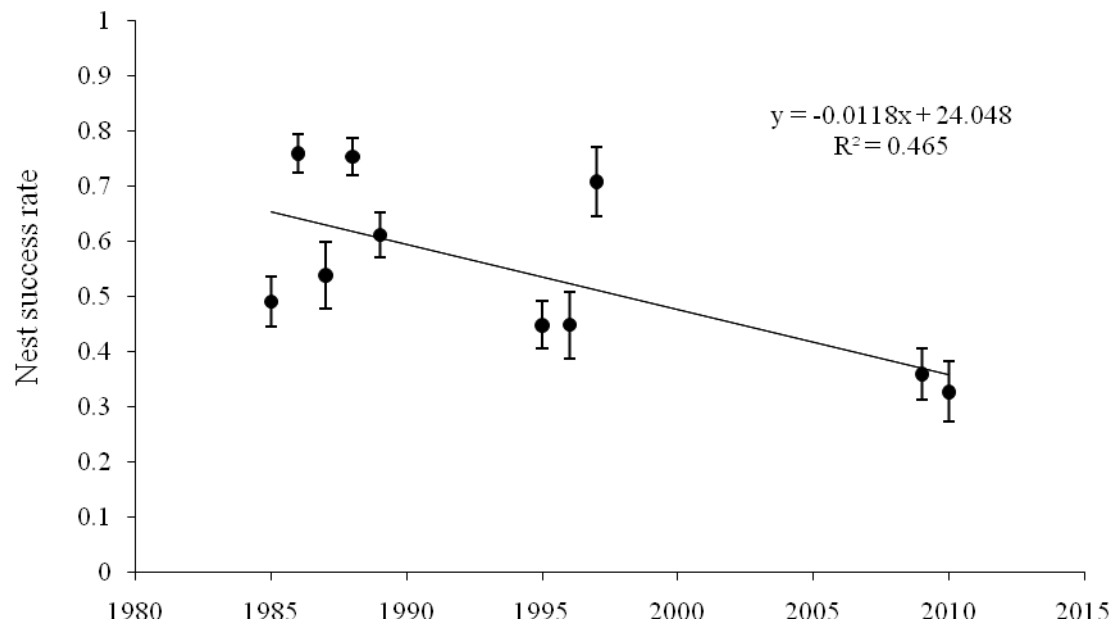


Figure 2.4. Nest success and standard error of AFRP Canada geese during 1985–1989, 1995–1997, and 2009–2010.



Chapter 3
BROOD SURVIVAL OF ATLANTIC FLYWAY RESIDENT POPULATION
CANADA GEESE IN NEW JERSEY

Introduction

Canada goose (*Branta canadensis*) summer mortality is dominated by losses during the gosling stage and especially during the first 2 weeks following hatch (Steel et al. 1957, Brakhage 1965, Zicus 1981, Eberhardt et al. 1989a). For example, estimates of Atlantic Flyway Resident Population (AFRP) gosling survival have ranged from 24–84% (Conover 1998, Huskey et al. 1998, Peters et al. 2004, Dunton and Combs 2010), depending on location and survey technique. Many predators affect AFRP Canada goose gosling survival during their first weeks, including avian (e.g. American crows [*Corvus brachyrhynchos*] and red-tailed hawks [*Buteo jamaicensis*]), mammalian (e.g. red fox [*Vulpes vulpes*], raccoon [*Procyon lotor*], and striped skunk [*Mephitis mephitis*]), and aquatic predators (e.g. snapping turtles [*Chelydra serpentina*]) (McGillvrey 1969, Ball et al. 1975, Talent et al. 1983, Sargeant and Raveling 1992, Hanson 1997, Conover 1998). Other factors influencing gosling survival include the availability of brood-rearing habitat, formation of gang broods (Warhurst et al. 1983, LeBlanc 1987), meteorological effects (Fondell et al. 2008), age of the adult (Wang 1982, Rockwell et al. 1993, Black and Owen 1995), density-dependent limitations on gosling fitness (Sedinger et al. 1998)

and artificial feeding and protection through human intervention and urban development (Atlantic Flyway Council 2011, Dunton and Combs 2010).

Unfortunately, obtaining reliable survival estimates of hatchling waterfowl through fledge has been shown to be very challenging, primarily due to their small size, precocial behavior, and the habitats in which they live (Stolley et al. 1999). Methods of measuring gosling survival often include 1) observing changes in the total number of young present at a location (Geis 1956, Brakhage 1965), 2) observing changes in brood size (Zicus 1981, Williams et al. 1993a, Flint et al. 1995, Jacobs and Dunn 2004, Peters et al. 2004, Mainguy et al. 2006), or 3) mark-recapture of individually-marked goslings (Leafloor et al. 2000, Jacobs and Dunn 2004, Peters et al. 2004, Mainguy et al. 2006). Observing changes in the total number of young can bias survival estimates, due to immigration/emigration during the brood-rearing period (Stolley et al. 1999). Observing changes in marked broods, or broods associated with marked adults can lead to a more accurate estimate. However, caution must be used in this analysis, as brood-mixing is often present in goose populations. The mark-recapture technique is the most accurate of these three methods, but requires a considerable amount of effort to be present during hatch, track brood movements for two months, and locate all broods during recapture. Stolley et al. (1999) suggested incorporating mark-recapture techniques using both individually-marked goslings and radio-marked adults as a more accurate method for measuring survival during this stage; however, there is potential bias in any study involving the marking of birds.

Further complicating estimation of survival during the gosling stage is total brood loss, which is an important component that has proven to be difficult to quantify (Talent

et al. 1983, Orthmeyer and Ball 1990, Batt et al. 1992, Williams et al. 1993b, Grand and Flint 1996, Krapu et al. 2000). In many mark-recapture studies of young geese, only broods that are present during recapture are used to estimate survival (Bruggink et al. 1994, Leafloor et al. 2000). This is due to the inability to distinguish totally lost broods from those that are absent during recapture. Broods that experience total loss are inherently not represented during recapture, and thus must be accounted for using other methods, such as through the marking of breeding adults. Estimates of total brood loss in prior gosling survival studies have ranged between 17.2–44.4%, with most occurring during the first few weeks following hatch (Flint et al. 1995, Stolley et al. 1999). In this study, we account for brood mixing and adoption in survival estimates, but do not account for emigration.

Due to biological variability and past methodological biases, it is important to estimate total gosling survival in the presence of both total and partial brood losses using multiple methodologies. This is especially important in the AFRP Canada goose population, which has been increasing and is of concern for damage management. Therefore, the focus of this study was to estimate 1) total brood loss, 2) partial brood loss 3) brood survival, combining total and partial brood loss estimates, and 4) daily gosling mortality during the first two weeks following hatch.

Study Area

Nest searches were conducted at 12 locations across 6 counties in New Jersey that were known nesting and brood rearing sites (Fig. 1). They were also locations where New Jersey Division of Fish and Wildlife (NJDFW) staff conducted annual molt banding drives from late June through early July, allowing for a high probability of recapture

occasions of marked birds. Locations included 3 state-owned wildlife management areas, 1 fish hatchery in an urban area, 6 municipal parks in suburban residential areas with associated lakes, 1 county landfill in an urban area, and 1 privately-owned camp in a rural residential area. All locations were nesting sites with adjacent brood-rearing areas where Division staff regularly caught broods in the past, leading us to expect little emigration.

Methods

Field Methods

I conducted nest searches with assistance from NJDFW staff at the 12 study locations throughout the nesting period to locate nests and determine expected hatch dates from 1 April–10 May 2009 and 2010. I aged embryos utilizing both field candler (modified from Weller 1956, Cooper and Batt 1972) and egg floating (United States Department of Agriculture 2009) techniques to estimate the incubation stage and hatch date. Results from both methods were averaged to gain the most accurate estimate of hatch date (Reiter and Anderson 2008). During the second year of the study (2010), I applied 28-gram VHF-mounted neck collars with mortality sensors and a visible unique 4-digit alphanumeric code (Model A3590, Advanced Telemetry Systems, Inc., Minnesota) to 50 adult birds incubating monitored nests during the 2 weeks prior to hatch. This subsample was randomly selected, but depended on the ability to trap the bird on the nest. Radio-marked adult birds were used to locate broods during the brood-rearing period (Bruggink et al. 1994).

On the day prior to nest hatch, I used a 12" x 24" plastic expandable mesh bag (Big Apple Packaging; Appendix D) to contain a random sample of the clutches during the hatching period to mark entire broods, stratified by location. An evaluation of the

effect of these nest bags on hatch success was conducted (Appendix D), and I found no significant difference between this technique and the control group ($t_{148} = 0.794$, $P = 0.428$; Appendix D). On the day of hatch, I applied monel size #1005–1 fingerling fish tags (National Band & Tag Company, Kentucky) to the center of the outer web of one foot of all birds within pipped eggs or healthy hatched goslings (Alliston 1975). A consecutive three-digit code was imprinted on the topside of the web tag (001–999) for unique identification during recapture. Eggs were then covered with down and nest materials from the nest bowl to help prevent avian predation (Rearden 1951). I attempted to web tag all goslings located at these sites on their hatch date, dependent upon the number of nests discovered and the availability of field staff on the hatch date.

Randomly selected broods were also color-marked for observable identification to brood. I applied color markers in several shades to the head and neck on the hatch date. During the 2009 nesting season, I applied color with Sharpie™ markers in several shades for identification. During the 2010 nesting season, I used a commercial dye comprised of 50% water/50% alcohol, with trace amounts of dissolved dyes, including Malachite Green, Rhodamine B (Red), and Methylene Blue (Wadkins 1948, Serie et al. 1983). Dyes were expected to be observable for approximately 5 weeks (Geis 1956). I randomly color-marked broods on their hatch date, dependent upon the number of nests discovered, the number of goslings hatched, and the availability of field staff on the hatch date. After I placed all goslings and eggs back in the nest bowl, I observed adults until they returned to the nest. The application of all markers was approved by the Bird Banding Laboratory (BBL)/USGS Patuxent Wildlife Research Center under banding permit #06460.

Observations of color-marked broods and broods associated with marked adults were completed every other day following hatch for 2 weeks (Bart and Robson 1982), and then weekly until recapture in late June. Caution was taken to monitor broods from a distance to avoid observer bias. Information was recorded on brood size, presence of adults, age class of goslings (Yocum and Harris 1965), observed markers, age (HY/AHY) of unmarked birds, location, behavior, and formation of gang broods. Brood counts were not recorded when broods were located in areas of limited visibility, such as heavily forested or areas with tall grass. Instead, I recorded presence/absence of a mortality signal for the breeding adult with the location information for that day.

Recapture of web tagged goslings occurred during NJDFW's annual AFRP Canada goose molt banding program commencing in late June, in accordance with the Atlantic Flyway Resident Canada Goose Management Plan (Atlantic Flyway Council 2011). NJDFW staff marked all captured birds with standard federal aluminum leg bands, and the web tag number of any recaptured goslings. I also recorded measurements of culmen, tarsus, and ninth primary feather length, and body mass for all marked goslings, as part of a separate study. Observations of marked adults reported to the BBL were also used to locate birds and associated broods during the pre-fledged period.

Analytical Methods

I estimated survival in four components: 1) total brood loss from radio-collared adults, 2) partial brood loss via mark-recapture of web-tagged individuals from hatch until summer banding efforts, 3) total survival, including total and partial brood loss estimates, and 4) gosling mortality during the first two weeks following hatch by observing broods associated with radio-collared adults and color-marked broods. Due to

the inability to differentiate broods not present during recapture from broods that experienced total brood loss, only broods with ≥ 1 gosling present during recapture were used in estimating partial brood loss (Flint et al. 1995). Observations of broods associated with radio-collared adults as well as color-marked broods were based on the total sample, and included both total and partial brood losses.

Total brood loss was defined as the loss of all young associated with a parent (Bruggink et al. 1994, Leafloor et al. 2000). I estimated total brood loss using observations from radio-collared adults. Adults (and their associated broods) were located using VHF telemetry every second day for the first 2 weeks following hatch, and then once weekly until recapture. A marked adult was assumed to have experienced total brood loss if it was observed without a brood for ≥ 2 occasions, and the associated webtagged brood was not recaptured during banding drives. Additionally, we assumed that marked adults lost their brood if 1) they were not located through observations and aerial telemetry with a search area ~ 16.2 km radius around the site after previously being observed with a brood, and 2) associated marked goslings were not recaptured during recapture occasions. We accounted for brood adoptions in estimates of total brood loss by combining observations of total brood loss with the recapture of webtagged goslings. I conducted a survey during April 2011 in order to verify active radio signals on marked adults that were not recaptured during molt banding drives in 2010. Detection of a transmission during this time allowed me to rule out transmitter failure for marked adults with unknown brood survival, and thus confirm that the adult was not present during the brood rearing period in 2010. Because we were measuring survival of young associated

with marked adults, we assumed that movements outside of our search area during the brood-rearing period were made by flight without goslings.

To estimate partial brood loss, I used a maximum likelihood estimator (Manly and Schmutz 2001) to determine the survival of webtagged broods in which ≥ 1 gosling survived from hatch through the recapture. Broods that were not present during recapture were right censored. The mean exposure period for estimating partial brood loss was calculated using hatch and recapture dates of all broods present during recapture. The standard error was calculated by generating 50 bootstrapped samples of the data (Manly and Schmutz 2001). I used six covariates to build 20 *a priori* candidate models (including a global and null model) to predict brood survival that were compared using Akaike's Information Criterion, with a correction for small sample size (AICc; Burnham and Anderson 2003). Covariates included hatch date, % development, % forest, and % agriculture within 215 m of the nest site (Dunton and Combs 2010), number of broods present at location, and % extreme daily high temperature. To assure normality, the number of broods present at each location was natural log transformed, percent habitat compositions was cube root transformed, and extreme high temperature was square root transformed. Survival estimates of webtagged goslings were pooled among years.

I first calculated the total survival rate and standard error for the sample by taking the weighted estimate of total brood loss and partial brood loss during the study (Flint et al. 1995):

$$S_G = (P_{TBL} \times 0\% \text{ survival}) + ((1 - P_{TBL}) \times S_{PBL}) \quad \text{Equation 3.1}$$

where S_G is the sample-wide survival estimate, P_{TBL} is the proportion of broods that experienced total loss at 0% survival, and S_{PBL} is the survival rate for broods that experienced partial brood loss (Fig. 3.2).

To confirm total survival rates estimated from Equation 3.1, I also used observations of changes in brood size of color-marked only broods, as well as broods associated with neck-collared adults, to quantify fluctuations in the survival rate through 56 days using the iterative Mayfield method (Manly and Schmutz 2001). This method allowed for brood-mixing and daily estimations of mortality. Observations were made on the entire sample, and thus included observations of total and partial brood losses. Observation data was pooled among study years.

Results

I located and monitored 181 and 221 nests through hatch from 1 April–15 June 2009 and 2010. The mean hatch date for both 2009 and 2010 was 30 April ($SE \pm 0.66$ d). During 2009, I applied webtags to 352 hatchlings from 83 nests. During 2010, I applied webtags to 555 hatchlings from 130 nests. I recaptured 66 and 163 goslings, from 31 and 75 broods in 2009–2010, respectively. The mean exposure period between hatch and recapture was 56 d ($SE \pm 0.73$ d).

Out of 50 radio-collared adults in 2010, 38 adults successfully hatched nests. I attempted to recapture all broods present at each location during recapture, but missed one due to the inability to bring capture equipment into the brood-rearing site (heavily wooded swamp). However, I was able to observe this bird with her brood just prior to recapture. Of the 38 adults with successful nests, 12 adults lost their entire brood prior to

recapture. The proportion of radio-collared adults that lost their entire brood (P_{TBL}) was 0.316 for the 38 marked adults.

We recaptured 106 out of 213 webtagged broods during the study. Estimated survival accounting for partial brood loss was 0.465 ($SE \pm 0.026$) for 56 d, and was most influenced by the number of broods present at the location and the % agriculture within 215 m of the nest site ($AICc$ weight = 0.586; Table 3.1). Gosling survival was negatively influenced by the number of broods present, but was positively influenced by the % agriculture at the nest site.

I used the proportion of broods experiencing partial brood loss of 0.684 ($1 - P_{TBL}$) to estimate sample-wide survival for both years. The sample-wide estimated survival rate through 56 d using Equation 3.1 was 0.318 ($SE \pm 0.018$) for 2009–2010 (Table 3.2). To confirm this estimate, I color marked 85 broods at hatch, and observed marked broods on 99 occasions during 2009–2010. I observed broods associated with 38 marked adults on 149 occasions during 2010. Estimated survival through 56 d using brood observations was 0.363 ($SE \pm 0.042$). The daily mortality rate fluctuated from 0.032 to 0.364 during the first 14 days, followed by a rate that did not exceed 0.027 for the remaining duration of the exposure period (Fig. 3.3).

Discussion

The mortality of pre-fledged goslings is a crucial component in studying population dynamics of AFRP Canada geese. Due to the complexity in achieving an accurate survival estimate of these young birds, few estimates are available. Managers are often left using estimates from other populations that are under a different suite of circumstances (i.e. density, predator community, habitat type, flooding, or control

activities). This is one of the first studies of AFRP Canada goose brood survival to incorporate marking techniques of individual young along with brood observations of telemetered adults in an attempt to gain accurate estimates of both total and partial brood losses from hatch through banding.

Total brood loss is an important component to brood survival, and disregarding it can critically overestimate survival (Stolley et al. 1999). My total brood loss estimate of 0.316 is similar to prior studies (Rockwell et al. 1987, Eberhardt et al. 1989b). In accounting for total brood loss, my overall estimate of gosling survival was lowered by 0.147 (SE $\pm$ 0.032). Stolley et al. (1999) stated that without accounting for total brood loss, they would have overestimated survival for a population of geese at Fish Springs National Wildlife Refuge in Utah by 44%. Although many studies attempt to measure total brood loss through marked adults (Lawrence 1986, Bruggink et al. 1994, Peters et al. 2004), it is often estimated by looking at the number of marked adults that are recaptured without broods. However, because molt migration can be common in failed breeders in some regions (Nichols et al. 2003, Sheaffer et al. 2007) a failed breeder is less likely to be recaptured in the same brood rearing area two months after peak hatch (Eberhardt et al. 1989b). In observing adults with radiotransmitter-mounted neck collars, I was able to identify adults that experienced total brood loss prior to leaving the nesting area. All observations of total brood loss were recorded within the first 3 weeks following hatch, similar to prior literature (Flint et al. 1995, Stolley et al. 1999).

My survival estimate of partial brood loss (0.465) was within range, but on the lower end, of prior studies. However, resident Canada goose gosling survival rates through banding (B) or fledging (F) vary tremendously by region (e.g. 0.59 in Ohio [F;

Warhurst et al. 1983], 0.49–0.66 in Ontario [B; Bruggink et al. 1994], 0.76 in Connecticut [F; Conover 1998], 0.76 in South Carolina [B; Huskey et al. 1998], 0.60 in Missouri [F; Collucy 2001], and 0.244–0.76 in Pennsylvania [B; Peters et al. 2004, Jacobs and Dunn 2004]. Variation in estimates can be due to a mixture of local predator pressure, human influence on surrounding habitat, meteorological events, and measurement techniques (Stolley et al. 1999).

While the survival estimate of brood observations was similar to that of my weighted survival estimate, brood observations allowed me to look closely at daily mortality rates for the first two weeks following hatch. Mortality fluctuated tremendously during this time, and accounted for many of the total brood losses. Mortality decreased to almost 0% beyond this point, supporting the theory that the majority of mortality occurs early in the brood rearing period (Steel et al. 1957, Brakhage 1965, Zicus 1981, Eberhardt et al. 1989a).

The frequency of brood observations varied across sites, due to variation in the visibility of birds in their habitat. In urban-developed areas, broods were more often reared on large water bodies near manicured lawn areas, and were easier to observe. In native habitats, broods were usually reared in thick vegetation (low shrubs and forested areas) near streams and agricultural fields. Supporting these observations, my results of the mark-recapture analysis showed that agricultural land at the site level was an important variable in gosling survival. Agriculture fields, often adjacent to fragmented forest buffers, offer both food and protection from predators and extreme weather for young broods. Increased agricultural dependence by goose populations during fall-winter in recent decades (Jefferies and Drent 2006, de Jong 2010) may also be influencing nest

site selection. However, I was unable to find prior studies that have addressed agricultural influence on gosling survival of resident populations.

The effect of hatch date was not important in my leading model for partial brood loss. However, past studies on subarctic-nesting geese have demonstrated that vulnerability to predation can be elevated for early-hatching broods, while predator swamping can reduce the incidence of brood loss as more families hatch in colonial nesting areas (Cooke et al. 1984).

The locations used to estimate gosling survival were known nesting areas that were used as banding sites. Therefore, these areas tended to have higher densities of nests (range = 1–46 nests, mean = 10.1 nests (SE $\pm$ 2.7 nests)). I acknowledge that this may have biased my results due to density-dependent predator pressure (Owen and Black 1989, Larsson and Foslund 1994, Sedinger and Herzog [University of Alaska, unpublished data]) or density-dependent effects on clutch size (Cooch et al. 1989), which may, in turn, affect the occurrence of total brood loss. Density-dependent predator pressure or intraspecific competition may have also influenced emigration of broods. Although most broods were recaptured near their original nesting locations, one brood was recaptured 2.4 km away from their nest site during 2009, connected by residential land and a major roadway. Another brood was recaptured 5 km away from their nest site at a corporate park during 2010, connected by agricultural fields and small streams. Dunton and Combs (2010) documented a small subset of transient AFRP broods whose home range was $\sim$ 110ha, and classified them as “wanderers”. Such events may be influenced by high predation rates associated with high-density nesting areas (Owen and Black 1989, Larsson and Foslund 1994). Therefore, I recognize that my higher density

study areas may have negatively influenced individual behavior, movement, and total brood loss and recommend further research to estimate total brood loss with the addition of low density nesting areas.

Management Implications

Data from this study fills a critical gap in the development of a spatially-explicit population model for AFRP Canada geese in New Jersey. Acquiring current reproductive vital rates will assist in understanding the dynamics of recruitment as a function of population size. I recommend that managers cautiously utilize this survival estimate in evaluating annual recruitment, keeping in mind that estimates of total brood loss may vary by region. The survival estimate of partial brood loss may be more applicable in areas which experience little or no total brood loss. I encourage managers to include total brood loss in gosling survival studies, in an effort to prevent overestimation of gosling survival. Furthermore, use of multiple marking techniques, identifying both individual goslings and broods through marked adults, allows for verification of survival estimates.

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Table 3.1. Summary of model-selection procedure examining variables affecting brood survival of AFRP Canada geese in New Jersey, USA from 2009–2010. I report Akaike’s Information Criterion (AICc), the relative difference in AIC values compared to the top-ranked model (Δ AIC), the AIC model weight (W), and the number of parameters in the model (K).

Candidate Models	AICc	Δ AICc	Weight	K
Density + %Ag	274.361	0.000	0.586	3
HatchDate + Density	277.395	3.034	0.129	3
Density + %Forest	278.305	3.944	0.082	3
Density + HiTemp	278.695	4.334	0.067	3
Density + %Developed	279.135	4.774	0.054	3
HatchDate + HiTemp + Density	279.449	4.970	0.049	4
HiTemp + Density + %Developed	280.501	6.022	0.029	4
HatchDate + Density + %Ag	284.997	10.518	0.003	4
Global Model	286.648	11.556	0.002	7
HatchDate + Density + %Developed	287.763	13.284	0.001	4
HiTemp + %Developed	309.059	34.698	0.000	3
Null Model	309.826	35.582	0.000	1
HiTemp + %Forest	310.553	36.192	0.000	3
HiTemp + %Ag	311.557	37.196	0.000	3
%Ag + %Forest	311.845	37.484	0.000	3
HatchDate + HiTemp	312.093	37.732	0.000	3
HatchDate + %Developed	312.115	37.754	0.000	3
HatchDate + %Forest	312.789	38.428	0.000	3
%Developed + %Ag + % Forest	313.263	38.784	0.000	4
HatchDate + %Ag	313.865	39.504	0.000	3

Table 3.2. Proportion and survival estimates of total brood loss (S_{TBL}), partial brood loss (S_{PBL}), and sample-wide survival estimates (S_G) of AFRP Canada goose broods from hatch until recapture during 2009–2010 in New Jersey, USA.

Estimate Type	Proportion of Sample	Survival Estimate	
		Mean	SE
Total Brood Loss	0.316	0	-
Partial Brood Loss	0.684	0.465	0.026
Sample-wide	1.000	0.318	0.018

Figure 3.1. Twelve locations used to study AFRP Canada goose brood survival during April-July, 2009–2010 in New Jersey, USA.

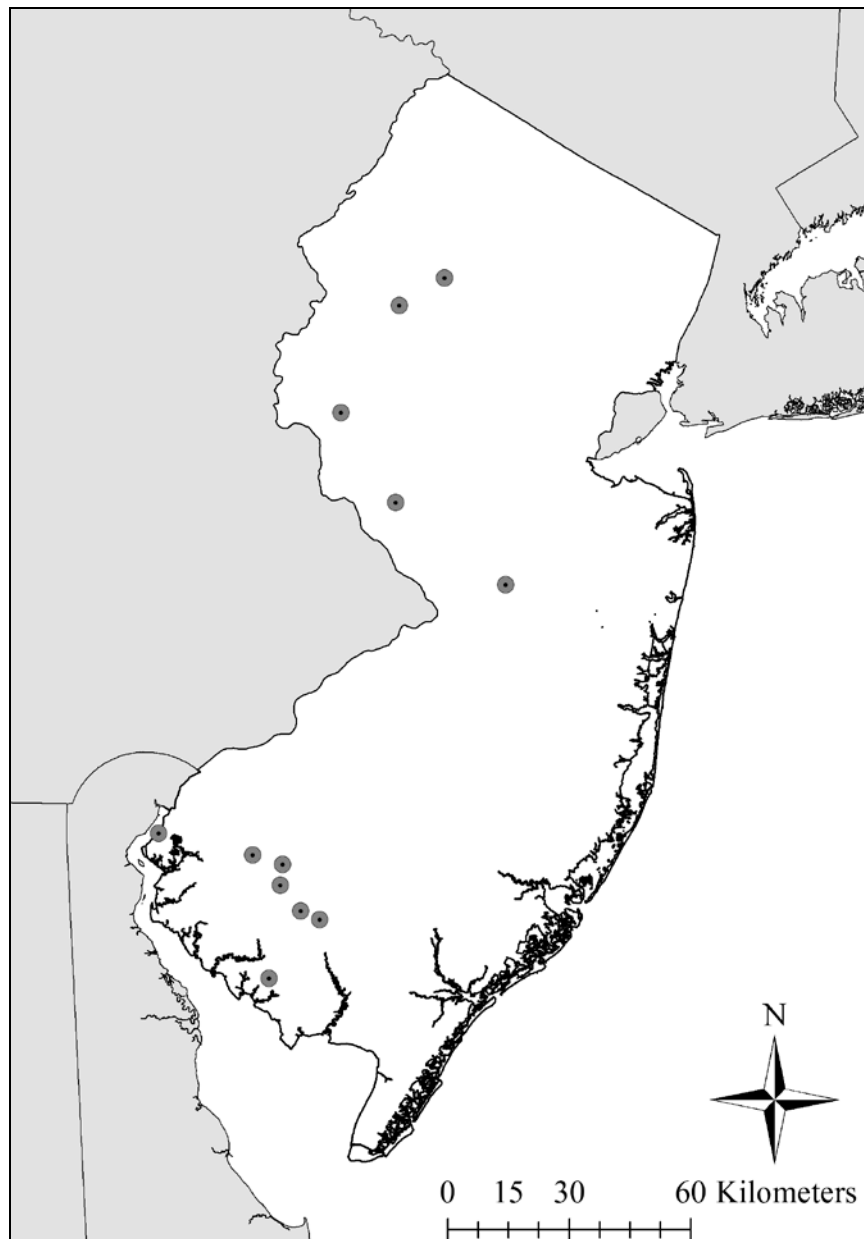
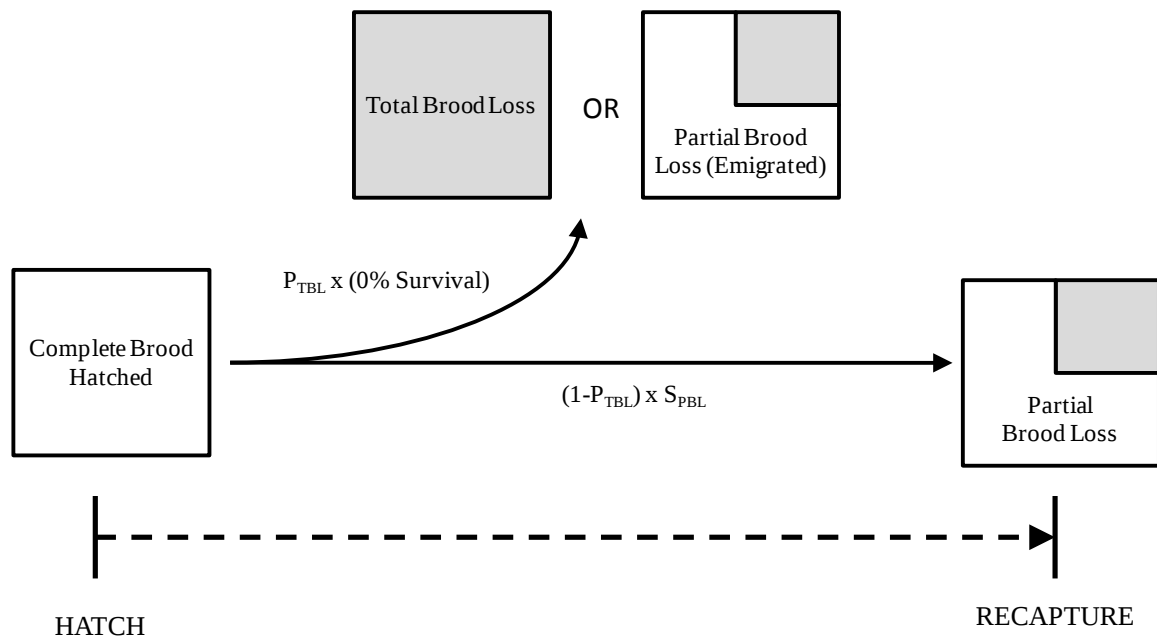
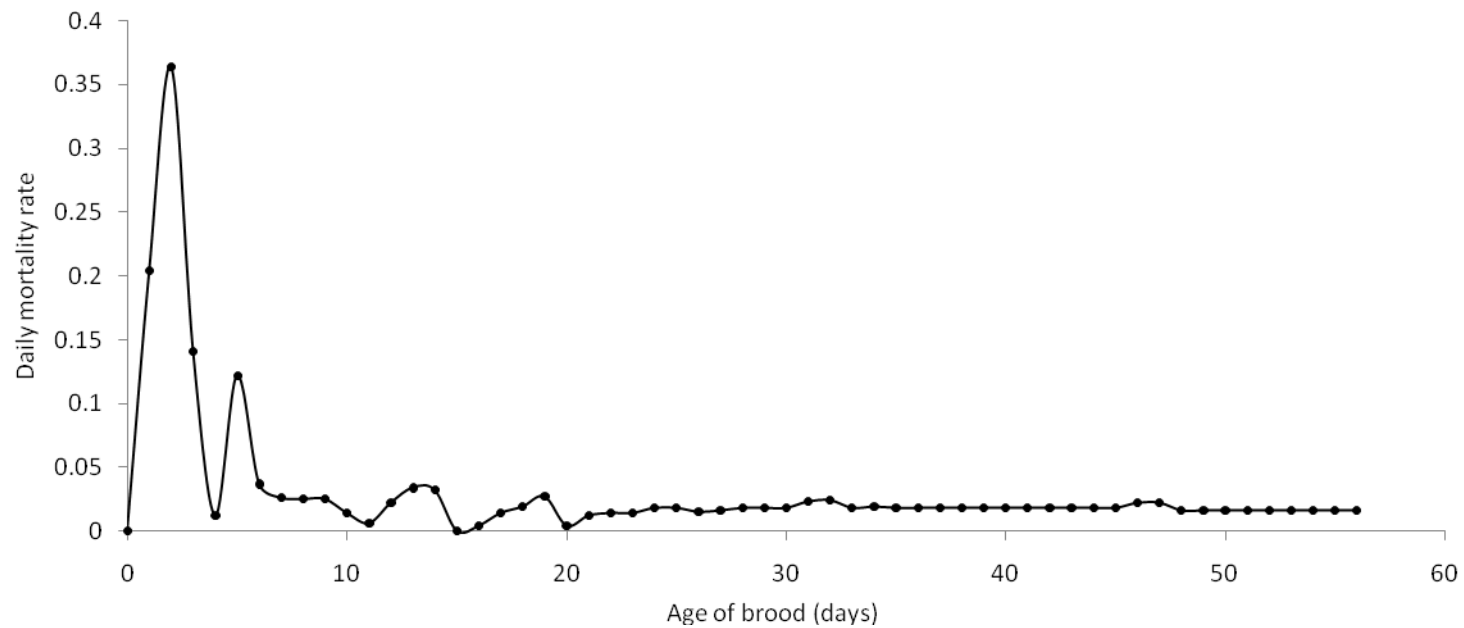


Figure 3.2. Gosling survival estimate is composed of a proportion of broods that are totally lost during brood-rearing (TBL), and the remaining proportion of broods that are exposed to partial brood loss (PBL). Only broods that have partial losses are present during recapture, making it difficult to distinguish TBL from broods not present (emigrated) during recapture.



$$\text{Gosling Survival} = (P_{TBL} \times 0\% \text{ Survival}) + ((1 - P_{TBL}) \times S_{PBL})$$

Figure 3.3. Estimate of daily mortality rates of AFRP Canada goose goslings from hatch until recapture during 2009–2010 in New Jersey, USA. Estimates are based on observations of both broods associated with marked adults and broods identifiable through color marking.



APPENDIX A

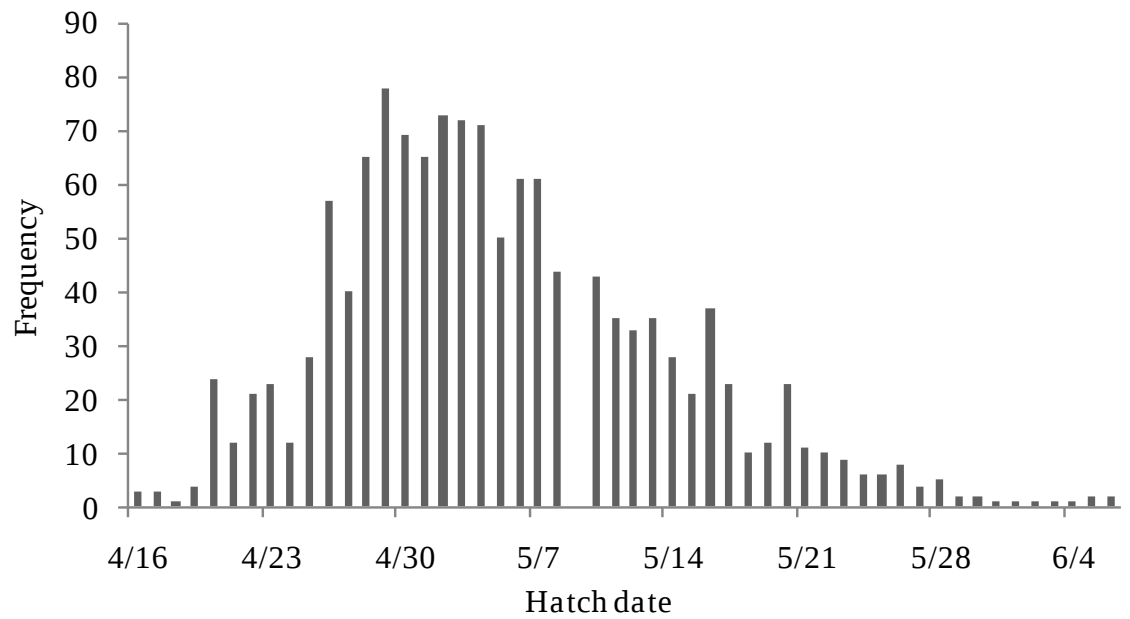
(a) MEAN NEST INITIATION DATE (+/- SE), AND (b) MEAN HATCH DATE (+/- SE) BY PHYSIOGRAPHIC STRATUM AND YEAR FOR CANADA GOOSE NESTS IN NEW JERSEY, USA

(a) MEAN NEST INITIATION DATE (+/-SE)						
YEAR	PHYSIOGRAPHIC STRATUM					TOTAL
	Coastal Plain	Piedmont	Highlands	Valley & Ridge	Salt Marsh	
1985	3/24 (2.4)	3/18 (1.2)	3/22 (4.5)	3/19 (6.1)	3/25 (1.9)	3/21 (0.9)
1986	4/6 (1.5)	4/4 (1.2)	3/26 (3.0)	4/11 (0)	ND	4/4 (0.9)
1987	4/1 (1.5)	4/3 (1.0)	3/24 (1.5)	3/18 (0)	ND	4/2 (0.8)
1988	3/29 (1.8)	4/1 (0.7)	3/29 (4.1)	4/7 (0)	ND	3/31 (0.7)
1989	4/5 (2.9)	4/3 (0.7)	3/29 (2.4)	ND	ND	4/3 (0.6)
1995	ND	3/31 (0.7)	3/29 (1.1)	ND	ND	3/31 (0.6)
1996	3/26 (2.6)	4/6 (1.1)	4/5 (2.0)	ND	4/3 (3.0)	4/5 (0.9)
1997	4/8 (4.7)	4/7 (1.4)	4/7 (3.4)	ND	4/2 (3.7)	4/7 (1.2)
2009	3/31 (1.4)	4/2 (1.1)	4/1 (1.6)	ND	4/8 (4.3)	4/2 (0.8)
2010	3/27 (1.2)	3/29 (1.2)	4/2 (1.6)	4/8 (0)	3/29 (2.5)	3/29 (0.7)
Average	3/31 (0.7)	4/1 (0.3)	3/30 (0.7)	3/24 (4.8)	3/27 (1.5)	3/31 (0.3)

(b) MEAN HATCH DATE (+/-SE)						
YEAR	PHYSIOGRAPHIC STRATUM					TOTAL
	Coastal Plain	Piedmont	Highlands	Valley & Ridge	Salt Marsh	
1985	5/5 (2.0)	5/2 (0.9)	5/7 (2.4)	5/4 (0)	5/9 (1.6)	5/4 (0.7)
1986	5/10 (2.3)	5/3 (1.3)	5/2 (2.4)	5/10 (0)	ND	5/5 (1.1)
1987	5/4 (1.2)	5/7 (1.1)	4/29 (1.4)	4/25 (0)	ND	5/5 (0.8)
1988	5/2 (2.3)	5/5 (0.8)	5/3 (4.8)	5/13 (0)	ND	5/4 (0.7)
1989	5/11 (3.7)	5/4 (0.5)	5/3 (2.3)	ND	ND	5/4 (0.5)
1995	ND	5/3 (0.6)	5/2 (0.9)	ND	ND	5/3 (0.5)
1996	5/5 (0.9)	5/9 (1.1)	5/6 (1.9)	ND	5/11 (0.9)	5/8 (0.9)
1997	5/11 (4.3)	5/9 (1.3)	5/10 (3.3)	ND	5/3 (5.1)	5/9 (1.1)
2009	5/3 (1.1)	5/7 (1.4)	5/5 (2.3)	ND	5/8 (4.7)	5/6 (0.9)
2010	5/2 (1.0)	5/3 (1.0)	5/7 (1.4)	5/14 (0)	5/2 (1.9)	5/3 (0.6)
Average	5/5 (0.6)	5/5 (0.3)	5/5 (0.6)	5/6 (2.6)	5/8 (1.3)	5/5 (0.2)

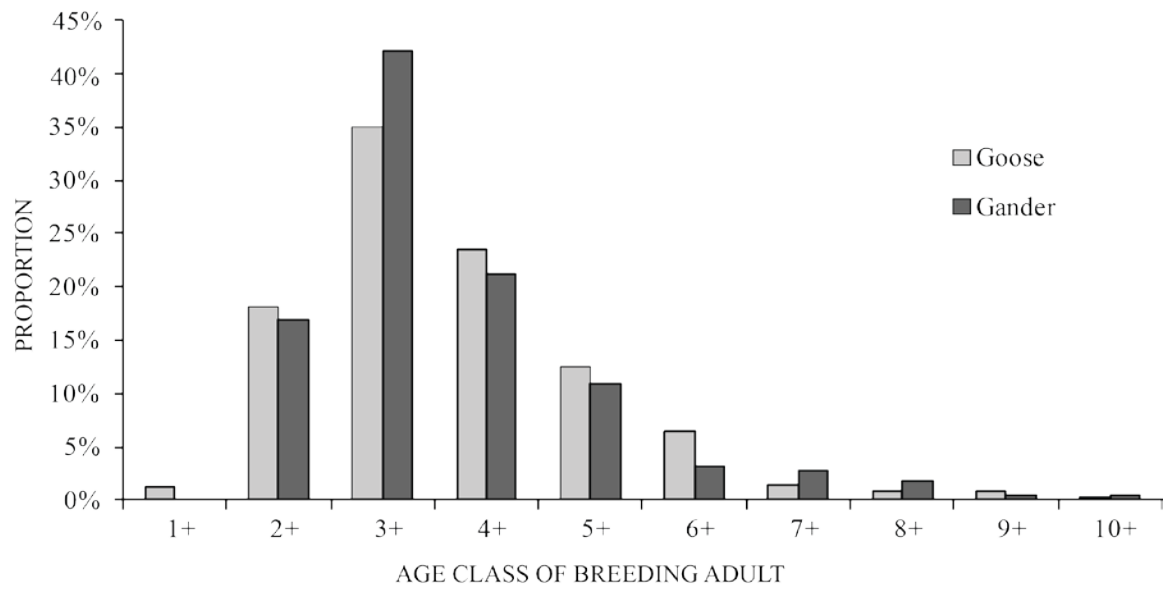
APPENDIX B

FREQUENCY OF CANADA GOOSE NEST HATCHES IN NEW JERSEY DURING STUDY YEARS FROM 1985–1989, 1995–1997, AND 2009–2010



APPENDIX C

AGE DISTRIBUTION OF BREEDING ADULTS BY AGE CLASS AND SEX DURING 1985–1989 IN NEW JERSEY, USA



Goose	n =	4	62	120	81	43	22	5	3	3	1
Gander	n =	0	37	92	46	24	7	6	4	1	1

APPENDIX D

EVALUATION OF A CLUTCH CONTAINMENT METHOD DURING HATCH IN RESIDENT CANADA GEESE FOR MARK-RECAPTURE STUDY

(Submitted for publication with the Wildlife Society Bulletin)

Introduction

Measuring survival of goslings through fledge has been shown to be very challenging, primarily due to their small size and the habitats in which they live (Stolley et al. 1999). Most gosling mortality occurs in the first two weeks following hatching (Steel et al. 1957, Brakhage 1965, Zicus 1981, Eberhardt et al. 1989), making this stage a critical component in estimating gosling survival. However, results can vary drastically across populations, habitats, techniques, and/or level of effort (Stolley et al. 1999).

Several approaches are used to estimate gosling survival; including comparing total hatchling counts to total gosling counts at a later date as well as the comparison of mean number of hatchlings per nest to mean brood size at a later date. Unfortunately, both inherently overestimate survival due to the inability to account for total brood loss, brood mixing, or emigration (Zicus 1981). Mark-resight-recapture can improve estimates, particularly when using a combination of individually marked hatchlings and marked adults (Stolley et al. 1999). Although meta-analyses may be beneficial, they rely upon the accuracy of individual studies, which can vary greatly.

Of additional concern, in a hatchling mark-recapture study, disturbance caused by nest visits during the brooding period can cause older hatchlings to depart the nest site

with the adults prematurely, leaving the newly hatched birds unprotected, not fully brooded, and possibly abandoned. Brooding of hatchlings in the nest bowl typically lasts about 24 hours (Brakhage 1965), allowing for drying of feathers, thermoregulation, and absorption of the remaining nutrients from yolk lipids (Batt et al. 1992). The initial brooding period is followed by a permanent departure from the nest site for brood rearing. Additionally, repeated nest visits are often required during the last 3–5 days in order to verify the exact hatch date. This added disruption can increase the likelihood that adults will flee the nest site with only a partial brood during subsequent visits.

To address problems of partial clutch abandonment and reduce disturbance due to multiple nest visits, we evaluate a method that uses a mesh clutch containment bag during the hatch period. Containment of the clutch allows for marking of complete broods, with the intent of minimizing disruption of natural brooding activities and reducing abandonment of newly hatched birds by fleeing parents.

Study Area

We conducted nest searches at 11 locations across 6 counties in New Jersey that were known nesting and brood rearing sites (Fig. A4.1). Locations included state-owned wildlife management areas and fish hatcheries, municipal parks with associated lakes, a closed municipal landfill, and a privately-owned youth camp. Study sites ranged in size from 6–135 ha. The mean high temperature for April and May 2010 was 20°C (69°F) and 24°C (76°F).

Methods

We conducted nest searches by foot and boat during the peak laying period from 1–30 April 2010. Embryos were aged utilizing both field candler (modified from Weller

1956, Cooper and Batt 1972) and egg floating (United States Department of Agriculture 2009) techniques to estimate the incubation stage and hatch date. We averaged the results from both methods to gain the most accurate estimate of hatch date (Reiter and Anderson 2008). We randomly assigned all nests to either a clutch bag treatment or no-clutch bag control group prior to hatch. We stratified the sample by location in order to reduce bias associated with other variables affecting hatch success.

On the evening prior to hatch, we contained the clutch of all nests within the treatment group with a 35.5 cm x 71.0 cm (12" x 24") green plastic expandable mesh clutch containment bag (Big Apple Packaging onion sack; \$0.14/bag; Fig. A4.2). The mesh size was 4.8 mm x 4.8 mm, offering limited potential for legs or wings to become entangled. We contained a maximum of 5 eggs within each bag and we used 2 bags if clutch sizes were >5 eggs. We left as much open space as possible within the bags to facilitate movement of hatching goslings and space for egg remains and closed bags with an overhand knot to ensure containment of the clutch. After treatment, we covered each bag with down and materials from the nest bowl to help prevent avian predation (Rearden 1951). We also visited nests within the control group just prior to hatch, in order to verify the exact hatch date. We used vocalizations of young, or "peeping", as an indication that the nest would hatch in about 2 days (Kossack 1950, Cooper 1978). We used the presence of egg pipping, evident by a star-shaped crack on the surface of the shell, as an indication that the nest would hatch within one day.

We revisited all treatment clutches ≤ 18 hrs following containment for hatch. We recorded the number of hatched goslings within each clutch on their hatch date. We removed goslings as well as pipped and unpipped eggs from the nest bag. We applied

monel size #1005–1 web tags (Alliston 1975) to the center of the outside web of the right foot of hatchlings and birds within star-pipped eggs, as part of a separate study of gosling survival. NJDFW staff recaptured marked goslings during annual molt banding efforts in late June 2010. This study was conducted under a banding permit from the Bird Banding Laboratory/USGS Patuxent Wildlife Research Center (permit #06460).

We determined the number of eggs that hatched from nests within the control group by either counting the number of 1) goslings within the nest bowl, 2) eggshells with intact membranes in the nest bowl, and/or 3) goslings associated with the adult near the nest.

We calculated mean hatch success and standard error for the treatment and control groups using all nests that were active on the day prior to hatch. Hatch success was defined by the number of goslings that hatched divided by the number of eggs present on the day prior to hatch. We assumed that variation in natural hatchability was similar across both the treatment and control groups. We used a two-tailed Student's t-test ($\alpha = 0.05$) to test for differences between the mean hatch success of the treatment and control groups. We also calculated the proportion of hatchlings that were successfully marked within each brood for the treatment and control groups, and tested for differences between the proportions of the two groups using a one-tailed Student's t-test ($\alpha = 0.025$).

Results

We located and monitored 222 Canada goose nests in 2010. We assigned 110 nests to the treatment group and 111 nests to the control group. Seventy one nests failed during the incubation period prior to hatch. On the day prior to hatch, 72 nests remained in the

treatment group, and 79 nests remained in the control group. The average clutch size was 5.17 eggs ($SE \pm 0.12$ eggs).

The mean hatch success of the treatment group was 0.803 ($SE \pm 0.02$), while the mean hatch success of the control group was 0.834 ($SE \pm 0.032$). There was no significant difference between the mean hatch success of nests contained with clutch containment bags and the control group ($t_{148} = 0.794$, $P = 0.428$). Six hundred thirty-one goslings hatched from 151 nests; and of those, we web tagged 555 goslings for use in a separate gosling survival study. Seven goslings were found dead in nest bags from the treatment group, and six goslings were found dead in nest bowls from the control group. We were unable to distinguish natural deaths from those caused by the clutch containment bag in the field.

The average proportion of hatchlings marked within broods in the treatment group was 0.897 ($SE \pm 0.042$). The average proportion of hatchlings marked within broods in the control group was 0.824 ($SE \pm 0.040$). There was no significant difference between the proportion of marked hatchlings within the treatment and control groups ($t_{148} = 1.228$, $P = 0.111$).

Discussion

We did not find a significant difference between the hatch success of the treatment and control groups. The mean hatch success of nests within the treatment and control groups were similar to those of other AFRP Canada goose nesting studies (Rummel 1979, Huskey et al. 1998b, Conover 1998, Peters 2003). We did not mark a significantly larger proportion of hatchlings whose clutches were contained. However, due to the increased effort involved in visiting nests early in the day at each location, the overall mean

proportion of hatchlings marked within each brood was very high (0.855 ± 0.029 (SE)). In comparison with nesting locations in the sub-arctic, our study area included locations that were easily accessible for multiple nest visits with relatively little travel required. For gosling survival studies of sub-arctic nesting geese, this technique may offer researchers additional time during the hatch period to be present for marking entire broods.

We observed that incubating females in both the treatment and control groups spent time tending the contained clutch (i.e. rotating eggs, arranging down and nest materials) immediately after returning to the nest. We observed no behavioral difference in adults between control and treatment groups. However, in one instance, a contained clutch of unhatched eggs was found floating in the water adjacent to a nest on the edge of a pond. Given that the clutch was contained within the bag as a unit, the clutch apparently fell into the water when the female was tending the nest. Had this clutch not been contained within a bag, perhaps only a single egg would have fallen into the water.

This methodology successfully ensures that sampling efforts will measure full clutches with little to no harm to hatchlings. Although containing the clutch during hatch has the potential to allow for an increased sample size, we did not observe a difference in sample size using this technique. Nonetheless, we urge prudent caution to minimize potential biases with administering this technique. First, we applied bags during the later part of the day prior to hatch, and we removed them following morning to ensure that hatched goslings were not enclosed during the heat of the day. This issue may not be critical for contained clutches in sub-arctic conditions. Second, attention must be directed toward ensuring that all nest bags are removed on the hatch date, and that no unhatched eggs are left contained. This will avoid the rare occurrence of a late-hatching bird being

contained within a nest bag on a warm day after their brood has left the nest site. Third, although newly hatched goslings are not able to walk, ample space must be given for movement of hatchlings immediately following hatch. Fourth, when studies are conducted on public lands, there is the potential that members of the public will observe this technique in practice and not understand its purpose or that it is not causing undue harm. As a result, signage may be necessary in nesting areas that are open to the public.

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Figure A4.1. Eleven locations in New Jersey used to evaluate the effect of a nest containment bag on hatch success of Atlantic Flyway Resident Population Canada geese during 2010 breeding season.

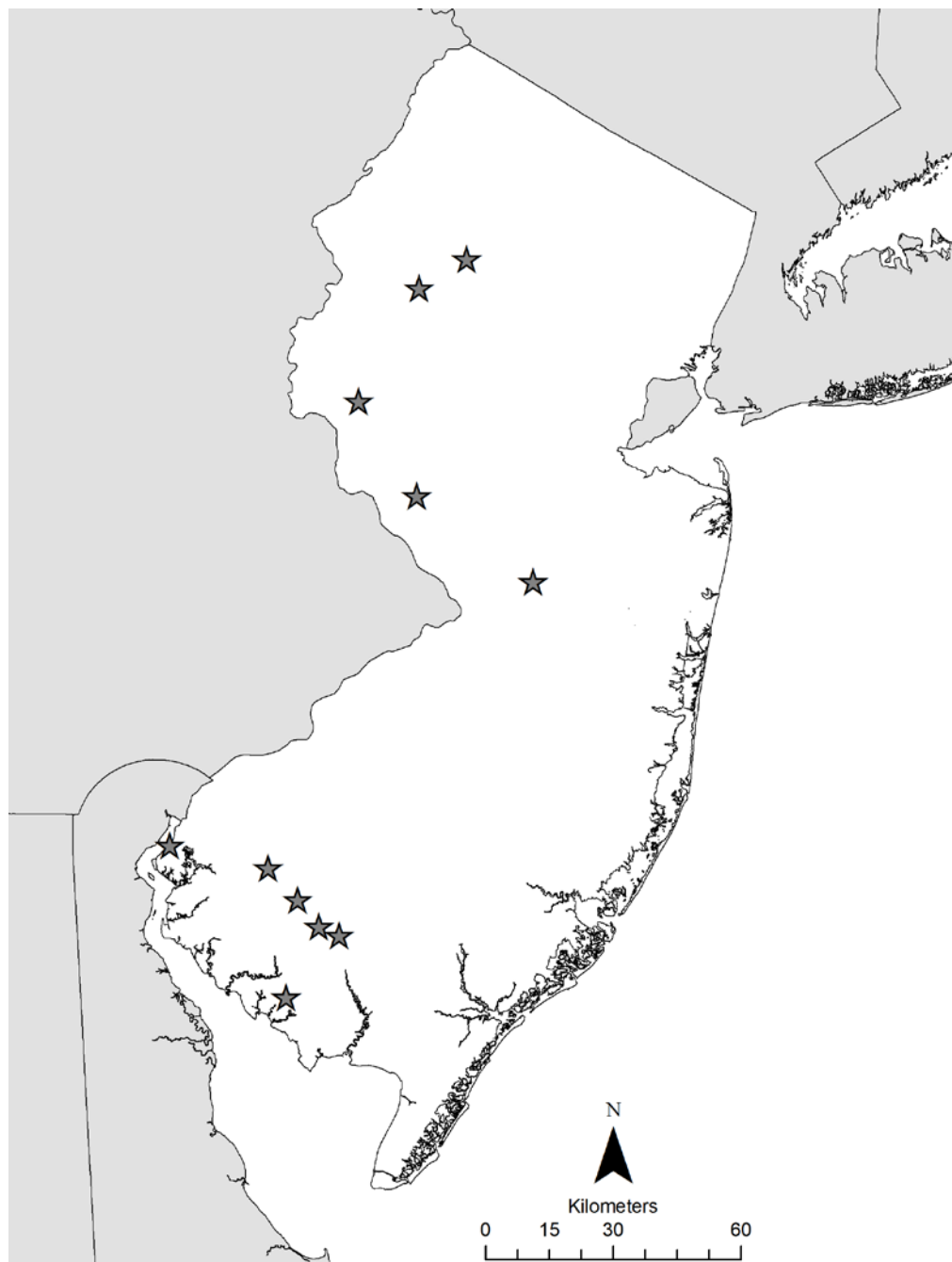


Figure A4.2. (a) Clutch containment bag with hatchling and 3 pipping eggs used during 2010 resident Canada goose nesting season in New Jersey. (b) Nest site with adult protecting clutch and young during hatch period.

(a)



(b)

