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Spatially-explicit land use effects on nesting of Atlantic Flyway resident Canada geese in New Jersey

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Atlantic Flyway resident population (AFRP) Canada geese *Branta canadensis* in New Jersey, USA, have grown dramatically during the last thirty years and are considered as overabundant in many areas. 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 must be taken into account in managing the population. We identified the site and landscape spatial scale extents at which land use features influenced nest site selection and nest success. Nest searches were conducted throughout the State during 2009–2010, and 309 nests were monitored through hatch to determine their fates. We ran a spatial correlation analysis of land use composition to identify spatial scale extents at which geese most considerably respond to their environment for nest site selection and nest success. All significant spatial scale extents were at or below 2.25 km for the five classified land use types. We emphasize that habitat-goose associations in densely urban areas were strongest at extents <1 km, while rural and natural areas were strongest at extents >1 km. Geese responded to human-dominated land uses at a smaller spatial scale extent than land uses with low human density. The strength of all nest-land use univariate relationships was low; however, our primary objective was to identify the scales extent at which geese associate with land use, rather than the intensity. We encourage managers to consider these scale-dependent associations in identifying important habitat variables in multivariate models; and if population control of AFRP Canada geese is of primary interest, then focusing on local habitat management will most likely have the largest influence in managing this population.

New Jersey is the most densely human-populated state in the United States of America, with more than 460 people km^{-2} in 2009 (United States Census Bureau 2011). The resultant demand for housing, recreational areas, roads and commercial areas has created increased urban and suburban nesting and brood rearing habitat for Atlantic Flyway resident population (AFRP) Canada geese *Branta canadensis* (United States Fish and Wildlife Service 2002). A secondary impact of high human density is a limited amount of land suitable for hunter harvest, limiting the major mortality factor of fledged AFRP Canada geese (Smith et al. 1999, Atlantic Flyway Council 2011). Urbanization may have contributed to a recent increase of AFRP Canada geese to approximately 106 000 birds in 2000 (CV $\pm$ 20 193 birds). The population has since decreased to an estimated population of about 80 000 in 2012 (New Jersey Division of Fish and Wildlife unpubl.). This population is still considered overabundant, and population control is a major management objective (Atlantic Flyway Council 2011).

To inform management, it is critical that researchers understand which features of anthropogenic habitat favor population growth of AFRP Canada geese. Pastor et al. (1997) argued that to understand relationships between habitat and productivity and inform population control efforts, managers need to identify at which spatial scale extent, from site to landscape, wildlife most significantly interact with their environment (Bissonette 2003). To date, several studies have assessed which spatially-explicit landscape variables influenced nest locations and nesting success of waterbirds (e.g. sandhill cranes *Grus canadensis*, Baker et al. 1995, mallards *Anas platyrhynchos*, Zicus et al. 2006, common loons *Gavia immer*, Kuhn et al. 2011).

Although Messmer (2010) found that productivity of AFRP Canada geese in Ontario was influenced by habitat associations at varying spatial scales, previous research has primarily focused on the effects of simple habitat attributes of Canada goose nesting ecology. For example, nest survival was reported to be positively influenced by increased urban development due to removal of forested and other natural areas, filling of natural water bodies, installation of sod lawns and man-made ponds with drainage, and reduced predator numbers (Hilley 1976, Ankney 1996, Gosser et al. 1997, Owen et al. 1998, Smith et al. 1999, Paine et al. 2003). In contrast, increased nest success in urban areas may be dampened by human-caused nest destruction. Natural lands such as forest, shrub and wetlands may be negatively correlated with nest success due to increased terrestrial predator habitat and flooding in coastal areas (Wolf 1955, Batt et al. 1992). To better inform population management decisions, this study investigates the direction and magnitude of both site and multiple landscape scale habitat associations on nest site selection and nest success of AFRP Canada geese in New Jersey.

Methods

Nest searching

We searched for nests of Canada geese on 250 randomly located 1-km^2 plots within New Jersey, USA, from 15 March–10 May 2009–2010. The 250-plot study area was held constant across years, and 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, 2000). We established three search criteria to prioritize the timing of plot searches based on data from three prior AFBWS years (2006–2008). Of the 250 plots, biologists had observed Canada goose pairs or nests on 181 plots during at least one of the three prior AFBWS years (2006–2008), and were searched three times during the laying and incubation period. The chronology of nest searches was conducted in accordance with nest initiation data from prior survey years. The 69 plots where Canada geese had not historically been observed were searched once by NJDFW biologists during the annual AFBWS from 15 April–10 May. We assume that all nests were discovered within plots, as biologists searched plots in their entirety on numerous occasions during the nesting season. We recorded the location and monitored weekly any discovered nests through hatch to determine whether the nests were successful. We defined nest success as a binary variable of fate by the hatch of at least one egg within the clutch (Mayfield 1961). We determined nest success 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 adults near the nest (Petersen 1990). We assumed that the use of apparent nest success is representative of actual nest success across the population. We defined the selected nest site as the location in which a nest was initiated within a study plot. The percent composition of habitat types within a defined spatial scale extent around a nest site were used to determine habitat–nest site selection relationships. We assumed that the habitat types available within the plot were representative of the options available to Canada geese during the process of nest site selection.

Habitat classifications

To explain how nest site selection and nest success could have been influenced by site and landscape scale land use/land cover (LULC) variables, we quantified habitat available to Canada geese at multiple spatial scale extents. To do so, we measured the composition of LULC types within a defined area around a nest. We regrouped 84 classifications within the 2007 New Jersey land use/land cover (New Jersey Office of Information Technology 2010) dataset into six land use/land cover types, including commercial/industrial (COM), urban/suburban (URB), rural residential (RUR), agricultural (AGR), natural (NAT) and water (WAT). This regrouping was performed to minimize the number of explanatory variables but allow for biological reasoning behind each correlation analysis. Gradients of urbanization were captured within this classification, with highly dense metropolitan residential and industrial development isolated from low-density rural housing developments. Additionally, since agricultural land uses offer premium wintering habitat for this population (Atlantic Flyway Council 2011), relationships between breeding and non-breeding habitats could be important.

To quantify relationships between site scale LULC composition and both nest site selection and nest success, we measured the percentage of the six LULC classifications within a 250 m buffer (Messmer 2010) around the center of each plot and nest location using geographic information system (GIS) software. To determine the appropriate range of landscape scale extents for LULC associations with nest site selection, we ran preliminary correlation analyses testing spatial scale extents from 0.25 km – 16 km radius circles centered on the nest site, using increments of 0.25 km. Results revealed that LULC was most strongly associated with nest site selection and nest success at distances below 3 km from nest sites for all LULC types. We then measured the percentage of LULC types within spatial scales ranging from a radius of 0.5 km – 3 km at 0.25 m increments around each nest location.

We minimized possible site scale effects on the landscape scale analyses by removing the 0.25 km radius area from each landscape scale extent (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. In 15 cases, nests with landscape scale extents expanding into bordering states were removed from the dataset.

To determine the spatial scale extent/s that most influenced nest site selection and nest success, we performed a correlation analysis among the six LULC at landscape scale extents from 0.25–3 km and the presence of a nest within a plot, as well as the success of a nest (PROC CORR, SAS). We 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 (Roland and Taylor 1997, Holland et al. 2004, 2005). The correlation of the proportion of LULC types to nest site selection and nest success resulted in r-values for each habitat category at all tested spatial scales. We 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 et al. 2011). The smallest radius within that range was used as the scale for determining the landscape scale extent that was most influential.

Results

During 15 March–10 May 2009–2010, we surveyed 250 plots, and determined the fate of 309 Canada goose nests within the study area. Eighty-two out of 250 plots had ≥ one nest. During 2009, 80 nests (51.6%) out of 155 nests were successful. During 2010, 82 nests (53.2%) out of 154 nests were successful. For nest site selection, selected spatial scales for each LULC type ranged from 0.5–1 km (Fig. 1). For nest success, the spatial scales for each LULC type ranged from 0.5–2.25 km.

Commercial/industrial

The proportion of commercial/industrial land use (COM) ranged from 7.2–8.3% within the spatial scales surrounding all study plot centers (nest site selection), and 8.7–11.2% surrounding successful nests (Table 1). The variation in percentages is the range when all spatial scales are considered. COM was positively correlated with nest site selection at the site level (0.25 km, $r = 0.285$; Fig. 1a). At a landscape scale larger than 0.25 km, COM was most correlated at a 0.5 km scale ($r = 0.262$), 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. 1b) and landscape scale of 0.5 km ($r = 0.119$) and then decreased toward 0 as the spatial scale increased beyond 1 km.

Urban/suburban

The proportion of urban/suburban residential land use (URB) ranged from 10.0–12.6% within the spatial scales surrounding all study plot centers and 9.7–12.6% surrounding successful nests. URB land use was positively correlated with nest site selection at the site level (0.25 km, $r = 0.286$; Fig. 1c), which, in turn, positively affected nest success ($r = 0.062$, Fig. 1d). At a landscape scale, nest site selection was positively correlated with URB within 0.5 km ($r = 0.215$). However, Canada geese nest site selection was less influenced by increasing amounts of URB habitat at broader scales. Nest success was most correlated at 0.75–1 km scales ($r = 0.082$–0.084) and correlations with habitat availability decreased toward 0 as the spatial scale increased beyond this point.

Rural residential

The proportion of rural residential land use (RUR) ranged from 11.1–12.2% for nest site selection and from 11.8– 12.8% surrounding successful nests (Table 1). RUR was positively correlated with nest site selection at the site level (0.25 km, $r = 0.106$; Fig. 1e). At a landscape scale, nest site selection was positively correlated with RUR at the 0.75 km 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 RUR at the site level ($r = 0.027$); however, correlations improved

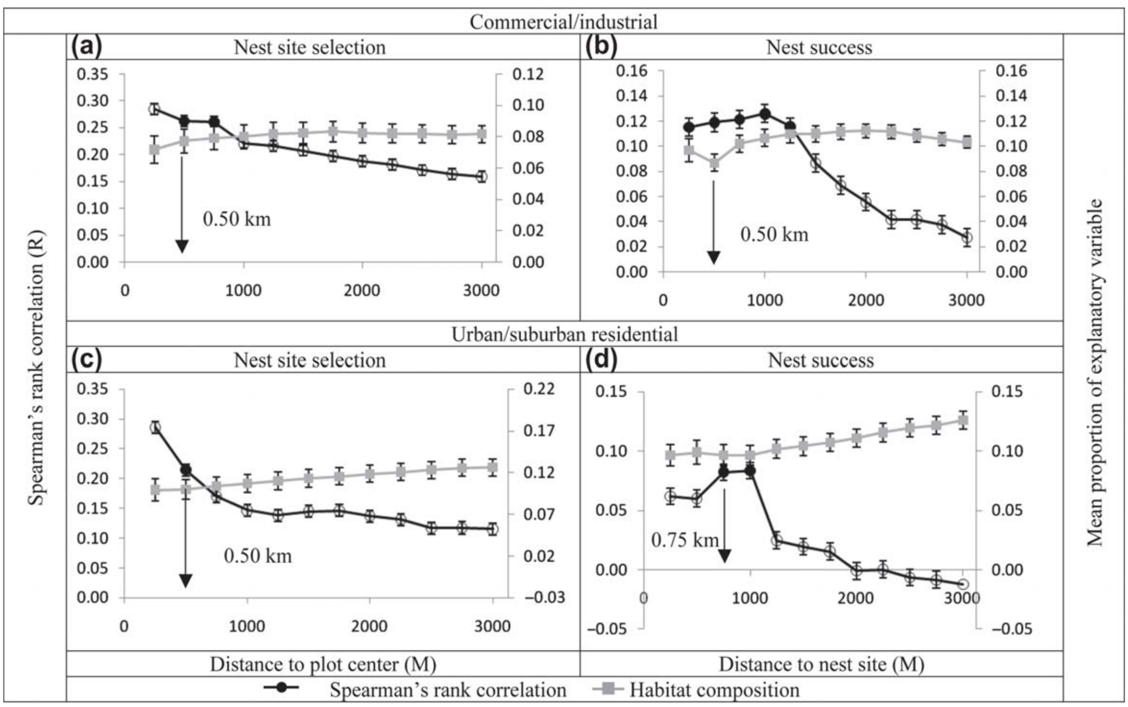

Figure 1. Mean ± standard error of Spearman's rank correlation coefficient between explanatory habitat variables measured within buffers of 0.25 to 3 km in 250 m increments around each plot center and nest site, and Canada goose nest site selection and nest success in New Jersey, USA, 2009–2010. Mean proportion of habitat variables measured at each spatial scale are depicted in grey. Black points indicate distances statistically similar to the spatial extent distance with the strongest correlation.

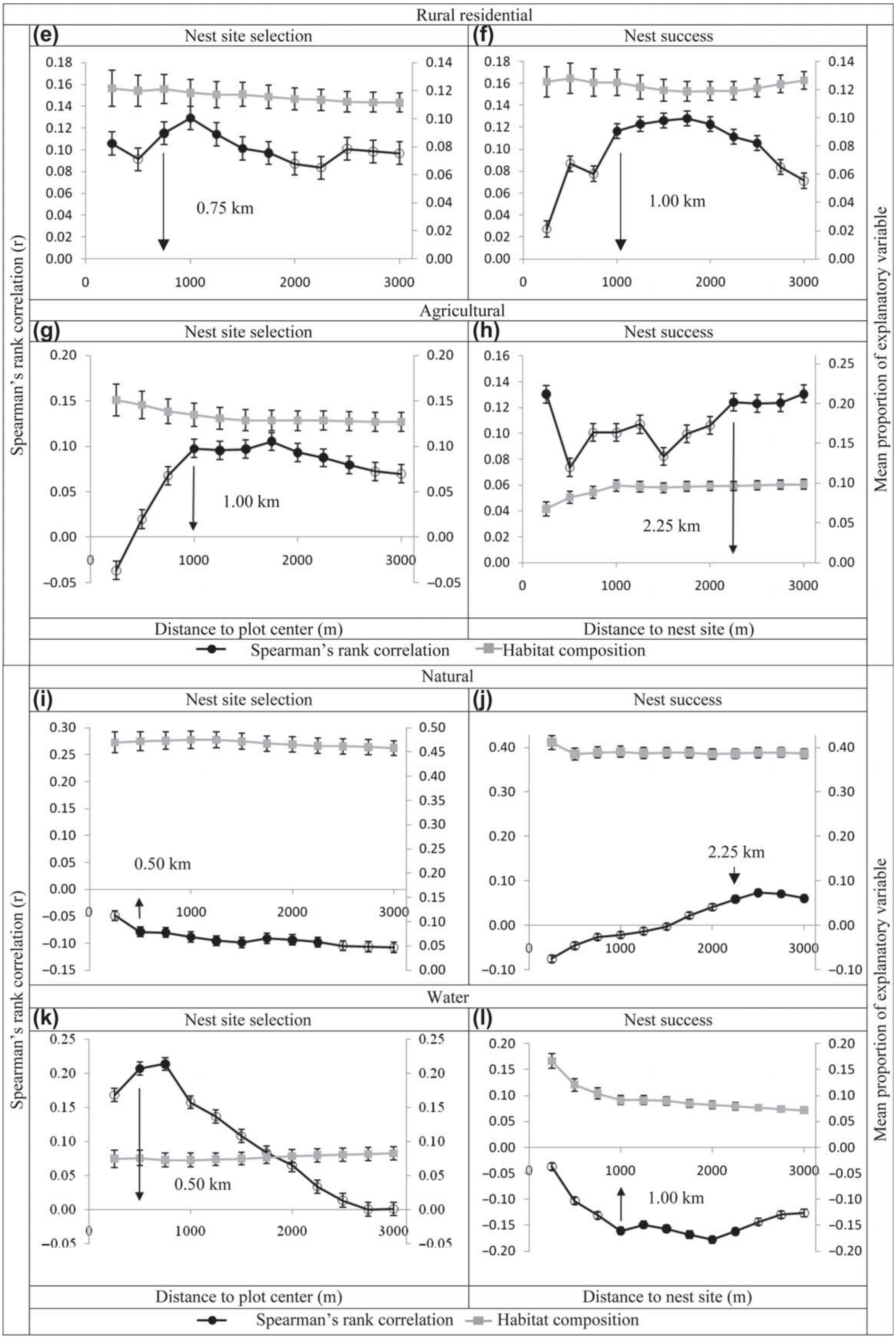

Figure 1. (Continued).

Table 1. Proportions of land use/land cover classifications found within spatial scale extents surrounding plot center (nest site selection) and nest location (nest success). Spatial scales ranged from 0.25–3 km.

	Nest site selection		Nest success	
LULC Type	Proportion	Spatial extent, (R)	Proportion	Spatial extent, (R)
COM	7.2–8.3%	0.50 km, $r = 0.285$	8.7–11.2%	0.50 km, $r = 0.262$
URB	10.0–12.6%	0.50 km, $r = 0.286$	9.7–12.6%	0.75 km, $r = 0.082$
RUR	11.1–12.2%	0.75 km, r = 0.115	11.8–12.8%	1.00 km, $r = 0.116$
AGR	12.7–15.1%	1.00 km, $r = -0.037$	6.8–9.9%	2.25 km, $r = 0.130$
NAT	45.8–47.5%	0.50 km, $r = -0.079$	38.5–41.1%	2.25 km, $r = -0.076$
WAT	7.3–8.3%	0.50 km, $r = 0.208$	7.2–16.7%	1.00 km, $r = -0.161$

substantially at the landscape scale of 1 km scales ($r = 0.116$; Fig. 1f).

Agricultural

The proportion of agricultural land use (AGR) ranged from 12.7–15.1% for nest site selection and 6.8–9.9% surrounding successful nests (Table 1). AGR was negatively correlated with nest site selection a site scale (0.25 km, $r = -0.037$; Fig. 1g). However, at increasing landscape scales, the presence of AGR improved nest site selection and was most correlated with a positive nest site selection when available within a 1 km 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 AGR at the site scale, nest success was positive ($r = 0.130$, Fig. 1h) and remained at a similar correlation out to a landscape scale of 2.25 km ($r = 0.124$).

Natural

The proportion of natural land use (NAT) ranged from 45.8–47.5% for nest site selection and between 38.5–41.1% surrounding successful nests (Table 1). NAT was negatively correlated with nest site selection both at the site scale (0.25 km, $r = -0.049$; Fig. 1i) 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. 1j), NAT became positively correlated with nest success when present at increasingly larger spatial scales peaking at 2.25–2.5 km scale ($r = 0.059$–0.073).

Water

Lastly, the proportion of water (WAT) ranged from 7.3–8.3% for nest site selection and from 7.2–16.7% surrounding successful nests (Table 1). WAT was positively correlated with nest site selection at the site scale (0.25 km, $r = 0.169$; Fig. 1k), and while the correlation with WAT improved at the 0.5–1 km scale ($r = 0.208$), it decreased toward 0 as spatial scales increased beyond this point. Despite the positive correlation with WAT for nest site selection, nest success was negatively correlated with the percent water at both the site scale ($r = -0.037$, Fig. 1l) and increasingly at a landscape scale of 1 km ($r = -0.161$). The correlation coefficient remained between -0.126 and -0.178 beyond 1 km through 3 km.

Discussion

The investigation of habitat–animal associations relies on managers' ability to understand the scale at which wildlife respond to and interact with their environment (Pastor et al. 1997). The extent of spatial scales may vary drastically among species and among populations, particularly with variation in mobility, resource requirements, and population size (Pastor et al. 1997). A generalist species with few resource requirements influencing the selection of a nest site (e.g. a resident Canada goose), 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. 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.

Decisions made by a nesting pair of geese are likely influenced by an array of variables, including landscape scale attributes, site scale characteristics such as the presence of water corridors or increased visibility to defend against predators, biological 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 commercial/industrial and urban/suburban residential land uses. Our results also support the idea 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 km^2 (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 are more variable in structure and appearance (such as commercial/industrial and urban residential were related to nest success on a smaller scale; 0.5 km–0.75 km) than that of land uses that were generally more homogenous (agricultural and natural areas; 2.25 km). Rural residential land use was related to nest success at a moderate scale (1 km); areas in which variation in structure and appearance are low to moderate.

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 due to the availability of suitable nesting habitat, 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. During this study, we identified 21 nests with oiled, shaken or punctured eggs. A key benefit of nesting in commercial/industrial areas is the continual growth, mowing and fertilizing of lawns, making available key nutrients for developing goslings during brood rearing (Batt et al. 1992). 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 (Botelho and Arrowood 1996). Additionally, limited urban drainage during spring storms may have influenced the negative association of urban areas with nest success.

Rural residential land use offers many attributes of an ideal nest site for resident geese (e.g. food, water, shelter, reduced predator community) at multiple spatial scales. Conversely, the Nest and Egg Depredation Order (Federal Regulation 50 CFR 21.50) allows private landowners to control nests on their property, a technique that 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 reproductive control during the nesting period.

Natural lands have the potential to offer increased habitat for both goose nesting and predator foraging. Consistent with prior literature, nest success was lower on natural lands in comparison to urban areas (Smith et al. 1999). The selection of nest sites was consistently negatively related to the proportion of natural land across all scales, which may be evidence that geese are adaptively selecting less natural nesting habitats in order to increase their likelihood of successful reproduction. Bowman and Harris (1980) suggest that nesting success is reduced in habitats where spatial heterogeneity is decreased (e.g. transitioning to uniform natural lands), due to increased 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 the proportion of water around a nest site was inversely related to nest success at all examined spatial scales. Large-scale effects of water such as heavy precipitation during April and May, as well as spring tides, may cause flooding in wetland habitats. 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 and nest success beyond a site scale, as seen in this study. Although it has been noted in prior literature that urban areas are associated with increased goose use during the breeding season (Gosser et al. 1997, Atlantic Flyway Council 2011), heavily urbanized areas may lack the resources necessary for producing young. Urban areas may also be more prone to flooding, given the high percentage of surfaces with impermeable cover. Commercial/industrial and urban residential areas vary widely in the structure and utility for Canada goose habitat, and influence both nest site selection and nest success on a smaller scale. Conversely, agricultural and natural areas, such as forests and marshland, are often more homogeneous in structure, and influence nest site selection decisions on a larger scale.

We suggest that managers utilize spatial scales < 3 km in identifying the effect of landscape-scale habitat variables on nest site selection and nest success, and further employ smaller scales in interpreting variation among urban-dominated landscapes. Although strong univariate land use–nest relationships were not identified, urbanized land uses are likely to have important indirect effects or multivariate relationships with nest site selection and nest success. Managers are encouraged to consider spatially explicit habitat–wildlife associations, and focusing management at the local scale for urban residential and commercial/industrial areas will most likely have the largest influence.

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