POPULATION DYNAMICS AND OCCUPANCY PATTERNS OF EASTERN SCREECH OWLS (*MEGASCOPS ASIO*) IN NEW YORK CITY PARKS AND ADJACENT SUBURBS

by

CHRISTOPHER M. NAGY

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Robert Rockwell

Date
Chair of Examining Committee

Laurel Eckhardt

Date
Executive Officer

Robert Rockwell
Rob DeSalle
Jason Munshi-South
Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

Abstract

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by

Christopher M. Nagy

Adviser: Robert Rockwell

Eastern screech owls (*Megascops asio*) are one of the few raptor species that permanently reside in New York City (NYC). To better inform management of this charismatic species in urban parks, I sought to determine the present status and future viability of existing screech owl populations in NYC and identify potential landscape characteristics that affect park occupancy by screech owls. Using captive, non-releasable owls and isolated free-living owls, I developed a method of identifying individual screech owls via vocalization analysis. Using call-broadcast surveys and subsequent recording of owl responses, I gathered capture-recapture histories of urban owls in three NYC parks and one comparison nature preserve, the Mianus River Gorge Preserve (MRGP), a rural/suburban nature preserve in Bedford, NY. These histories were used to estimate abundance and survival rate in each of the parks. I then projected simulated populations using my estimated adult survival and previously published yearling survival and reproductive rates. I built my projection model to include density dependence based on park area, realistic sex ratio fluctuations, and periodic drops in survival rate due to hypothetical environmental events. Survival in urban parks was 0.98 – 1.0, much greater than in the MRGP, 0.57 ± 0.15. Despite the high adult survival, populations in parks could be extirpated within 10 - 20 years by severe drops in survival rate (e.g., extreme winters, storms, or secondary poisoning)

if such conditions occurred more often than once every ten years or if parks were smaller than $1.0km^2$.

In 2008 and 2009, my colleagues and I conducted a citizen science-based study on screech owl occupancy patterns across three counties adjacent to NYC: Westchester and Putnam, NY, and Fairfield, CT. Volunteers conducted call-broadcast surveys on their own properties and sent my colleagues and me the results in 2008 and 2009. Occupancy and detection were modeled as functions of the amount of forest cover and impervious surface cover at each survey point. These models were validated against an independent dataset collected by myself and other trained scientists. Validated models indicated a negative association between occupancy and percent forest cover or, similarly, a positive association with percent impervious cover. Both the citizen science and the systematic datasets supported similar owl-habitat patterns of higher occupancy probabilities in developed areas compared to rural.

The above patterns described eastern screech owl habitat use in rural and suburban areas outside of NYC. I hypothesized that at some point urbanization would become too intense for owls to tolerate, and they would be primarily relegated to protected greenspaces in extremely urbanized cities, as I observed in NYC. In 2010, I surveyed 13 additional parks in NYC and the more urban southern sections of Westchester to characterize occupancy patterns in highly urban areas. I used similar landscape measurements as in the citizen science study, only these measurements were taken across the entire park. Occupancy appeared to decline sharply if the percent impervious cover surrounding a park rose above 50 – 60%. I interpreted this pattern as evidence that high urbanization around a park acts primarily as a barrier to immigration. It is also possible that high urbanization around a park leads to higher mortality from vehicles.

In terms of management, my work has indicated that in large parks (e.g., >1km^2), extinction probability is relatively low, but parks larger than 3km^2 may be less suitable if big parks allow the establishment of larger raptors such as barred (*Strix varia*) or great horned owls (*Bubo virginianus*). Managers can enhance population persistence by increasing the amount of available habitat via habitat restoration and reforesting or re-meadowing developed but unused parks (e.g., large lawns and paved areas) and increasing over-winter survival and reproductive rates by installing nest boxes. However, frequent chance events can extirpate any park-bound population, and thus managers and city planners should also look to enhance the probability of dispersal and recolonization via corridors or reducing the general level of urbanization around protected parks.

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Dedication

It may be cliché, but this dissertation is dedicated to the owls…Guys, sorry for all the noise.

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Chapter 1: Introduction

As more of the landscape is modified by human development, it has become clear that in addition to preserving pristine sites, conservation biologists must work to understand how developed areas can support diverse biological communities as well. In many cases, this requires management of certain species and some degree of modification of the developed location to facilitate the persistence of native species. Before management can proceed, a thorough understanding of the dynamics of the target populations must be achieved. In truly urban areas, scattered greenspaces such as parks, cemeteries, and community gardens may offer the only suitable habitat scattered within a matrix of poor or unsuitable urban space. In urban areas, raptors are often the most abundant predator species (Gehlbach 1994b, Minor et al. 1993, Stout et al. 2006), partly due to their mobility, inconspicuousness, and the high prey abundances (rodents, small birds, and insects) often found in urban areas. In addition to the ecological functions these predators perform, urban raptors provide aesthetic, recreational, and educational benefits to the general public, making management of these species valuable both biologically and socially. Research on these species and their unique dynamics in an urban landscape is needed to direct management efforts.

Eastern screech owls are an excellent example of an “urban adapter” species (McKinney 2002, Shochat et al. 2006). Multiple studies have shown that this species has greater survival and reproductive rates in (Gehlbach 1994) and more often occupies (Artuso 2009) moderately developed “suburban” areas than contiguous, undisturbed forest. The species is usually associated with young-to-middle aged hardwood forests and is often termed an “edge predator” due to its use of forest-meadow and riparian areas for foraging (Sparks et al. 1994, Artuso 2009).

It is thought that the semi-developed, fragmented yet somewhat-forested characteristics of suburbia allow for greater food abundance and/or concentration, less competition and predation by larger raptors, and a more stable climate than undisturbed forest (Gehlbach 1994 and 1995).

However, eastern screech owls have rarely been studied in extremely urbanized areas such as New York City, where population density can be >20,000 people/km^2 (U.S. Census Bureau 2010). In such areas, screech owls appear to be confined to wooded parks. Advantages similar to suburban areas could exist in truly urban areas (e.g., greater rodent populations, lack of larger predators) but the demographic risks brought on by small, isolated populations could outweigh the advantages. I sought to determine if existing eastern screech owl populations were stable and had a reasonable short-term (i.e., 10 – 50 years) chance of persisting in NYC. I also wanted to characterize those urban parks that did contain owls compared to those that did not, i.e., what landscape characteristics seem to predict park occupancy by screech owls.

In Chapter 2, I outline the development of a method that can discriminate individual screech owls by their main courtship and territorial call. In Chapter 3, I use this technique to build recapture histories of owls in three NYC Parks and one suburban preserve from recordings of wild owls elicited via call-broadcast surveys. From these, I use mark-recapture analysis to estimate detection rate, annual abundance, and adult survival. These vital rates are used to build a projection model that incorporates density dependence based on park area, sex ratio variability, and periodic fluctuations in survival. Based on multiple simulations, I draw conclusions about population persistence and the minimum viable area needed to minimize extinction risk.

In Chapters 3 and 4 I use a relatively new method of modeling presence-absence data to find what landscape characteristics seem to predict where one might find screech owls. This method, known as occupancy-detection analysis (MacKenzie 2006), models site occupancy while taking the method-specific detection rate into account. This allows the researcher to correct for false negatives (not finding the animal even though it is really there). Models based on raw presence-absence data often model patterns of detection rather than the true distribution of the animal.

Chapter 3 focuses on a three-county wide suburban region north of NYC. To sample such a large area, my colleagues and I employed a citizen-science study. We enlisted and trained volunteers to survey their own property for eastern screech owls using call-broadcast surveys identical to the ones I used myself. In Chapter 4, I describe a study I performed across 13 additional NYC parks and three Westchester County parks to examine occupancy patterns in highly urbanized areas. Both of these studies helped to characterize eastern screech owls' response to the full spectrum of urbanization.

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Chapter 2: Identification of individual Eastern Screech-Owls (*Megascops asio*) via vocalization analysis

Abstract

To more easily and non-invasively monitor urban Eastern Screech-Owl populations, we developed a method of distinguishing individual owls using their calls. A set of seven variables derived from recordings of “bounce” calls taken from 10 known (either free-ranging birds recorded at a single site on a single night or identifiable captive owls) owls was tested using a model-based clustering analysis (Mclust) as a method of discriminating individual owls. The cluster analysis correctly classified these calls with 98% accuracy. A second set of calls from 9 owls was used to further test the method and properly classified 84% of the calls using the same variables. Four owls were recorded repeatedly from 2008 to 2010 to determine the extent to which calls changed over time; the cluster analysis correctly assigned 89% of the calls to the correct owl regardless of the year the recordings were made. Based on these results, we are confident that the Mclust analysis can be used to reliably and safely estimate abundance and survival of Eastern Screech-Owls within the time frame of a few years and of population sizes <15 owls.

Nagy, C. and R. F. Rockwell. *In press*. Identification of individual Eastern Screech-Owls (*Megascops asio*) via vocalization analysis. Bioacoustics.

Introduction

The Eastern Screech-Owl (*Megascops asio*) is a small raptor that inhabits mixed-hardwood forests in the United States and southern Canada east of the Rocky Mountains. This species can tolerate some human development and can be found in suburban and urban parks, golf courses, and other semi-developed greenspaces (Gehlbach 1995). Screech-Owls are one of the few raptors that can persist in small urban parks (Lynch and Smith 1984, Smith and Gilbert 1984, Gehlbach 1995), and managers would benefit from knowledge about their survival rates and small-scale habitat use in these areas. As part of a larger study on urban Screech-Owls in the New York City (NYC) metropolitan area, we sought to develop a non-invasive method to identify and monitor individual Screech-Owls to estimate abundance and adult survival.

Screech-Owls are difficult to trap and there are concerns regarding the behavioral effects of telemetry (Gehlbach 1994). They have been monitored successfully via nest boxes for long-term studies in Texas (Gehlbach 1994) and Ohio (VanCamp and Henny 1975), but daily sampling of such boxes can be quite time-consuming and when we attempted such a survey in NYC we did not have sufficient success. Screech-Owls defend territories throughout the year, especially from spring through late summer (Ritchison et al. 1988), and like many other owls announce their presence to rivals via vocalizations. They also attract mates and communicate to mates and offspring via frequent vocalizations, and will readily respond to call-broadcast broadcasts (Lynch and Smith 1984, Dorn and Dorn 1994, Bosakowski and Smith 1997). If a method of identifying individual Screech-Owls via vocalization analysis could be developed, then current call surveys could yield mark-recapture data as well as site occupancy information.

Attempts at developing a method to discriminate individuals based on vocalizations has been successful in numerous species of birds (corncrakes (*Crex crex*): Peake et al. 1998; barred owls (*Strix varia*): Freeman 2000; wood owls (*Strix woodfordii*): Delport et al. 2002; great bitterns (*Botaurus stellaris*): Gilbert et al. 2002; western screech-owls (*Megascops kennicottii*): Tripp and Otter 2006; woodcock (*Scolopax rusticola*): Hoodless et al. 2008; willow flycatcher (*Empidonax trailii extimus*): Fernandez-Juricic et al. 2009; summarized by Terry and MacGregor 2002) as well as a few mammals (male fallow deer (*Dama dama*): Reby et al. 1998; swift fox (*Vulpes velox*): Darden et al. 2003; African wild dog (*Lycaon pictus*): Hartig 2005). If a reliable method of discerning individuals based on their vocalizations can be found, researchers can non-invasively monitor otherwise cryptic or difficult-to-sample species, often for a fraction of the cost, effort, and negative effects associated with other methods (Terry et al. 2005, Hoodless et al. 2008, Fernandez-Juricic et al. 2009). To be truly effective, however, the vocalizations must be of consistent form so that a set of variables can be repeatedly measured from them. These variables should exhibit low within- relative to among-individual variation (Terry et al. 2005). In addition, an animal's vocalizations (and derived variables) should ideally stay consistent over time so that individuals can be tracked over many years (Delport et al. 2002, Terry and MacGregor 2002, Terry et al. 2005).

To develop and test a method to census and monitor Screech-Owls with no previous knowledge regarding abundance, we used calls recorded from captive owls housed at rehabilitation clinics and free-living (i.e., wild) owls sampled in disparate locations to build a large set of recordings of "known" individual owls. We measured a number of variables from the "bounce" call (see Cavanagh and Ritchison 1987, Gehlbach 1995) and assessed their usefulness as individual markers. Using a model-based cluster analysis, we classified the recordings from half of the owls, and then re-tested the analysis on the other half using the same variables. Third, we clustered the recordings from a subset of owls that were recorded over the course of two or three years to determine the extent of change in calls over time.

Methods

Eastern Screech-Owls are typically thought to have two calls that are used as broadcast vocalizations. The “whinny” call is a territorial call and general alarm call (Cavanagh and Ritchison 1987, Gehlbach 1994) and can be quite variable even within a single bout (Figure 1A). The “bounce” call generally consists of a series of quickly repeated notes on a steady pitch. It is also used as a territorial call as well as communication between mates and between parents and offspring (Cavanagh and Ritchison 1987, Gehlbach 1994). Thus, we thought the bounce call would be the most likely to contain information that was individual-specific, as also recommended by Cavanagh and Ritchison (1987). While gathering and analyzing our recordings, we found that there appeared to be two forms of the bounce call: a “long bounce” which could range from approximately 5 sec to as long as 45 sec and was delivered at a steady note rate and frequency (Figure 1B), and a “short bounce” (Figure 1C) which was approximately 2 – 4sec long and had three distinct phases where the note length and the time between each note changed. The first and third phases had substantially faster note rates than the middle (second) phase, and the phases could be easily identified visually on a spectrogram and/or by listening to the call at 0.4 speed. Occasionally the frequency of the short bounce changed slightly from phase to phase.

In our experience, the long bounce was used less often than the short bounce in response to broadcast surveys. If an owl was heard calling independently (i.e., not in response to our broadcasts) it always vocalized long bounces. When an owl used long bounces in response to our broadcasts, in most cases they eventually switched to a short bounce. Also, when we observed owls calling to fledglings in the late spring, only short bounces were used. Thus, because the different phases of the short bounce would allow more variables and more variability to be measured, and because of the use of the short bounce in parent-offspring communication and in response to our broadcasts, we thought the short bounce had the best potential as an individual identifier and as a tool to monitor Screech-Owls via call-broadcast surveys.

Three sets of Eastern Screech-Owls were recorded during this study. The first set of ten owls was recorded between April and December 2008 and was used for the initial model development ("build set"). Six of these were free-living owls recorded at parks and preserves in New York State: Mianus River Gorge Preserve, Bedford; Ward Pound Ridge, Pound Ridge; Harriman State Park, Rockland and Orange Counties; and Saxon Woods Park, White Plains. In these cases we only used recordings from one owl at each site or recordings from two owls that were recorded simultaneously to ensure that each free-living owl was in fact a separate individual. The remaining four owls were permanent captive birds at rehabilitation centers in New York, New Jersey, and Pennsylvania and thus could be identified. The second set of nine owls ("test set") was recorded in 2008 and 2009 to test the method on independent recordings. Two of the captive owls in the build set were re-recorded three months later in the same season and used in the test set. The six free-living owls in the test set were recorded at the Mianus River Gorge Preserve and Riverdale, Van Cortland, and Inwood Parks, NYC. In addition, we were able to record four owls repeatedly from 2008 – 2010 to determine if owls' calls changed across years ("multi-year set"). One of these, a free-living owl, was recorded in June 2008, April 2009, and June 2010. We were reasonably certain that this owl was a single individual because of the reliability at which we could find it and elicit calls at the same location and the distinctive timbre of its calls (this owl was actually the inspiration for investigating this method). Two captive owls were recorded in May 2008, December 2008, December 2009, and one from this pair was recorded again in October 2010 (the second died in early 2010). A final captive owl was recorded in December 2009 and November 2010. Overall, we recorded 265 calls from 17 owls: 10 unique owls were used in the build set, seven unique owls plus new calls from two build set owls were used in the test set, and 2 owls from the build set and 2 owls from the test set were used in the multi-year set.

Captive and free-living owls were recorded after dark using a Sennheiser ME67 shotgun microphone with a foam windscreen and a Marantz PMD 661 digital recorder at a 44.1kHz sampling rate. Vocalizations were elicited via broadcasting a mixture of alternating bounce and whinny calls (from Elliott et al. 1997 and our own field recordings) with a portable CD player. The entire bout was recorded and we used as many calls from each bout as possible. Some calls were censored if background noise (car traffic, airplanes, trains, police sirens, other wildlife, etc.) made it impossible to measure frequency or note variables. We converted all recordings to spectrograms and measured variables on usable short bounce calls using Raven 1.3 (Cornell Lab of Ornithology 2008). The discrete Fourier transform (DFT) used by Raven 1.3 to generate spectrograms from waveforms must be parameterized by a DFT size that determines the number of discrete frequency-amplitude measurements plotted on the spectrogram from the waveform. This value was held constant at the highest value of 65,536 samples (0.732 Hz grid size). Spectrogram transformation also requires a parameter called window size that determines how precisely the spectrogram will measure frequency, i.e., the bandwidth of the frequency filters. Frequency changes less than the chosen bandwidth will not be discernible by the DFT. There is a tradeoff between frequency and time resolution: a small window size will provide high resolution on the temporal scale and low frequency resolution, while a large window will provide high frequency but poor temporal resolution (Charif et al. 2008). We tested three common window sizes with our build dataset to determine which was optimal for discriminating owls. To do this we measured all frequency-based variables from spectrograms built with windows of 256, 512, and 1024 samples. Temporal variables were measured directly on the waveform when possible or on the smallest window size.

We measured the number of notes, duration, center frequency (CF; the frequency that divides the call into two frequency intervals of equal energy), first quartile frequency (1QF; the frequency that divides the call into two intervals that contain 25% and 75% of the energy in the call), third quartile frequency (3QF; the frequency that divides the call into two intervals that contain 75% and 25% of the energy in the call), the interquartile range (the frequency difference between 3QF and 1QF), and the note rate (NR). These measurements were taken on the entire call and each of the three phases of the short bounce. We also calculated the proportion of total notes and the proportion of total duration in each phase of the short bounces (28 variables total). As an initial index of the amount of variation within individuals compared to the variation amongst individuals, we calculated the proportion for individuality coding (PIC; Sokal & Rohlf 1995), which, for a given variable, is the coefficient of variation for the total set of measurements divided by the average of the coefficients of variation for each individual. If the ratio of these CV's is greater than 1, then there is likely more variation amongst individuals than there is within them, and the variable can potentially be used as a predictor of individual identity (Robisson et al. 1993). Within-owl CV was calculated by ($\mathrm{SD}_i/{}_i$) × ($1+1/4n_i$) × (100), where SD_i, ${}_i$, and n_i are the standard deviation, means and number of calls for owl *i*, respectively. Total CV for the entire sample was calculated by (SD/) × 100. PIC was calculated by total CV divided by the average within-owl CV (Sokal & Rohlf 1995, Charrier et al. 2004).

Owls called at approximately 650Hz (center frequencies ranged from 516.4 to 1051.8 Hz across all owls) and 14.5 notes/sec. After eliminating uninformative variables first with PIC and then iteratively to maximize cluster accuracy with the build set, the final clustering variables (regardless of choice of window size) were center frequency (CF), first- and third-quartile frequencies (1QF and 3QF), the note rate of the entire call (NRall), and the note rates for each call phase (NR1, NR2, and NR3). These variables were standardized and entered into a model-based cluster analysis using the Mclust package (Fraley and Raftery 2007) for R. This agglomerative clustering method considers clusters (in this case, individual owls) as multivariate normally distributed components in a mixture, and can estimate the total number of clusters (*G*) by finding the maximum likelihood estimate for *G* given a range of possible clusters. Models are then ranked with Bayesian Information Criterion (BIC) to determine which model best fits the data without overfitting. In addition, models can be parameterized to allow for varying volumes, shapes, and orientations among clusters (Fraley and Raftery 2007, Xu and Wunsch 2009), although this adds additional parameters to the model and thus penalizes the model's BIC. We did not use priors for modeling (Fraley and Raftery 1998, Fraley and Raftery 2007). Since we were interested in a method that would estimate the number of animals from a set of calls without any prior knowledge of *G*, an approach that provided estimates of *G* and associated likelihoods as well as assigning all observations to clusters was necessary. Group membership likelihoods for each observation were also calculated to assign observations (calls) to clusters (owls).

The final set of spectrogram variables was reduced to the set that gave the highest accuracy via Mclust in estimating *G* and assigning individual calls to the correct cluster. When these variables were determined using the build set, the same variables were measured from calls of the test set (using the optimal spectrogram window size in Raven 1.3) and entered into the cluster analysis to determine if the variables performed well on an independent set of recordings (i.e., was our variable set generally applicable, or specific only to data in the build set?). Next, to informally examine the maximum number of owls that could be discriminated, we ran a pooled dataset of the entire build and test sets together (17 owls total). In particular, we were interested in whether the calls from the two owls found in both the build and tests sets would cluster together despite being recorded at different times in the season in this large dataset.

Lastly, the calls from the four owls that were recorded repeatedly across years were entered as a third dataset. In this analysis we constrained the model structure to components with equal shape and volume. Calls that were quite different from each other yet occupied otherwise “sparse” areas of the dataspace (e.g., the high or low extremes) might cluster together if clusters were allowed to be very large or take alternate shapes. Restricting volume and shape ensured that the Mclust analysis would not group calls together that were in reality quite different from each other. The tradeoff for this constraint was to risk over-estimating the number of owls (clusters) by assuming owls have similar variation in calls. If the respective calls from each of these owls clustered together across years, then we could have some confidence that the method could be used to track owls from year to year (at least to a maximum of three years). If this was not the case, the method might still be useful in obtaining a “snapshot” abundance from year to year but could not be used to monitor individual owls (e.g., for annual survival estimation) over long time periods.

Results

The cluster analysis, using data measured from spectrograms with a 256 sample window size, correctly assigned all but 2 of the 88 calls (98%) in the build set to the correct owl using a model with ellipsoidal components of equal volume, shape, and orientation (“EEE” Table 1, Figure 2). The other two spectrogram window sizes did not perform as well: data measured with a window size of 512 samples yielded a BIC-selected best model with the correct number of clusters (10) but used a more complicated cluster structure with variable volume and orientation (“VEV”). Measuring call variables with a window of 1024 samples yielded a BIC-selected best model with 20 clusters (twice as many owls as there actually were). Subsequent measurements were therefore derived from spectrograms with window sizes of 256 samples.

The analysis using the test set selected the same model form of “EEE” but was slightly less accurate (Table 1), with a BIC-selected best model of 10 components (Figure 3). The correct number of owls was 9, not 10; however, the extra cluster was made up of only two observations from two different owls and thus could easily be identified and removed by looking at the classifications of individual calls. The model correctly classified 53 out of 63 calls (84%). When all calls from both sets were pooled together, they were classified correctly with 84% accuracy, again with an “EEE” model structure. The model properly classified the two re-sampled owls that were present in the original build and test sets. However, the method predicted 1 extra cluster (18 owls) than was truly present, similarly to the test set alone.

Of the 114 calls from the 4 owls recorded in 2008 – 2010, 102 were clustered with the correct owl (89%; Table 1 and 2) using a model with ellipsoidal components of consistent shape and volume but variable orientation (“EEV”; Figure 4). The calls from each owl seemed to change only slightly from year to year, with some indication that calls get lower in pitch and somewhat slower with time.

Discussion

The Mclust clustering algorithm performed well, clustering two independent sets of data and discriminating individual owls over a few years. Vocal individuality had been found for a number of owl species (Galeotti and Pavan 1991, Galeotti et al. 1993, Freeman 2000, Delport et al. 2002, Tripp and Otter 2006) and this is not surprising as aural communication and identification would likely be important for nocturnal birds. The classification accuracies of this method (85 – 98%) are comparable to other vocalization-based methods for other species (Freeman 2000, Delport et al. 2002, Gilbert et al. 2002, Tripp and Otter 2006, Hoodless et al. 2008, Fernandez-Juricic et al. 2009). Traditionally, discriminant function analysis has been used to categorize observations into groups, but the groups must be known and fixed (e.g., male/female, known species or subspecies, age class, etc.). For wildlife monitoring or abundance estimation, discriminant function analysis is thus of limited use because, first, the number of groups is often unknown and, second, the groups (individual animals) being measured disappear and appear over time as individuals die or emigrate and are born or immigrate. Using discriminant function analysis, observations from new individuals would be assigned to the most similar starting cluster, not assigned to a new group. Model-based clustering allows for classification of observations as well as maximum likelihood estimation of the number of groups.

We were initially surprised that the smallest spectrogram window size provided the most useful data, as greater window size should provide more precise frequency measurements. However, when we compared measurements taken across the three window sizes, only Q1F and

Q3F appeared to vary substantially (Table 3). As window size increased, the quartile frequency measurements moved closer to the center frequency. This may have caused data points to "constrict" across these two frequency variables and thus pull away from otherwise similar points. This could lead to a greater number of clusters being predicted by the Mclust routine since only the most similar points remained close to each other in multidimensional space. Indeed, the top two models using the largest window size had 20 and 19 clusters (although the 10 cluster "EEE" model had the third best BIC). When the classifications given by the 20-cluster model were examined, the extra clusters were in fact wholly contained within individual owls' bouts.

We were particularly concerned with developing a method that uses variables that can be reliably measured even in sub-optimal recording conditions, namely near roads, major highways and busy NYC flyways. In a field setting, where background noise and inconsistent recording conditions are a reality, measures such as call duration, raw number of notes, or upper harmonics are often unreliable because they can be recorded poorly. A few notes at the beginning or end of a call may not be sufficiently recorded, so call duration, numbers of notes, and measures taken on a specific start or ending note can vary not by individual animal but by recording conditions. Often, animals may not be close enough for the recording equipment to pick up harmonics and other faint characteristics. Note rate, however, requires only a few notes in each component of the call, and a frequency measured across the total duration of the call can be calculated reliably with only the middle and the loudest portion of the call – provided the call generally remains at a steady frequency, as is the case with Screech-Owls' bounce calls. Additionally, the use of energy-based frequency measures available in the Raven software was more accurate – compared to measuring the maximum, middle, and minimum by hand – because small discrepancies in the spectrogram selections of call boundaries do not substantially affect the resulting frequency calculations.

We were able to distinguish 10 and 9 individual owls with >85% accuracy. As more individuals are added to an analysis, one would expect greater and greater amounts of overlap between clusters, and eventually discrimination among individuals would become difficult. When the two datasets were pooled (17 owls total), the method did cluster the two identical owls together across separate bouts, but the overall classification rate dropped below 85% and the number of clusters was over-estimated by 1 owl. This suggests that clusters may begin to overlap excessively around 15 or 16 owls. However, any identification method need only have the capacity to discriminate up to the maximum number of individuals that would reasonably be expected to inhabit an area of interest. For urban parks in NYC with rather small, fragmented woodlands (e.g., the areas of Inwood, Riverdale, and Van Cortland Parks are 61ha, 25ha, and 361ha, respectively, including developed space such as parking lots and lawns), one could expect to encounter more than 10 – 15 owls in only the largest sites. Proper classification will also depend on the particular individuals that are sampled. Most center frequencies hovered around 570 – 620 Hz, with two individuals calling above 950 Hz on average. Owls that call at very high frequencies will be more distinguishable than those who call within the “average” range of 570 – 620Hz. Cavanagh and Ritchison (1987) observed that female eastern screech owls generally call at higher frequencies and at slower rates than males. Unfortunately, we did not know the sexes of the owls we recorded. However, our frequencies tended to be lower on average (654Hz) than both males (721Hz) and females (823Hz) in central Kentucky, and those owls with higher frequency calls tended to sing faster (in contrast to Cavanagh’s and Ritchison’s (1987) findings). Some species have been known to modify their calls to sound more (MacGregor and Krebs

1989) or less like their neighbors (Walcott et al. 2006) and/or to stand out from background noise in urban areas (Warren et al. 2006, Wood and Yezerinac 2006). Future research can determine if Eastern Screech-Owls that live close to one another exhibit more or fewer differences than would be expected by chance or if urban owls seem to shift their calls relative to their rural counterparts. While center frequency appeared to be the most important single factor to determine individuality (PIC = 3.17, see Appendix), the specific combinations of phase-specific note rates was important, particularly between NR1 and NR3.

In within-season analyses, “EEE” models (with ellipsoidal shapes and equal volumes and orientations) were always selected. The selection of an “EEV” model – with varying component orientations – in the multi-year analysis suggests that vocalizations were beginning to diverge from their initial measurements. While the analysis was able to account for this variation, researchers should be aware that (not surprisingly) owls’ calls do not stay completely consistent for their entire lives. Screech-Owls lived on average for 4.1 ± 2.8 (SD; median 2.6 years) years in Texas (Gehlbach 1994) and 3.1 ± 2.6 years (median 2.0) in Ohio (VanCamp and Henny 1975) so a limit of approximately 3 years in terms of call consistency is adequate for most owls. Still, since those owls that live longer play a large role in recruitment rates over their lifetimes, monitoring long-lived individuals would be important for population studies. We also caution others that our multi-year dataset was rather limited, owing to the difficulty of finding captive owls that can be recorded and identified for many years, and thus large populations may not be discernible over time. However, one could potentially perform multiple analyses of data from consecutive years and then link clusters across years. Any new owls that establish themselves in the study area should appear as new clusters, unlinked to any cluster in the previous year. Alternatively, researchers could simply estimate total abundance each year and compare these census counts to abundances derived from multi-year analyses. While the latter is able to provide individual survival rates, annual census counts may be analytically simpler and can still provide information on population trends and status.

The use of the short bounce for this method was based on a few factors. As stated above, bounce calls seem to be used in behavioral contexts that would be expected to require individually distinguishable characters (e.g., mate-mate and parent-offspring communications). Second, they were the most common call recorded. However, since the vast majority of our calls were elicited as a result of an artificial broadcast, Screech-Owls may in fact use other calls more often, or call characters may change substantially in other contexts. For example, occasionally an owl was heard calling before we began our artificial broadcasts and these bouts consisted almost exclusively of long bounces only. Thus, it is possible that short bounces are primarily used in aggressive territorial disputes or courtship displays, and currently our method is untested using calls from other behavioral contexts.

It would also be useful to find variables that could determine individuality using long bounce and whinny calls, something we did not have the time or resources to pursue for this study. Long bounces may be used in pair or parent-offspring communication as in the short bounces but lack the phase-based variation of the short bounce. To develop a method based on long bounces, reliable variables other than center and quartile frequencies and note rates will have to be found. Preliminary analyses of long and short bounces using only the three frequencies and the note rate of the entire call (the only note rate measurable on long bounces since they have no discernable phases) had poor discriminating power. Development of a method based on whinny calls would probably be even more difficult: to our own ears, we noted substantial variability in whinny durations, frequencies, and general forms even within a single bout. However, if possible, using the three types of call would allow additional verification of cluster classifications and should allow more individuals to be discriminated.

Using vocalization analysis to monitor individuals has many advantages. Non-invasive techniques such as these minimize the danger to study animals and can be used in urban areas where project visibility is often high and public opinion regarding trapping and handling local wildlife may be quite unfavorable (Nagy *pers obs*). The cost of recording equipment and analysis software (~$2,000 total) is less than the cost of a telemetry-based study. The latter also has constant costs involved in replacing or refurbishing transmitters, while a vocalization study has only the initial cost. Telemetry will still be necessary if the study objectives require precise and numerous locations, however, especially if one uses call-broadcast surveys – which draw owls to the researcher – to obtain recordings. Mist netting and banding may be less expensive but can be more labor-intensive and, without telemetry, usually cannot yield repeated samples of individuals within a single season. For biologists and land managers with limited time and budgets – as usually is the case among researchers studying urban wildlife and common, non-game species – methods that can be performed on a small budget are often the only options.

Acknowledgements

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Table 1 – BIC scores for initial (build set) model-based clustering of Eastern Screech-Owl bounce calls, New York City, Long Island, and Westchester, NY, and Millington, NJ. 2008 – 2010.

Dataset	Model[a]	d[b]	*G*[c]	BIC [d]	Log-likelihood
Build	EEE, 10 clusters	7	10	336.89	403.55
	EEE, 11 clusters	7	11	316.22	410.79
	EEE, 12 clusters	7	12	302.11	421.31
Test	EEE, 10 clusters	7	10	-84.81	179.25
	EEE, 11 clusters	7	11	-109.77	183.34
	EEE, 12 clusters	7	12	-116.99	196.31
Multi-year	EEV, 4 clusters	7	4	-611.91	-17.05
	EEV, 3 clusters	7	14	-677.98	-118.76
	EEV, 6 clusters	7	11	-734.86	-9.84

[a] "EEE" indicates a model with ellipsoidal components of equal shape, volume, and orientation; "EEV" indicates a model with ellipsoidal components of equal shape and volume and variable orientation.

[b] number of dimensions (variables)

[c] number of components (clusters) estimated by the model

[d] BIC = (2* Log-Likelihood) – (k) * log(n); see (Fraley and Raftery 2007):

For "EEE" models, $k = (G * \mathrm{d}) + (G - 1) + [(\mathrm{d} * (\mathrm{d} + 1)]/2$

For "EEV" models, $k = 1 + (\mathrm{d}-1) + G * ((\mathrm{d}*(\mathrm{d}-1))/2)$

Table 2 – Cluster designations, number of calls per owl/season, and number of calls misclassified per owl/season using a 4-cluster model with ellipsoid clusters of consistent shape and volume and variable orientation (“EEV”), New York and New Jersey, 2008 – 2010.

Owl[a]	Spring ‘08[b]	Winter ‘08[b]	Spring ‘09[b]	Winter ‘09[b]	Spring ‘10[b]	Winter ‘10[b]
RT1 (C)	A(2, 0)	A(9, 0)	NS	A(17, 0)	NS	NS
RT2 (C)	B(26, 0)	B(10, 0)	NS	B(5, 0)	NS	B(3, 0)
SC1 (C)	NS	NS	NS	C(10, 4)	NS	C(6, 2)
VC1 (F)	D(4, 0)	NS	D(16, 1)	NS	D(6, 3)	NS

[a] “C” indicates a captive owl; “F” indicates a free-living owl.

[b] Cluster designation (total number of calls, number of misclassified calls); “NS” indicates the owl was not sampled in that season.

Table 3 – Frequency measurements (mean and SD) using three different window sizes for spectrogram production of calls from 10 eastern screech owls, New York and New Jersey, 2008 - 2010.

Window Size (samples)	Center Freq. (Hz)	1st Quartile Freq. (Hz)	3rd Quartile Freq. (Hz)
256	644.1 ± 100.6	569.2 ± 99.8	719.9 ± 101.7
512	644.8 ± 100.5	603.7 ± 99.6	685.3 ± 101.8
1024	645.4 ± 100.9	619.7 ± 101.2	670.1 ± 100.5

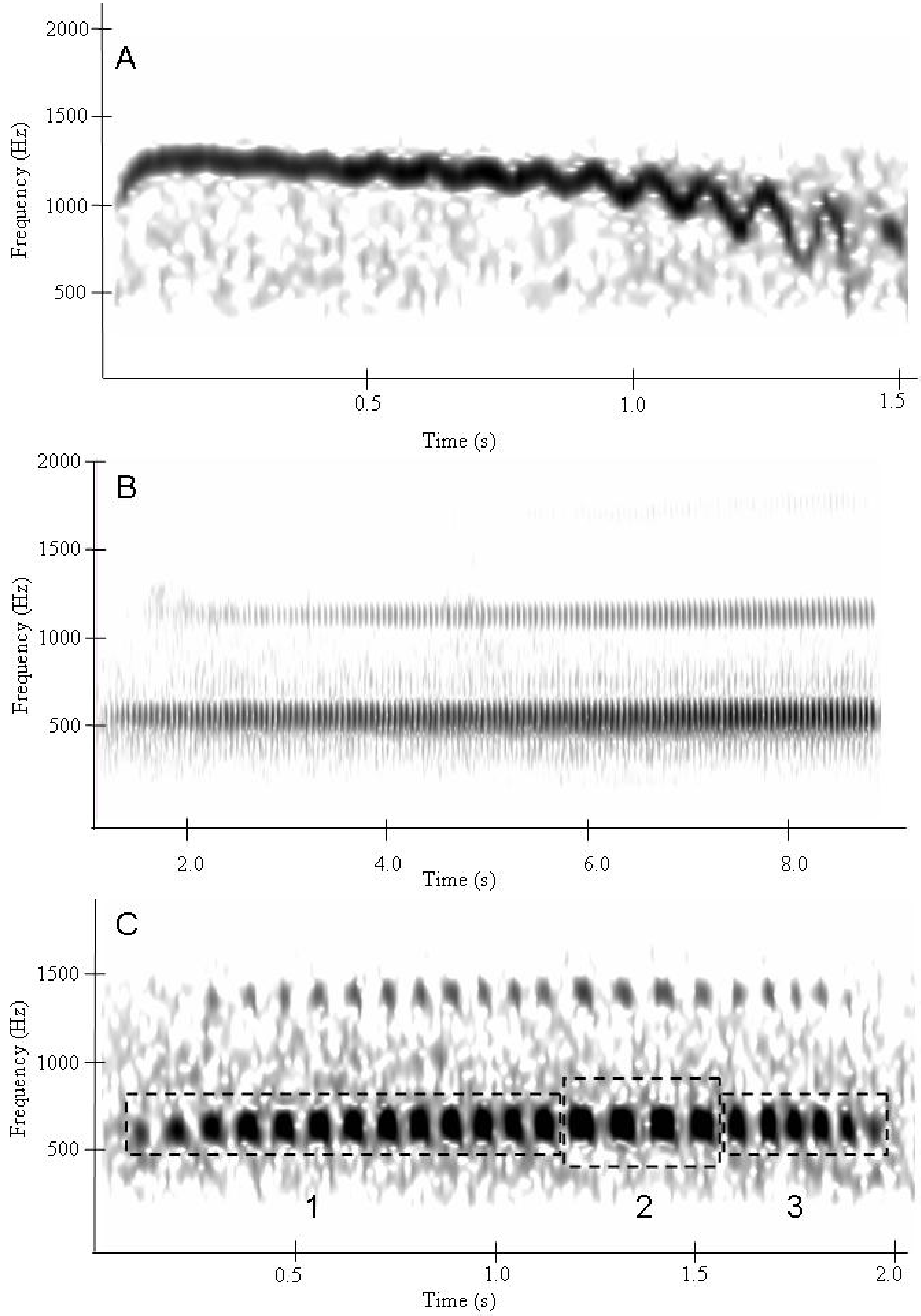

Figure 1 – Sample spectrograms of whinny (A), long bounce (B), and short bounce (C) calls of Eastern Screech-Owl. Selections 1, 2, and 3 in C represent the 3 phases of the call.

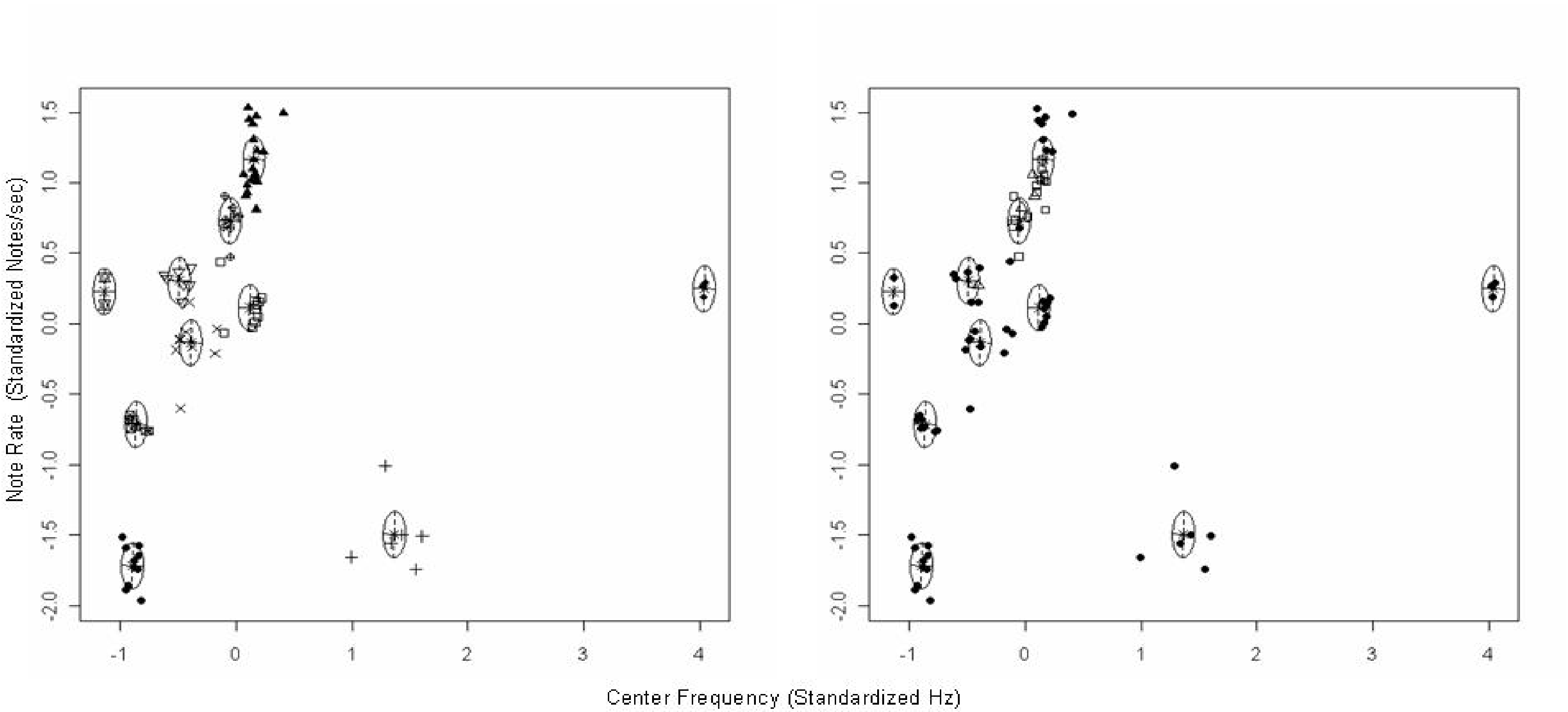

Figure 2 – Final clusters and covariance ellipses of the build set of 10 Eastern Screech-Owl short bounces calls plotted along 2 of the 7 variables used in the analysis. Cluster assignments (left) are based on the BIC-selected best model with 10 components. Black dots in uncertainty plot (right) represent observations in the 0 – 75% quantile of uncertainty; square dots represent observations in the 75 – 95% quantile, and triangular dots are observations in the 95% quantile of uncertainty.

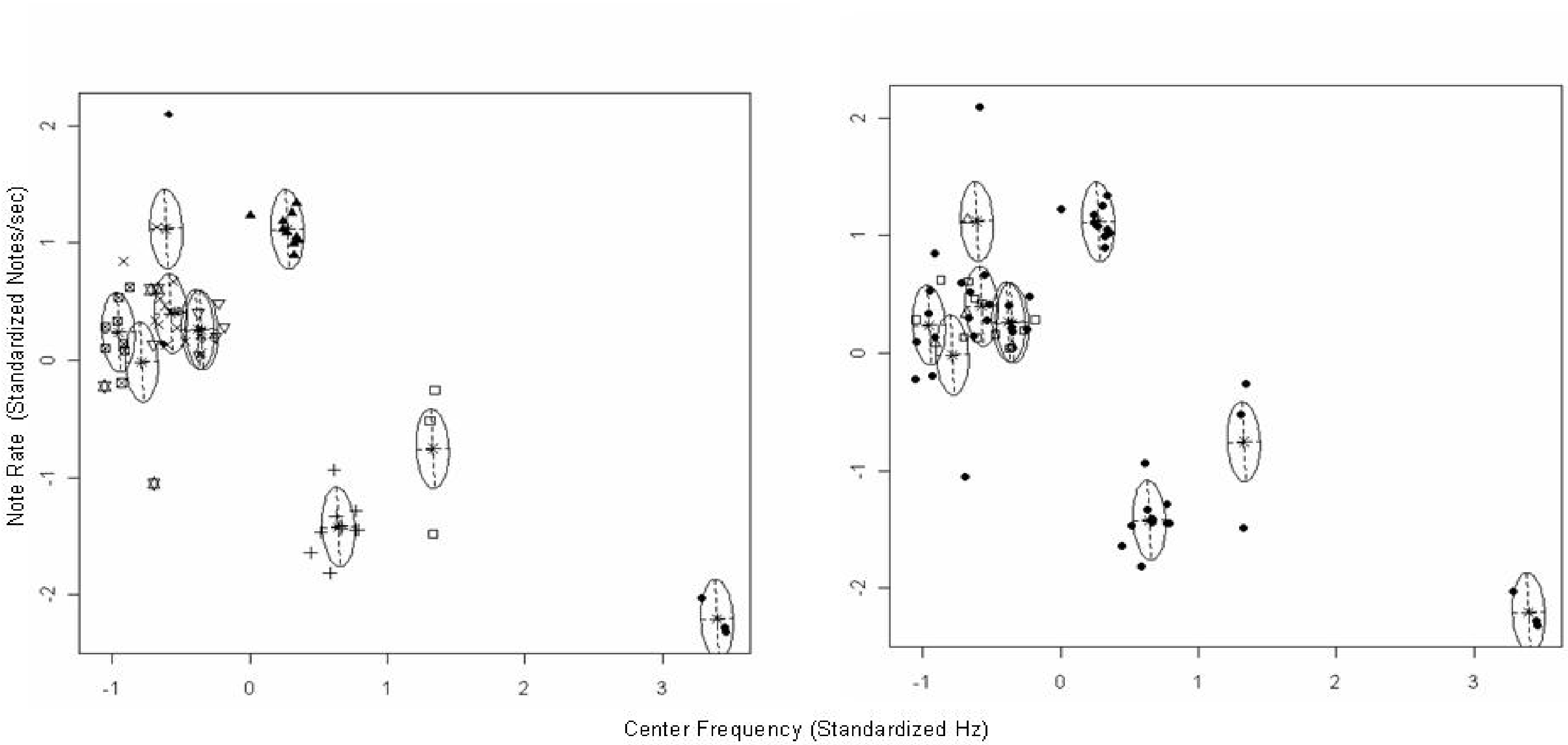

Figure 3 – Final clusters and covariance ellipses of the test set of 9 Eastern Screech-Owl short bounces calls plotted along 2 of the 7 variables used in the analysis. Cluster assignments (left) are based on the BIC-selected best model with 10 components. Black dots in uncertainty plot (right) represent observations in the 0 – 75% quantile of uncertainty; square dots represent observations in the 75 – 95% quantile, and triangular dots are observations in the 95% quantile of uncertainty.

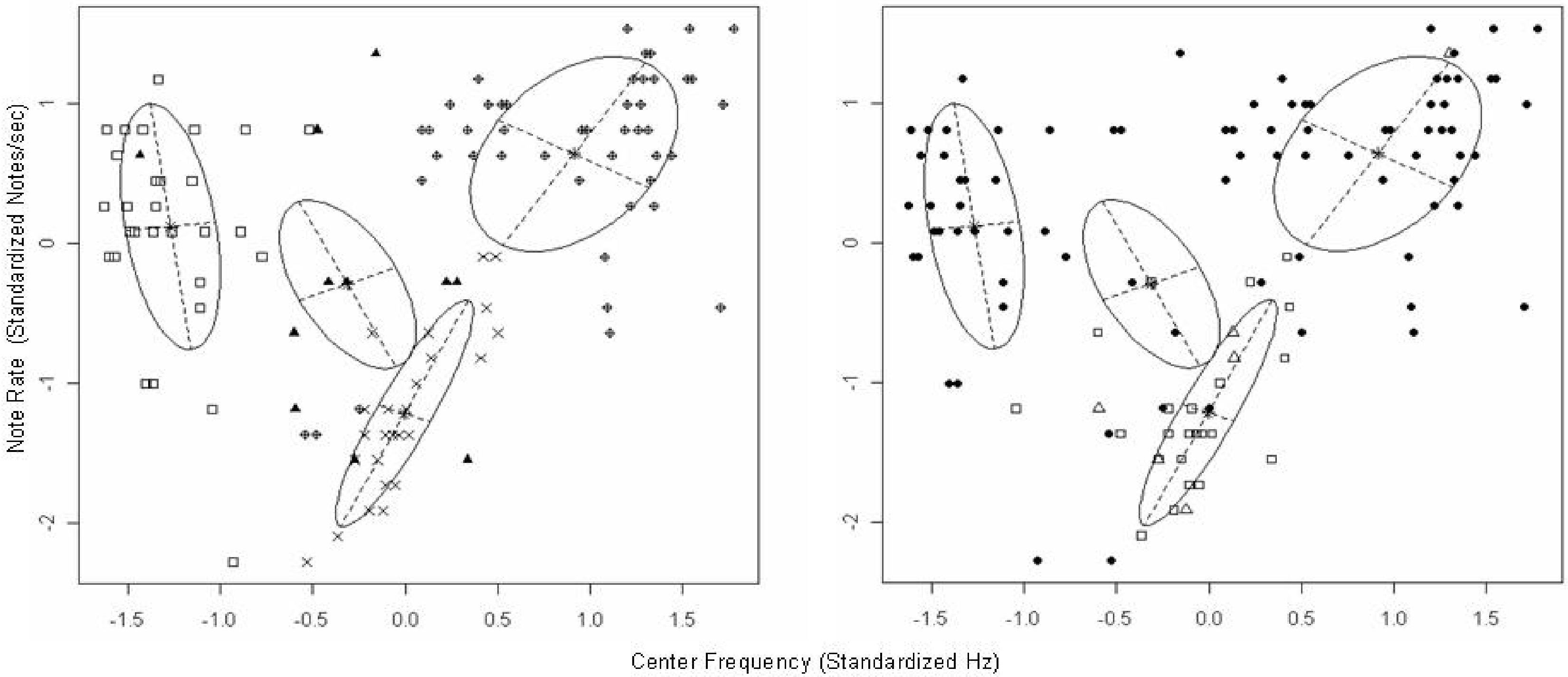

Figure 4 – Final clusters and covariance ellipses of the multi-year set of 4 Eastern Screech-Owl short bounces calls plotted along 2 of the 7 variables used in the analysis. Cluster assignments (left) are based on the BIC-selected best model with 4 components. Black dots in uncertainty plot (right) represent observations in the 0 – 75% quantile of uncertainty; square dots represent observations in the 75 – 95% quantile, and triangular dots are observations in the 95% quantile of uncertainty.

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Chapter 3: If They Can Make it Here: Eastern Screech Owl (*Megascops asio*) Population Viability in three New York City Parks

Abstract

Wildlife populations in urban areas are often relegated to parks and other greenspaces of limited size, and stochastic environmental and demographic events can have a large impact on overall persistence. To investigate the present status and likely future persistence of eastern screech owls (*Megascops asio*) in New York City, I used call-broadcast surveys to monitor owl populations in three New York City parks and one suburban/rural preserve in nearby Bedford, NY. Owl responses were recorded and analyzed to identify individual owls to build recapture histories, which were used to estimate abundance and survival rate in a capture-mark-recapture analysis. Populations were then projected using the estimated survival and previously published reproductive rates using an age-specific, density-dependent model that accounted for varying sex ratio, park area, and periodic perturbations of survival rate. Survival in urban parks was 0.98 – 1.0, much greater than in the suburban preserve, 0.57 ± 0.15. Despite the high adult survival, populations in parks could be extirpated within 10 - 20 years by extreme "crashes" in survival rate (e.g., extreme winters, storms, or secondary poisoning) if crash frequency occurred more often than once every ten years or if parks were smaller than 1.0km^2. Managers should work to increase or enhance the available habitat and future park designs should provide wooded areas 1.0km^2 or larger.

Introduction

Predator species may be particularly rare in urban spaces due to prey and space requirements, sensitivity to human presence (VanDruff et al. 1996), and secondary pesticide accumulation (Elliot et al. 1997). Hence, they may be found in relatively low densities, patchy distributions, and exhibit unique ecological or behavioral characteristics compared to conspecifics in less disturbed areas. These differences make such species of particular interest and challenge to biologists from both conservation and research perspectives.

In urban areas, raptors are often the most abundant predator species (Gehlbach 1994, Minor et al. 1993, Stout et al. 2006, Isaac et al. 2008), partly due to their mobility, inconspicuousness, and the high abundances of preferred prey (rodents, small birds, and insects) often found in urban areas (Sorace 2002, Rytwinski and Fahring 2007). In addition to the ecological functions these predators perform, urban raptors provide aesthetic, recreational, and educational benefits to the general public, making management of these species valuable both biologically and socially. Research on these species and their unique dynamics in an urban landscape is needed to direct management efforts.

In New York City (NYC), eastern screech owls (*Megascops asio*) are one of the most common raptors. While known to disperse moderate distances (natal dispersal ≤16.9 km (Belthoff and Ritchison 1989)), this species is non-migratory (Gehlbach 1995); thus, urban populations are year-round residents and presumably confined to the local area. Screech owls have often been associated with human development (Lynch and Smith 1984, Smith and Gilbert 1984, Nagy et al. *in press*) or have been shown to have increased vital rates or densities in suburban or urban areas (Gehlbach 1994, Artuso 2009). Naturally-occurring (i.e., non-introduced) screech owl populations have been located in a handful of parks in the boroughs of

Manhattan and Bronx, New York City (NYC). They have also been found in two parks in Staten Island (Blue Heron and High Rock Parks) and are thought to be common in that borough (Nagy, *pers. obs.*). With the possible exception of suburban Staten Island, screech owls in NYC are presumed to be confined to wooded parks, though they may disperse through the urban matrix to some extent.

The intensely developed areas of Manhattan and Bronx, NYC are on the most extreme end of the urbanization spectrum. Most screech owl studies that have shown a positive relationship between human development and screech owl site occupancy (Artuso 2009, Nagy et al. *in press*) or population growth/stability (Gehlbach 1994) focused on suburban or urban areas of moderate density. Parks are the only places in NYC where eastern screech owls have been found in modern times, though owls have been observed foraging and roosting in city streets adjacent to occupied parks (Nagy 2004). It is possible that certain parks in highly urbanized areas could provide adequate “greenspace” for owls to roost, nest, and forage while providing the typical urban benefits of fewer predators, abundant and/or concentrated food (Gehlbach 1994), and milder winters (Gehlbach 1995). On the other hand, small and isolated owl populations found in urban parks within an expansive urban matrix may suffer increased local extinction rates due to environmental or demographic stochasticity (Pimm et al. 1988, Thomas 1990, Morris and Doak 2002).

In this study, I sought to estimate the survival rate and future status of eastern screech owls using capture-mark-recapture analysis**.** Three NYC parks and one suburban/rural site outside of NYC, the Mianus River Gorge Preserve (MRGP) in Bedford, NY, were sampled for the presence of screech owls via call-broadcast surveys in NYC Parks. Response bouts were recorded in the field and recapture histories were obtained by using a previously developed method to identify individual owls from the characteristics of the owls' calls (Nagy and Rockwell *in press*). The survival rates and population densities of the NYC parks and MRGP were compared to explore the differences of urban park populations versus populations in more typical habitat. Projection matrix modeling was then used to examine the persistence and population sizes of urban parks of various areas under density-dependent and environmentally variable conditions. My goal was to use the population modeling approach to inform future screech owl management efforts in NYC Parks.

Methods

Study Site Descriptions

Three urban parks in NYC were used in this study: Inwood Hill Park in the borough of Manhattan; Van Cortlandt Park in the Bronx, and Riverdale Park in the Bronx. Inwood Hill is a small 79.5 ha (55ha protected wooded area) park on the northern tip of Manhattan Island. It is surrounded on the north and west by the Hudson River and on the east and south by highly urbanized residential and commercial areas. The Henry Hudson Parkway, a major highway that runs along the Hudson River through the Bronx and Manhattan, and the Amtrak railroad, cut through the western portion of the Park. The undeveloped sections consist of 100 -150 year old hardwood (primarily oaks *Quercus* spp., maples *Acer* spp., and hickory *Carya* spp.) forest, although there are a few white pine (*Pinus strobes*) stands and a small area managed as a meadow. Red-tailed hawks (*Buteo jamaicensis*) regularly nest in this park and there is the occasional sighting of a great-horned owl (*Bubo virginianus*) but no other raptors are commonly observed there outside of the migratory season (Nagy, *pers obs*.). Van Cortlandt Park is the third largest Park in NYC (464ha total, 231.8ha protected woodlands). It is also primarily an oak-hickory hardwood forest with some riparian and wetland areas. A public golf course also provides some amount of scattered wooded habitat. The Park is bisected by 4 major highways. Red-tailed hawks and great-horned owls are found there, though the latter is uncommon (Nagy, *pers. obs.*). Riverdale Park (84ha, 45ha protected wooded area) is a small park in the western Bronx neighborhood of Riverdale, just north of Manhattan (and Inwood Park) along the Hudson River. Unlike Van Cortlandt and Inwood Hill, the surrounding area is better described as suburban rather than urban as most structures in the adjacent area are single family homes on relatively larger properties or small apartment buildings. The forest is a similar oak-hickory hardwood forest. All parks have extensive trail systems and see heavy year-round recreational use by residents.

The Mianus River Gorge Preserve (MRGP) is located in Bedford, Westchester County, NY. This 305ha preserve consists of old-growth eastern hemlock (*Tsuga canadensis*) and mid-succession hardwood forests surrounded by light residential development. Raptors other than eastern screech owls commonly found there include barred owls (*Strix varia*), great-horned owls, red-tailed hawks, and rarely northern goshawks (*Accipiter gentiles*) and Cooper's hawks (*Accipiter cooperii*).

Field Recordings

From 2008 – 2010, I surveyed Inwood Hill and Van Cortlandt Parks, New York City, and the Mianus River Gorge Preserve, Bedford, NY using nighttime call-broadcast surveys in the wooded areas of each park. Broadcast recordings consisted of a mixture of alternating bounce and whinny calls from Elliott et al. (1997) and my own field recordings and were broadcast with a portable CD player for 10 minutes at each survey site. Each site on a 300m grid was surveyed from spring to early fall in 2008 (three times), 2009 (six times), and 2010 (four times). If an owl responded, its calls were recorded using a Sennheiser ME67 shotgun microphone with a foam windscreen and a Marantz PMD 661 digital recorder at a 44.1kHz sampling rate. Each site was sampled no more than once a month because I wanted to minimize habituation to the broadcast calls and the effect repeated surveys might have on the owls' behavior. In early 2010, I found owls in Riverdale Park as well, and sampled that park for a single year.

Determination of Recapture Histories from Owl Recordings

I identified individual owls by their calls using the method developed by Nagy and Rockwell (*in press*) that enters frequency and note rate measurements on the "short bounce" calls into a model based cluster analysis ("Mclust," Fraley and Raftery 2007). This method estimates the number of clusters (individual owls) in a set of observations (calls) and classifies each observation into a cluster. The short bounce call is used by eastern screech owls for territorial, courtship, and mate-mate and parent-offspring communication purposes (Cavanagh and Ritchison 1987). The call consists of a short (2 – 4 second) trill of relatively uniform frequency that varies in note rate in three distinct phases. Nagy and Rockwell (*in press*) found that two independent sets of 9 – 10 known eastern screech owls could be discriminated on the basis of the variation in the center frequency (CF; the frequency that divides the call into two frequency intervals of equal energy), first quartile frequency (1QF; the frequency that divides the call into two intervals that contain 25% and 75% of the energy in the call), third quartile frequency (3QF; the frequency that divides the call into two intervals that contain 75% and 25% of the energy in the call), the note rate of the entire call and the first, second, and third phases of the call (NRall, NR1, NR2, NR3, respectively).

Since I was attempting to identify individuals from populations of unknown owls, the clusters and classifications could not be externally validated or checked. However, there were a few restrictions I could set on the cluster analysis that could be used to determine if the classifications were reasonable. First, a set of recordings taken from a single owl on a single night at a single site (hereafter, a “bout”) is known to be from a particular owl, and thus should be classified together by the Mclust program. Other bouts from different sites and/or recorded at different times could be from the same owl or a different one, but calls within a single bout should cluster together. It follows that, first, the maximum number of owls in a population can not be higher than the total number of bouts recorded there, and second, no single cluster can be made up of fewer calls than the bout with the fewest calls.

I generated spectrograms for every short bounce call I recorded from 2008 – 2010 using Raven 1.3 (Cornell Lab of Ornithology 2008). As recommended by Nagy and Rockwell (*in press*), spectrogram DFT size and window size were set to 65,536 and 256 samples, respectively. The seven variables were measured from all usable calls; some calls could not be used because of excessive, wide-band background noise from highways or planes. I also censored bouts if the total number of usable calls in the bout was fewer than three.

Observations from each park were analyzed separately across the three years in the Mclust analysis. Model structure was restricted to clusters with equal volumes and shapes but could vary in orientation (“EEE” and “EEV”, see Fralhey and Raftery (2007) and Nagy and Rockwell (*in press*)) and the maximum number of possible clusters was set to the maximum number of bouts recorded in each park. Resulting clusters with fewer than three observations were taken as superfluous groupings and eliminated since no bout had fewer than three calls. For the larger parks, in three instances some bouts were split evenly across two or more clusters. If this split occurred equally across a number of bouts then I grouped the clusters together (i.e., as samples from a particularly variable owl). Resulting clusters and call classifications were used as repeated observations of individual owls and converted to recapture histories for the capture-mark-recapture (CMR) analysis.

Estimation of abundance and survival using CMR analysis

Recapture histories were entered into a robust design CMR (Pollock 1982, Kendall et al. 1995) in Program MARK 6.1 (White and Burnham 1999), where years were the primary sampling periods (3) and successive surveys within each year were the secondary periods (3, 6, and 4 in 2008, 2009, and 2010, respectively). The robust design was formulated as a population growth model as described in Pradel (1996) which estimates survival (Φ), recruitment (f), initial capture probability (p), and recapture probability (c). I used the Huggins (1991) likelihood formulation in which abundance (N) is estimated as a derived parameter once p and c are estimated. This model framework assumes that the population is closed among secondary sessions, i.e., within years. This assumption was not completely upheld, as certainly at some point owls left or died during the spring and summer, but the effect of its violation would be minimal as adult owls typically stay in their established territories most of their lives (Bent 1938, Gehlbach 1995) and winter mortality is much greater than the other seasons (Gehlbach 1994, Nagy 2004).

I modeled survival and recruitment as functions of Park (P) or whether the site was in New York City (urban) or the MRGP (rural; UR). Capture and recapture rates were kept constant and equal ($c = p$) for all models except two post hoc models (see Results). I also included a model with survival and recruitment held constant across sites. The candidate model set thus consisted of 7 models which were compared using AIC_c (Burnham and Anderson 2002). Survival rates and estimates of abundance were calculated based on the AIC_c-selected best model or w_i-averaged estimates of supported models if no clear best model was found. Since Riverdale was only monitored for one year, I could not estimate annual survival. I used a closed population CMR analysis to estimate abundance in Riverdale.

Population projection

CMR modeling showed that there was a substantial difference between survival in urban parks (Van Cortlandt and Inwood) versus the rural site (MRGP; see Results). To determine the persistence of the park populations, I projected the populations forward using a Lefkovich-style population matrix based on vital rates (age-specific survival and fertilities) and the average population sizes for each park over the three year period using MATLAB 7.1 (The Mathworks 2005). I avoided the use of population viability software packages (e.g., VORTEX, RAMAS) because I wished to tailor my model to this system and be aware of the assumptions of my model. The source code for these programs is not available and I preferred to “code from scratch.” I chose two age classes, yearlings (from fledging to first birthday) and adults (>1 year old). Egg-to-fledge survival was incorporated into the reproductive rates as fledges per adult owl (Table 1). I used my estimated survival rates (via the CMR analysis, above) as the estimate of adult survival (S_a) and a previously published yearling survival rate (S_y) estimated from reintroduced screech owls in another NYC Park (Nagy 2004). Reproductive rates were gathered from Gehlbach (1994) and Van Camp and Henny (1975). Matrices were parameterized in a pre-breeding census framework (Caswell 2001). I ran all combinations of the base reproductive rates (Table 1) as separate simulations (256 total) in a deterministic projection. A separate matrix was made for MRGP using the site-specific adult survival I estimated and the published reproductive rates and yearling survival. Initial population size was set at 6 owls (the lowest observed population size was 7 owls).

Rapid exponential growth for the majority of simulations was observed using the urban survival rates, so I incorporated a density-dependant function into the model. I hypothesized that, given the very high adult survival rate in the NYC parks (>0.9, see Results) and the territorial nature of the species, juvenile screech owls would be forced to disperse from the parks if density was high, while adult survival and reproduction would remain similar. This relationship could be incorporated mathematically by reducing S_y as density increased (dispersing fledglings would effectively be "locally dead" in terms of the park population). Gehlbach (1994 and 1995) concluded that eastern screech owl densities in suburban Texas averaged 11.8 owls/km^2. I regressed density versus survival rate, with $S_y = 0.22$ at 0 owls/km^2 and $S_y = 0$ at 11.8 owls/km^2. The resulting linear function was used to incorporate density dependence into the S_y term of the projection matrix. The population asymptote with this function was slightly lower than 11.8 owls/km^2 so I adjusted the slope function to bring the mean asymptotic population size to 11.8 owls.

Once a suitable density-dependence function was determined, I investigated the probable fate of these populations using a stochastic model. In this model, all reproductive rates were allowed to vary uniformly within the range of published values (Table 1). Survival rates were also allowed to vary ± 0 - 10% annually from the point estimates of 0.22 and 0.90. Furthermore, because eastern screech owls tend to be monogamous (Gehlbach 1995), chance variation in sex ratio can reduce the effective reproductive population size (the reproductive population is effectively twice the number of the less numerous sex). I therefore modeled the population sizes of each sex and determined the sex of offspring each simulation year based on binomial probability. Even though the survival and reproductive rates were identical between males and females, the proportion of males and females born each year were random samples from a binomial distribution. This introduced variation in the sex ratio which could lead to variations in reproductive output and thus variation in population size and persistence. Juvenile survival was still dependent on the total density (i.e., the sum of both sexes). After each simulated year, population vectors were rounded to the nearest integer to remove “partial owls.”

This stochastic model could also incorporate “crash” years in which there was some chance that the S_a value for that year could be decreased by 60% during each time step for each simulation. These perturbations were meant to simulate especially lethal years due to environmental change such as very cold or snowy winters, severe weather events (hurricanes, blizzards, nor’easters), or discrete mortality events (secondary poisoning, chance predation or vehicle collisions above normal, etc.) where a large portion of the resident population dies. I chose 60% because on average this was equal to the lowest recorded survival rate of owls older than 1 year (0.36; Gehlbach 1994). The model also could scale the density dependence function according to area so that parks smaller or larger than 1 km^2 could be properly modeled (smaller parks would have lower maximum densities and thus could go extinct more easily).

Effects of Perturbations in Survival Rate, Sex Ratio, and Park Area

Using this stochastic model, I explored the effects of the frequency of periodic reductions in adult survival (“crash rate”), initial sex ratio, and park area on the persistence of the three NYC study sites. To measure these effects, I used starting populations based on the average population sizes of $0.25km^2$, $0.62km^2$, $3.62km^2$ (the total forested areas of Riverdale, Inwood, and Van Cortlandt Parks) and $1.0km^2$ parks after 500 years (1,000 simulations). After 500 years, the populations stabilized to an effective carrying capacity and changes from this size would therefore illustrate the effect of crash rate or skewed sex ratio. Starting these populations from a set size regardless of area would confound the treatment effects, e.g., if a starting population size was set too large, it would decline regardless of any effect of crash rate or sex ratio. Once appropriate starting population sizes were found, hypothetical populations were projected 5,000 times using crash rates of 0.025, 0.05, 0.10 and 0.15, and again using three different sex ratios, 1:1, 2:1, and 3:1. These operations were performed on hypothetical parks of the four areas (0.25, 0.61, 1.0, and 3.62km^2) for 50 years.

Results

Vocalization analysis and individual identification

I recorded a total of 901 usable bounce calls; 311 from Inwood, 215 from Van Cortlandt, 70 from Riverdale, and 305 from the MRGP. The best-fit model for the Inwood calls was a seven cluster model with one cluster having only two observations. The Van Cortlandt calls were best modeled with a 13 cluster model. Three of these clusters were consistently found together within bouts from a single site; these clusters were put together as they were clearly recorded from the same owl. Riverdale was best modeled by nine clusters; two of these clusters had <3 observations. Lastly, the MRGP was best modeled with an 18 cluster model. Three clusters had fewer than three observations and were removed. Two additional clusters occurred within other clusters so these were pooled. Thus over three years, I recorded six unique owls from Inwood, 10 from Van Cortlandt, and 13 from the MRGP. For the one year I sampled Riverdale, I found seven owls.

Survival and abundance estimation

A preliminary examination of capture histories showed that only one owl disappeared in Inwood and Van Cortlandt during the study. Thus, I expected a very high survival estimate for these parks. The top CMR model estimated survival as a function of urban or rural location (Table 2). Two other models performed well and predicted similar trends of higher survival in the urban sites. There was a substantial drop in ΔAIC_c the fourth and fifth top models so I used model-averaged estimates for survival and abundance based on recalculated Akaike weights (w_i) of the top four models. The three worst models were those that modeled survival as a constant across all sites and had poor support compared to the others (Table 2).

Model-averaged estimates of survival in the urban sites were very high, ranging from 0.98 – 1.0, since only one owl disappeared in these sites during the study. Because of this near-boundary estimate, numerical convergence could not be reached during maximum likelihood estimation and standard errors of these point estimates were not calculated. Model-averaged MRGP survival was 0.57 ± 0.15 (mean ± SE), which is slightly lower than other published rates (60 - 70%; Gehlbach 1995) in suburban and rural settings.

Initially I thought greater background noise may make detection during call-broadcast surveys more difficult in urban areas. However, I also noticed that barred owls often responded to broadcast screech owl calls at the MRGP. In addition, screech owls would often abruptly stop calling just before a barred owl called (Nagy, *pers. obs.*); if screech owls were avoiding barred (and perhaps great horned) owls then detection might be lower in the MRGP. The model that included urban-rural effects in both survival and the detection parameters did well (ΔAIC_c = 1.67) while the model with an urban-rural effect in just the detection parameters alone performed poorly ($\Delta AIC_c > 6$). Model-averaged detection under the constant detection and redetection models was 0.32 ± 0.04. When modeled as an urban-rural effect, detection was 0.33 ± 0.04 at Inwood and Van Cortlandt and 0.27 ± 0.07 at the MRGP.

Population modeling

The CMR estimate of 0.98 – 1.0 found in Inwood and Van Cortlandt was extremely high and the true long-term survival rate is probably lower (i.e., eventually owls must die). Thus, for modeling purposes, I used an adult survival of 0.90 to avoid nonlimited survival (i.e., "immortal owls"). When modeled without density limitations, all simulations exhibited positive growth (λ ranged from 1.05 – 1.22), although a few simulations did not grow quickly (Figure 1). The population projection for the MRGP showed that only 32 of the 256 combinations of vital rates yielded $\lambda > 1$.

The density dependant function obtained was

$$S_{y,t} = 0.22 - 0.0105\,(N_{t-1}),$$

where $S_{y,t}$ = yearling survival at time *t* and N_{t-1} = total abundance at time $t - 1$. The 256 reproductive rate combinations were projected again with this function included for S_y. These projections illustrated the range of possible outcomes from best-case to worst-case for a hypothetical population in a 1.0km^2 park (Figure 2A), since the smallest and largest simulations would be those that had the lowest and highest value for every parameter value, respectively. We originally thought that the general stochastic model, which allowed reproductive rates to vary within simulations annually within the range of published values (Table 1), would thus show a generally more "plausible" pattern rather than the extremes (Figure 2B). However, when other population characteristics were included – modeling males and females separately, including sex determination of offspring, allowing adult survival to vary up to 10% annually, and rounding partial owls – the variation of the resulting simulations increased greatly and more closely resembled the range of possibilities illustrated by the earlier rate combination model (Figure 2C).

Initial sex ratio by itself appeared to have little long-term effects on owl populations. In most cases, sex ratios stabilized and any differences in population sizes due to an initial 2:1 or 3:1 sex ratio compared to 1:1 were largely eliminated after 5 – 15 years (Figure 3), although the largest park seemed to take longer to do so. The exception was the 0.25km^2 park: the 1:2 and 1:3 simulations were nearly always smaller than the 1:1 populations out to 50 years (but still had extinction rates of 0%) and mean sex ratio never fell below 2:1. No simulations with altered sex ratios went extinct.

Crash rate had a clearly negative effect on the hypothetical populations. Every level of annual crash rate (0.025, 0.05, 0.1, or 0.15) caused some percentage of simulations to go extinct (compared to no extinctions at 0% crash rate; Table 3). Smaller parks had greater extinction rates than larger parks (Figure 4). Crash rate also reduced the average population size compared to corresponding no-crash simulations. This effect was exacerbated as time progressed (Figure 5).

Discussion

Urban vs. Rural Populations

The NYC (urban) parks, Inwood and Van Cortlandt, had much higher survival rates than the MRGP (rural/suburban), and models that contained urban-rural effects on φ performed well. Models with park-specific survival still showed a marked difference in the estimated survival between Inwood and Van Cortlandt ($\varphi = 1.00$ and 0.98) versus the MRGP ($\varphi \approx 0.57$) across all supported models. This confirms and expands the trend of higher survival in more developed areas found by other studies (Smith and Gilbert 1989, Gehlbach 1994, Artuso 2009) into the extremely urbanized landscapes of NYC. Eastern screech owl success in suburban and urban areas has been attributed to greater prey abundance and concentration (Gehlbach 1994), lack of predators (primarily avian; Gehlbach 1995), and more stable and warmer winter climate (Gehlbach 1994, Nagy 2004). Urban areas pose their own dangers such as vehicle collisions

(VanCamp and Henny 1975, Gehlbach 1994), risk of secondary poisoning, and a potential lack of older stands of trees and snags that provide nesting cavities (Belthoff and Ritchison 1990, Gehlbach 1994, Nagy 2004). However, screech owls are largely park or other greenspace (cemeteries, botanical gardens, etc.) dwellers in very urbanized cities such as NYC and this may limit the risk of vehicle collisions if the park is large enough to provide foraging territory for the owls and not overly fragmented by roads.

When the respective survival rates were incorporated into deterministic population models, the urban models displayed exponential growth while the MRGP models tended to decline or stay constant (Figures 1 and 2). A possible reason for the lower MRGP survival rate is that there may be more avian predators and competitors there (barred owls, great horned owls, and red-tailed hawks are common). Habitat may also be somewhat limited because a large portion of the MRGP is old-growth hemlock forest, which is not typical screech owl habitat (Smith and Gilbert 1984, Sparks et al. 1994) particularly if such areas are co-opted by larger owls.

Despite the lower survival rate, the MRGP had similar abundances and densities to the other sites (Table 4) although there was a decline from 13 ± 3.64 (mean + SE) owls in 2008 to 6 ± 1.40 owls in 2010. This suggests either a higher turnover rate at the MRGP (with associated higher reproductive or immigration rates than I used) or changing conditions at the MRGP that do not favor screech owls. It seems likely that owls could disperse into the MRGP easier than into the urban sites since the MRGP is surrounded by undeveloped land or lightly developed residential homes as opposed to the nearly 100% developed cover of NYC. Gehlbach (1994) suggested a nine-year cycle for eastern screech owl abundances in Texas; it is possible I measured a downturn along a similar cycle at the MRGP. These cycles were theorized to be based on the ebb and flow of reproductive success of long-lived females: as successful, long-lived females produced more recruits, the inexperienced and on-average poorer parents would subsequently compete with their more skilled mothers. Poor reproductive years overall would result as even the skilled mothers would do poorly because of competition. The population would decrease substantially and the few adult owls that survived would be successful and produce more recruits (Gehlbach 1994 and 1995). Individual subpopulations remain extant via immigration during bad years and provide dispersers to other subpopulations during good years.

Significant cyclical dynamics seem less likely in the urban populations. The Inwood and Van Cortlandt populations have persisted for over 10 years (Nagy, *unpub. data*) and any substantial downturn in survival in the smaller parks could easily lead to local extinction. In addition, since fledglings are likely ousted from the park population altogether if there are adult owls nearby, the cyclic competition between inexperienced yearlings and proven adults would not occur. This may be another reason for the greater survival in urban parks: potential yearling competitors are thrown out and must disperse to a non-contiguous area. However, local extinction does occur; in the summer and fall of 2007 I monitored 2 owls in Alley Pond Park, Queens, but was unable to detect any owls in this park in 2008 – 2010 despite multiple surveys.

This leads to the obvious question of the occurrence of inter-park movement by screech owls, and whether or not such dispersal has a substantial role in subpopulation persistence. Landscape-level modeling of occupied and unoccupied parks, the areas around them, and their distribution in NYC may shed some light on these questions (see Chapter 4).

Urban Park Perturbation Dynamics

While the discrete nature of urban parks allows greater adult survival, possibly by limiting predators and minimizing intraspecific competition, it also appears to limit the resilience of these populations to stochastic events. Even with a 0.025 incidence of crash (a bad year occurs roughly once every 40 years), there were noticeable effects on simulated park populations (Figure 5). The effects of varying crash rates on mean population size were proportional with regard to park area: e.g., after 10 years, the mean percent difference between a 0.0 crash rate and a 0.10 crash rate were similar across all park sizes (54% to 67%). However, the rate of population extinction was vastly greater in small parks (Figure 4). Clearly, smaller parks will have lower carrying capacities and can more easily hit 0. In addition, a lower maximum population (due to a small park area) means that even if a population does survive a crash and starts to rebound, its growth will be slower because density dependence comes into play at lower abundances.

Sex ratio appeared to balance to roughly 1:1 within 10 – 15 years and thus mean population sizes did not greatly differ across starting sex ratios (1:1, 2:1, and 3:1). However, the ratio never fell below 2:1 in the smallest area size tested (0.25km2). A skewed sex ratio would further limit recovery after a bad year because any density dependent effects would operate at magnitude equivalent to a larger population than is actually breeding. In parks larger than 0.5km2, sex ratio alone does not seem to be a serious management concern. However, the sex-specific stochastic model exhibited considerably more variation in population sizes than the stochastic model with no sex differentiation. This is likely due to the added variation of selecting the sex of offspring from a binomial distribution as well as rounding decimal individuals to the nearest integer. This variation is likely important and should be incorporated into models describing small populations (Lacy 2000, Ferrer 2009).

The selected magnitude of the so-called crashes might be more or less intense than what actually occurs in nature. However, these simulations show that even populations with high adult survival that can easily reach carrying capacity in stable environments can still be extirpated by chance events, particularly if the parks are small (Pimm et al. 1988, Thomas 1990, Lacy 2000, Morris and Doak 2002).

Site-Specific Implications

The densities in two of the urban parks (Table 4) were lower than the 11.8 owls/km^2 reported by Gehlbach (1994) and used for my density dependent modeling, except in Riverdale Park. In the case of Riverdale, the area surrounding the Park is more suburban than urban, so the effective habitat at this site is likely much larger than the designated area of the park. While I only sampled within the parks, call broadcast surveys could have pulled in owls that held territories outside of the park. The more suburban matrix surrounding this park and the possibly larger effective size of the site may explain the existence of a screech owl population in a park of this size.

The density at Van Cortlandt Park was quite low, especially considering that most of the simulation modeling would suggest that a park as large as Van Cortland should have almost ten times the observed densities. In fact, the Van Cortlandt densities were more similar to the MRGP and published densities for rural areas in central Texas (0.4 – 4.4 owls/km^2; Gehlbach 1995). There may be a point where a park becomes large enough to operate cyclically – and thus at reduced densities – without lowering survival rate. Less speculatively, I included the large Van Cortland golf course and a few ponds and wetlands in my estimation of available habitat since screech owls often use forest-edge and open woodlands (VanCamp and Henny 1975, Gehlbach 1994) and forage along shorelines of ponds (Prescott (1985) and Ritchison and Cavanuagh (1992) observed fish as prey items; Nagy *pers. obs.*) and in riparian areas (Artuso 2009). A more restrictive definition of available habitat (removing small bodies of open water, including only wooded stands of the golf course and not lawns) would reduce the area and increase the density. However, it seems inappropriate to selectively modify a site's area so that it fits an *a priori* density; rather it may be that Van Cortlandt simply has poorer habitat than Riverdale or Inwood Park despite its large size. The presence of great horned owls (Nagy, *pers obs.*) and the numerous highways that crisscross the park may also limit movement and available habitat.

Periodic reductions in adult survival can cause increased risk of local extinction and lower average population sizes for simulated parks of all sizes. Differences in population size and extinction risk became meaningful at time scales as short as 10 years in parks smaller than 1.0km^2 (Figure 4 and 5), indicating that despite the high observed survival rates there is still short-term risk of local extinction in small parks, e.g., at Inwood and Riverdale Parks.

Management Implications

If crash years operate at a rate of approximately one a decade or less, then most parks of 0.61km^2 or larger will probably remain stable within 15 - 20 years. If substantial reductions in adult survival occur more frequently or if the park in question is particularly small, then local extinction becomes a concern in 5 – 10 years. This study assumed that park populations exist in a vacuum in that I did not model immigration into parks and yearling dispersers effectively died when they left their natal park. This may not be the case as all three urban parks were within 4km of each other (dispersing yearlings can move up to 16.9km, although the average is 2.7 – 4.4km (Belthoff and Ritchison 1989, Gehlbach 1994)), and any successful dispersal among parks will increase the persistence of local populations. Future monitoring and research should focus on measuring the long-term variability in adult survival, obtaining estimates of reproduction in urban parks, and the occurrence and magnitude of "bad" years.

Metapopulation dynamics of the overall NYC population clearly need to be investigated, but managers should not hinge the viability of local screech owl populations on chance dispersal from other parks or the suburbs outside of New York. Management options for screech owls in urban parks are limited since adult survival appears about as high as possible already. Typically, reproductive output can be enhanced at a site by installing nest boxes (which screech owls use readily) with predator guards, which often increases the available nest sites (VanCamp and Henny 1975) and potentially nest success. Boxes also provide cold weather roost sites which could enhance over-winter survival. However, given a crash rate of 0.15 (one event approximately every 6.67 years) in a 0.5km^2 park, a 50% increase in adult fertility would only decrease the 20 year extinction rate by 18.0%. In a 2.0km^2 park, the same increase in fertility would decrease the extinction rate by 50%.

Thus, the area effect on extinction risk is substantial and it appears that the best management strategy is to plan wooded parks larger than 1.0km^2. While increasing the total size of parks in a city is usually out of the question, future developments can be designed with this “minimum viable area” in mind. Also, opportunities to designate manicured areas or lawns as forest or forest-meadow restoration sites are available within many existing parks. Urban wildlife provides substantial cultural (Gilbert 1982, Pickett et al. 2001, DeStefano and DeGraaf 2003) and ecological (Flores et al. 1997, DeStefano and DeGraaf 2003, Cleveland et al. 2006) value but relatively few species – particularly predators – are able to persist in the most urbanized areas. Managers and city planners should strive to maintain and enhance populations of species that are able to make a living in the concrete jungle.

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Table 1 – Vital rates used in population modeling of eastern screech owls, Bedford, NY and New York City, NY, 2008 – 2010.

Population Parameter		Gehlbach (1994)			VanCamp and Henny (1975)	Nagy	
		Suburbs	Rural	Pooled	Rural	MRGP	NYC
Survival	Yearling Survival (S_y)	x	x	x	x	x	0.22*
	Adult Survival (S_a)	x	x	x	x	0.57	0.90
Reproduction	Proportion of Yearlings that Nest (NP_y)	x	x	0.88	0.80	x	x
	Fledges/All Nesting Yearlings (F/N_y)	1.80	0.80	1.30	1.23	x	x
	Proportion of Adults that Nest (NP_a)	1.0	1.0	1.0	1.0	x	x
	Fledges/All Nesting Adults	1.40	0.70	1.05	1.32	x	x

* from Nagy (2004)

Table 2 – AIC_c results for survival (φ) and abundance modeling of vocalization-based recapture histories of eastern screech owls, Bedford, NY and New York City, NY, 2008 – 2010.

Model	k	ΔAIC_c	w_i	$-2\log(L)$
$\{\varphi(UR), f(.), p, c(.)\}$	3	0.00	0.51	318.99
$\{\varphi(UR), f(UR), p, c(.)\}$	4	2.13	0.18	318.89
$\{\varphi(P), f(.), p, c(.)\}$	4	2.14	0.18	318.91
$\{\varphi(P), f(P), p, c(.)\}$	5	3.23	0.10	317.70
$\{\varphi(.), f(.), p, c(.)\}$	3	6.63	0.02	325.62
$\{\varphi(.), f(P), p, c(.)\}$	4	7.82	0.01	324.58
$\{\varphi(.), f(UR), p, c(.)\}$	4	8.80	0.01	325.56

Table 3 – Extinction rates (% simulations extinct out of 5,000) of simulated eastern screech owl populations in hypothetical urban parks.

Park Size (km^2)	Crash Rate (annual)	Years Into the Future				
		5	10	15	20	50
0.25	2.5%	0	0	0	0	0
	5%	0.74	2.6	5.46	8.84	35.46
	10%	1.88	7.66	15.84	24.7	71.44
	15%	8.32	27.22	45.28	61.68	96.54
0.61	2.5%	0	0	0	0	0
	5%	0.1	0.42	0.96	1.68	11.16
	10%	0.28	1.32	3.84	7.76	41.68
	15%	1.22	7.56	18.04	30.1	85.22
1.00	2.5%	0	0	0	0	0
	5%	0	0.04	0.12	0.26	3.24
	10%	0.02	0.36	1	2.58	18.38
	15%	0.08	1.82	5.98	13.16	62.48
3.62	2.5%	0	0	0	0	0
	5%	0	0	0	0	0.06
	10%	0	0	0	0	1.02
	15%	0	0.08	0.34	1.06	16.46

Table 4 – Estimated abundances (SE) of eastern screech owls from capture-mark-recapture modeling of vocalization-based recapture histories of eastern screech owls, Bedford, NY and New York City, NY, 2008 – 2010.

Park	2008	2009	2010	Density (Mean abundance/km2)
Inwood (0.61km^2)	3.76 (1.85)	7.68 (1.55)	5.12 (1.24)	9.0
Van Cortlandt (3.62km^2)	7.52 (2.68)	7.68 (1.55)	11.52 (1.94)	2.5
MRGP (3.11km^2)	13.15 (3.64)	8.96 (1.68)	6.40 (1.40)	3.1
Riverdale (0.25km^2)	x	x	8.81 (3.22)	35.9

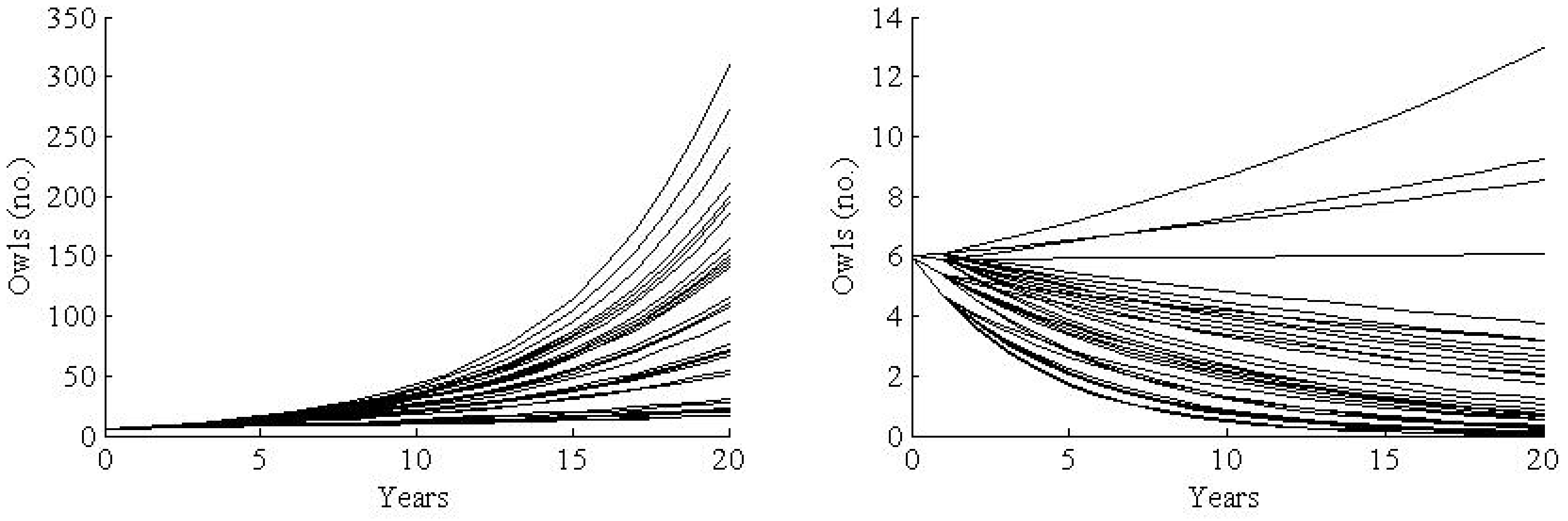

Figure 1 – Outcomes of vital-rate combination models of eastern screech owls in urban (left) and rural-suburban parks (right). Vital rates used for each combination are found in Table 1.

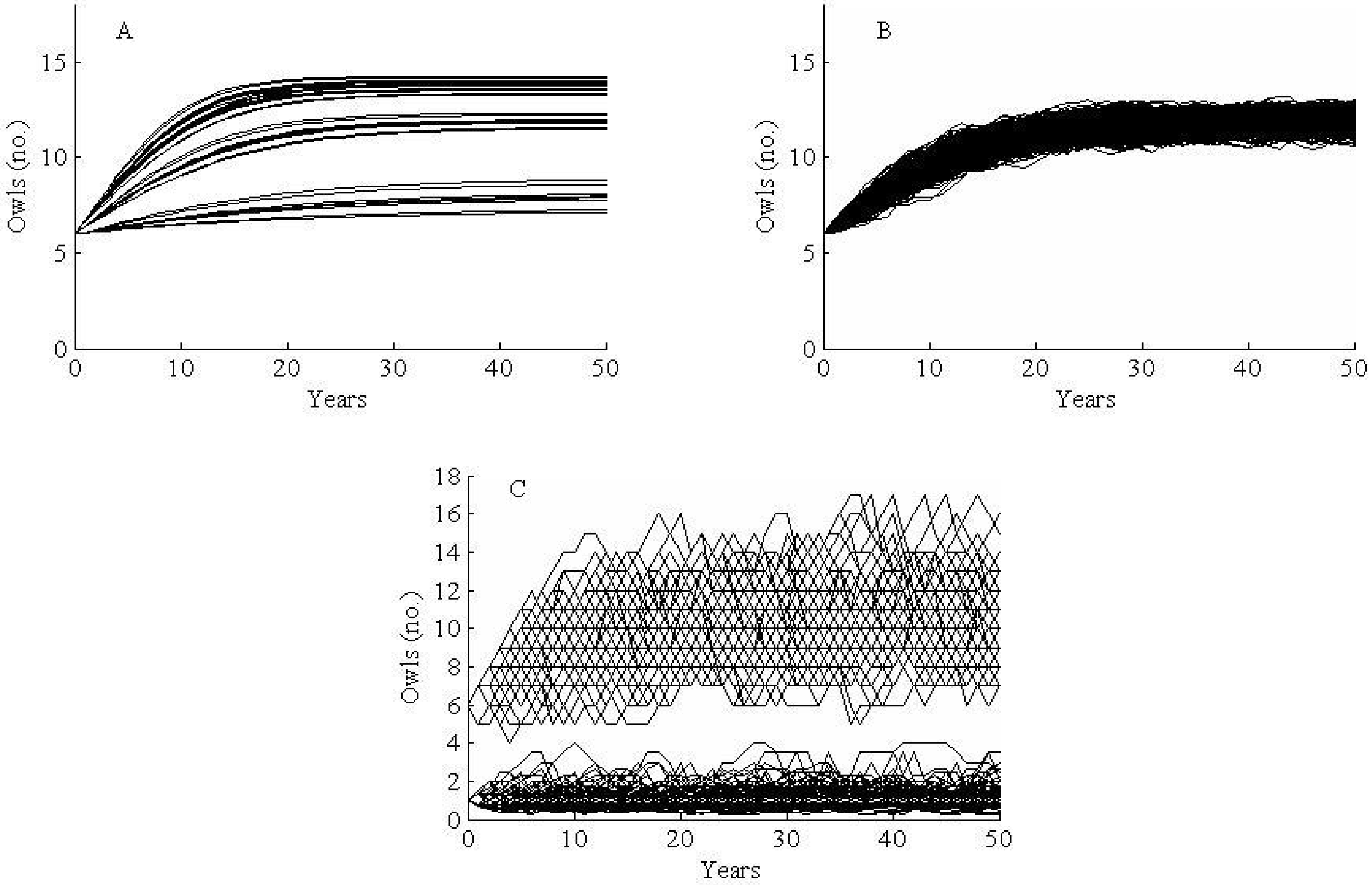

Figure 2 – Density dependent outcomes of three models of eastern screech owls in an 1.0km2 urban park: individual vital rate combinations (A), stochastic (B), and sex-specific and rounded stochastic (C). The lower set of lines in C display the sex ratio.

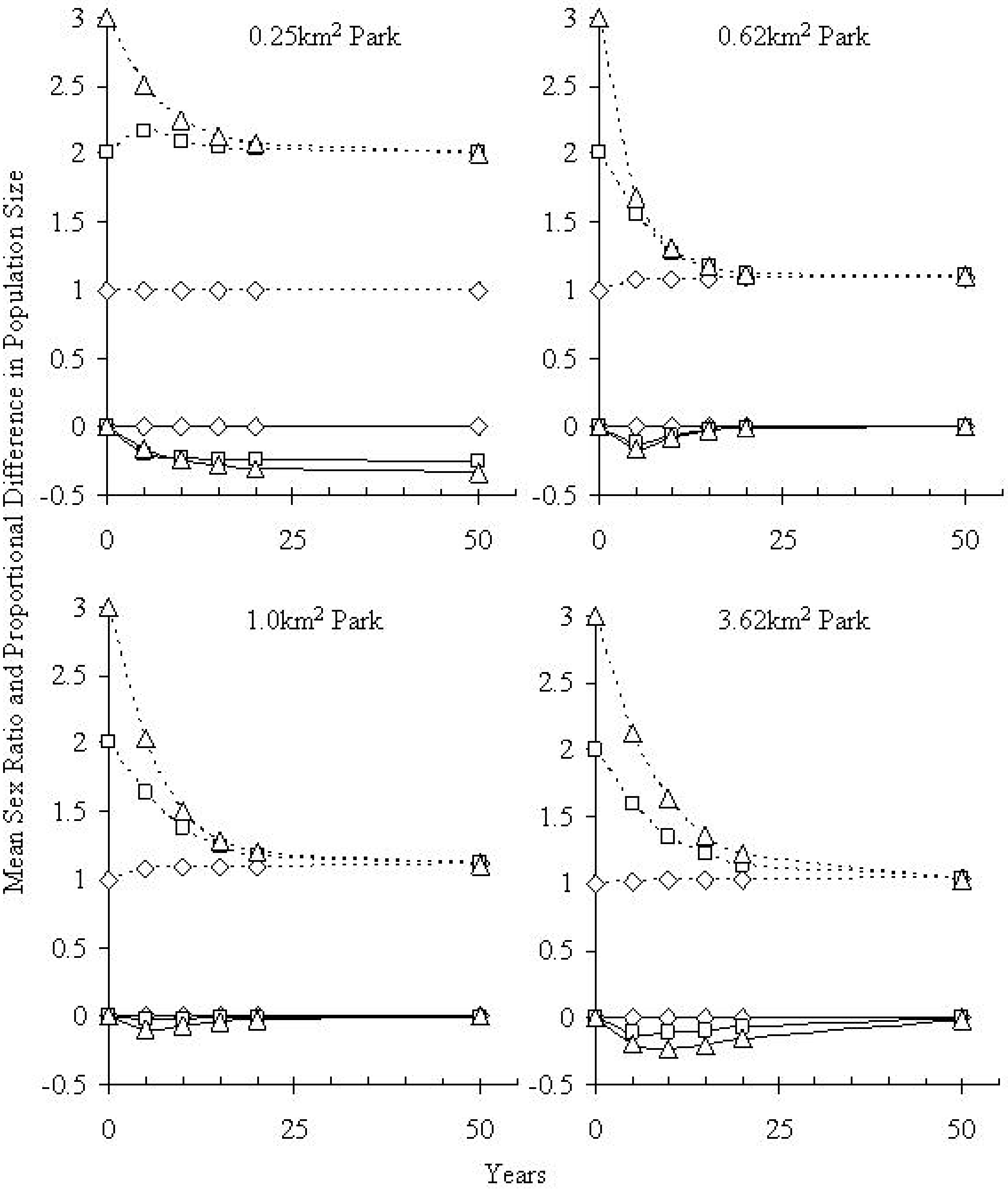

Figure 3 –Fluctuations in mean population size and sex ratio due to initial sex ratios of 3:1 (△), 2:1 (□) and 1:1 (◊) of modeled eastern screech owl populations in hypothetical urban parks. Dashed lines represent sex ratio fluctuations and solid lines represent mean proportional differences from the same population with a 1:1 sex ratio.

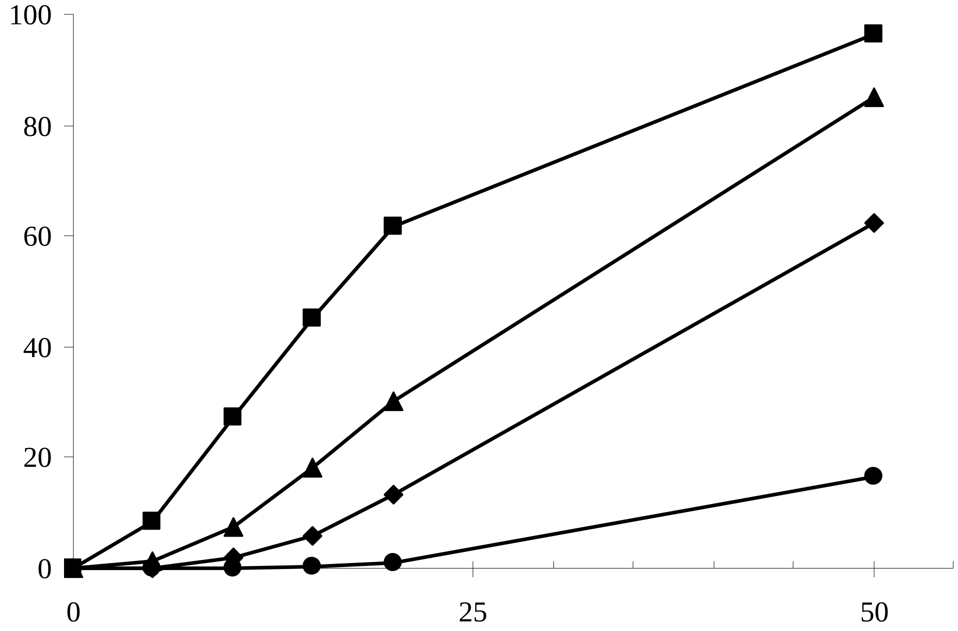

Figure 4 – Extinction rate (out of 5,000 simulations) of simulated eastern screech owl populations in hypothetical urban parks of 0.25 (■), 0.62 (▲), 1.0km (♦), and 3.62km^2 (●) with an annual crash rate of 0.10.

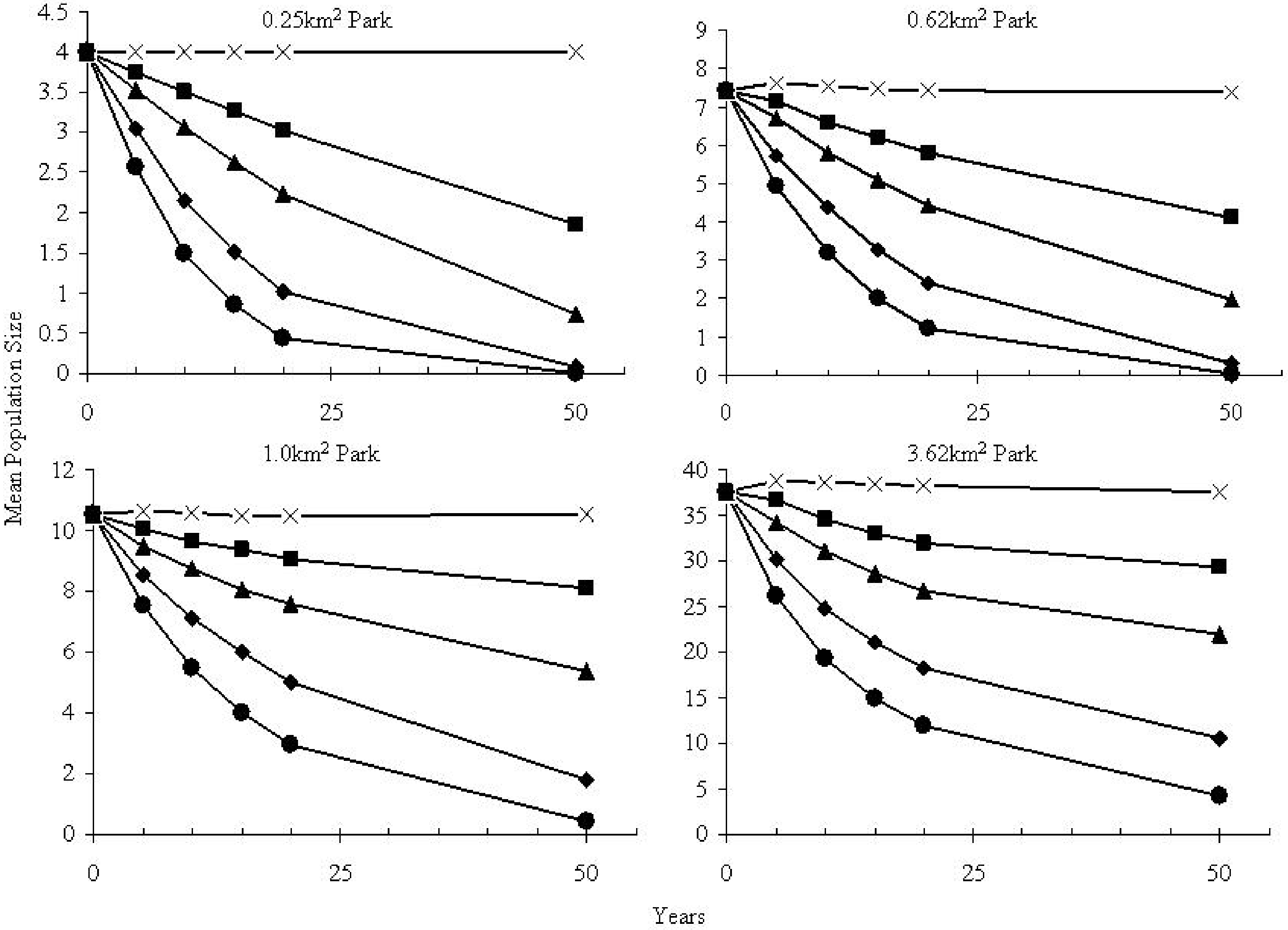

Figure 5 – Simulated population sizes of projected eastern screech owl populations in urban parks with crash rates of 0 (×), 0.025 (■), 0.05 (▲), 0.10 (♦), and 0.15 (●) annually.

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Chapter 4: Validation of a Citizen Science-Based Model of Site Occupancy for Eastern Screech Owls with Systematic Data in Suburban New York and Connecticut

Abstract

We characterized the landscape-level habitat use of *Megascops asio* Linnaeus (Eastern Screech Owl) in a suburban/urban region of New York and Connecticut using citizen–science methodologies and GIS-based land-use information. Volunteers sampled their properties using call-broadcast surveys in the summers of 2009 and 2010. We modeled detection and occupancy as functions of distance to forest and two coarse measures of development. AIC_c-supported models were validated with an independent dataset collected by trained professionals. Validated models indicated a negative association between occupancy and percent forest cover or, similarly, a positive association with percent impervious cover. When compared against the systematic dataset, models that used forest cover as a predictor had the highest accuracy (kappa = 0.73 ± 0.18) in predicting the occupancy observations in the systematic survey. After accounting for detection, both datasets support similar owl-habitat patterns of predicting occupancy in developed areas compared to highly rural. While there is likely a minimum amount of forest cover and/or maximum level of urbanization that Screech Owls can tolerate, such limits appear to be beyond the ranges sampled in this study. Future research that seeks to determine this development limit should focus on very urbanized areas. The high accuracy of the citizen science models in predicting the systematic dataset indicates that volunteer-based efforts can provide reliable data for wildlife studies.

Nagy, C., K.Bardwell, R.F. Rockwell, R. Christie, M.Weckel. *In press*. Validation of a Citizen Science-Based Model of Site Occupancy for Eastern Screech Owls with Systematic Data in Suburban New York and Connecticut. Northeastern Naturalist.

Introduction

As urbanized and suburban areas expand, many researchers are now investigating how more common and generalist wildlife species can – or can not – tolerate and adapt to human presence and development. Information regarding “urban adapter” species can assist managers and developers enhance biodiversity in developed areas or to design future developments with wildlife in mind. *Megascops asio* Linnaeus (Eastern Screech Owl) is a common raptor in eastern North America (Gehlbach 1995) and in the northeastern United States can be found in mixed young-to-middle aged forest (Bosakowski and Smith 1997, Gehlbach 1995, Smith and Gilbert 1984). It is well-known for tolerating some amount of development – indeed there are many instances of Screech Owls selecting or having higher survival and reproductive rates in lightly developed areas and/or edge habitats than in undeveloped, contiguous forest (Artuso 2009, Bent 1938, Gehlbach 1994, Smith and Gilbert 1984, Sparks et al 1994). However, in extremely urbanized areas (e.g., New York City and the adjacent municipalities), it is not ubiquitous.

Despite a wealth of general knowledge of the Eastern Screech Owl’s habitat, there has been little work (see Artuso 2009) done to quantify the response of Screech Owls to development over a large landscape that includes varying levels of development (e.g., how urban is too urban?). While *Strix occidentalis* Xantus De Vesey (Spotted Owl) and other less-than-common owls (*Strix varia* Barton (Barred Owl); *Athene cunicularia hypugaea* Molina (Burrowing Owl); *Aegolius acadicus* Gmelin (Saw–Whet Owl)) have been the subject of numerous habitat modeling studies (Spotted Owl: Azuma et al. 1990, Carroll and Johnson 2007, Franklin et al. 2000; Barred Owl: Corbin 2007, Singleton et al. 2010; Burrowing Owl: Lantz et al. 2007, Stevens 2008; Saw–Whet Owl: Grose and Morrison 2010), the Eastern Screech Owl is not a species of concern and has not received similar management-oriented attention.

Nevertheless, given the rapid spread of urbanized ecosystems, it seems prudent to better understand the impact of human development on habitat selection, population dynamics, and adaptation on Screech Owls.

Studying a widespread yet cryptic species such as the Screech Owl across a fragmented and largely privately owned landscape presents substantial challenges for data collection. In suburban areas, most of the land is owned privately and would require immense logistical effort to obtain access permission and sample in a timely manner. Additionally, staff and funding resources for a non-game, non-threatened species are limited and if one wishes to address landscape-level questions, traditional labor-intensive and costly methods (telemetry, mist netting, roost/nest box surveys) are simply infeasible. However, citizen science methodologies are becoming increasingly well-developed by wildlife researchers wishing to obtain data over large areas and who recognize the importance of involving the local community in conservation and management decisions (Bonney et al. 2009, Dickinson et al. 2010, Silvertown 2009). While in some circumstances, citizen science certainly has its own limitations regarding sampling bias and feasible research objectives (Bonney et al. 2009, Lepczyk 2005, Nerbonne and Vondracek 2003, Webster and Destefano 2004), most concerns regarding the quality of data collected by citizen science observers vs. trained “experts” have proven relatively trivial if proper training is ensured (Cohn 2008, Galloway et al. 2006, Penrose and Call 1995). If researchers can properly frame their objectives, train their volunteers, and provide some independent validation of their volunteer data, citizen science methodologies can be a very useful complement to more rigorous techniques, with the added benefit of involving stakeholders in local wildlife management.

In this study, we sought to measure Screech Owl distribution over a three-county area in Westchester and Putnam, NY and Fairfield, CT counties in relation to human development to evaluate the relationship between Screech Owl occupancy and urbanization. We used measures of development and forest cover around each survey site. Small scale site-specific variables certainly play a role in Screech Owl habitat selection (Belthoff and Ritichison 1990, Sparks et al. 1994), but we hoped to develop models that would find landscape-level patterns and could be easily implemented in new areas by natural resource managers.

We used a citizen science (CS) framework to collect information on Screech Owl distribution over a tri-County area and build our initial occupancy model. To evaluate the efficacy of this effort, we tested our CS models against a smaller, independent dataset collected systematically (SYS) in a section of the larger study area (the town of Ossining in Westchester County, NY). If the models developed with the CS dataset performed well in predicting the SYS dataset, then we could be confident that our citizen science methodology provided reliable estimates. In general, testing models with independent data is the ideal method of performance validation (Fielding and Bell 1997, Verbyla and Litvaitis 1989) and in addition to testing occupancy patterns of Screech Owls, our approach could further assess the congruence between citizen science and more traditional sampling frameworks.

Field–Site Description

The citizen science component of the study was conducted in Westchester and Putnam counties, in New York State, and Fairfield County in Connecticut. These three contiguous counties lay on the eastern side of the Hudson River. The landscape was generally a suburban mix of residential towns with light commercial development, a few large cities and, in the northern sections, larger areas of undeveloped forest. There was a distinct urban–rural gradient, with urbanization declining as one moves north through the counties and away from New York

City and, to a lesser extent, the City of Stamford, CT in southern Fairfield County. Putnam County was the most northern and rural of the three counties, with population densities along U.S. census tracts ranging from 42 to 755 people/km^2 ($\bar{x}$ = 167 people/km^2). The population density of Fairfield County ranged from 133 to 14,207 people/km^2 ($\bar{x}$ = 567 people/km^2). Westchester County had the steepest urban to rural variation, with population densities ranging from 87 people/km^2 in the northernmost sections of the County to 20,812 people/km^2 in the city of Mt. Vernon on the border of New York City ($\bar{x}$ = 733 people/km^2; U.S. Census Bureau 2010).

Methods

Field Protocol

Screech Owls are readily found using call-broadcast surveys (Cavanagh and Ritchison 1987, Johnson et al. 1981, Ritchison et al. 1988). Such surveys are inexpensive, easy to learn and perform, and thus lent themselves to a volunteer-based study. Survey protocol was identical in both the citizen science and systematic surveys: recordings of Screech Owl calls were played with a pattern of 20 seconds of calls (alternating between “bounce” and “whinny” calls, see Cavanaugh and Ritchison 1988) and 20 seconds of silence for 10 minutes. If an owl responded, the calls were stopped. All surveys were performed after dusk.

Citizen Science Survey

The citizen science aspect of this study was performed by volunteers who conducted call surveys on their properties at least twice in April to September of 2009 and 2010. Volunteer data collectors from the suburban Westchester and Putnam Counties, NY and Fairfield County, CT were recruited at local nature preserves, County Parks and schools in the spring of 2009. Additional volunteers were enlisted via the Ossining, NY School District in 2010 as part of a multiple-school science project. All recruitment sessions consisted of information and training workshops delivered by one or more of the authors. Participants learned about owl life history and species identification, habitat modeling and occupancy analysis, and how to conduct broadcast surveys at their homes. Field demonstrations were also provided following each workshop. Detailed directions, information, and downloadable owl call tracks were also available at a project website. The majority of the citizen scientist participants came from central Westchester.

We encouraged participants to perform 4 – 6 surveys in a six month period of April to September. We used this time frame to conduct surveys because owls most readily respond during the spring through late summer (Ritchison et al. 1988), and we thought volunteers would most likely perform surveys during the warmer months. Participants submitted data via an online survey or by direct email to project staff. Required data included date, survey address, time of survey, whether an owl was seen, heard, vocalized, or failed to vocalize. All participants conducted their surveys at their property or at a previously agreed-upon location. Street addresses were converted to GPS coordinates using Batchgeo (Holmstrand 2010). Our analysis required a minimum of 2 surveys per site if no owls were detected; a site that was surveyed only once was usable if an owl was detected.

To maintain volunteer interest, we updated all participants with current project information on a monthly basis. This included posting an interactive sighting map (via GoogleMaps API) that showed the current distribution of positive and negative sightings on the project website. We also held periodic project meetings and “owl walks” for interested participants. The downloadable recordings, data submission form, and progress maps were password protected on the website and accessible only to project participants in an attempt to minimize spam and “unauthorized” surveys as well as keep owl locations somewhat confidential. The website home page, survey instructions, and recruitment information were public.

Systematic Survey

In the summer of 2010 we established 30 systematic sites in the village (3024 people/km^2) and surrounding town (696 people/km^2) of Ossining, Westchester County, NY, which lies along the Hudson River in Westchester County about halfway between New York City and the northern extent of Putnam County. We chose Ossining to test our model owing to diversity of habitat types from dense human development in the village to more forested area in the surrounding town. Points were initially set in a 500m grid across the entire city; we later adjusted three points in the field for safety and security reasons because they were near a state prison. We alerted nearby residents and the Ossining Police Department prior to each survey night. Each of these 30 sites were surveyed three separate times between June and July 2010.

Habitat Measurement

Our chosen habitat covariates were measures of urbanization and human development and forest cover. We wanted our model to be easily used by managers and others and thus used only easily available GIS–based covariate data. Land–use and vegetative cover information was obtained from the 2006 NLCD (Fry et al. 2001). The NLCD provides land use categorizations and percent impervious (pavement and buildings) cover at 30 x 30m resolution for the entire United States. We characterized the amount of urbanization and forest cover in a 200m radius buffer zone around each CS and SYS survey site. We characterized the amount of urbanization of each survey site by the average percent impervious cover in the raster cells within the 200m zone (12.5ha, slightly larger than the average size of Screech Owl home ranges in suburban areas of 6 – 11ha; Gehlbach 1995) around each site (%I). Forest cover was estimated by the average number of forested cells out of total cells in the 200m survey zone (%F). These measurements are negatively correlated (e.g., a site with 100% impervious cover in all cells with have no forested pixels). However, there is room for considerable variation between the two measures since a cell can be categorized as forested and still have up to 80% non-forested area, and we thought it worthwhile to test each separately. All geographic measurements and calculations were performed using ArcGIS 9.3 and the Spatial Analyst extension.

Analysis and Model Validation

Our analysis consisted of two main phases. We first modeled detection and occupancy of Screech Owls in the CS dataset as functions of percent impervious or percent forested cover. Models that fit the data well were then used to predict the occupancy states of the SYS sites. Then the actual observations of the SYS data were compared to these predictions. We chose this method in order to simulate how wildlife managers would use a predictive model – determining occupancy probabilities for unknown sites. Accuracy of a model was defined as how often were the model's predictions correct after accounting for chance.

Occupancy and Detection Modeling of CS Dataset Predictive habitat mapping is a powerful tool for wildlife managers seeking to determine where a species is likely found (Austin 2002, Guisan and Thuiller 2005, Guisan and Zimmerman 2000), prioritizing conservation or restoration sites

(Cabeza et al. 2004, Guisan and Thuiller 2005), corridor identification (Clevenger et al. 2002, Corsi et al. 1999), and investigating patterns of species distribution in relation to environmental factors (Freeman and Moissen 2008*a*, Guisan and Thuiller 2005, Guisan and Zimmerman 2000). We used the occupancy modeling methodology developed by MacKenzie et al. (2006) where detection rate (p) and occupancy (ψ) are logistically modeled using maximum likelihood and candidate models estimating both are evaluated with Akaike's Information Criterion (AIC; Burnham and Anderson 2002). In this study we adjusted AIC to AIC_c for use with small sample sizes (Hurvich and Tsai 1989). We modeled p first under an intercept-only model of ψ and then used the AIC_c –selected best model for p while modeling ψ with covariates to reduce the size of the candidate model set (Mackenzie 2006, Negroes et al. 2010) and to enable comparisons of detection rate across the CS and SYS methodologies. All occupancy and detection modeling was performed with program Presence 3.0 (Hines 2006).

Eastern Screech Owls are often characterized as "edge" species and may occupy large undeveloped forest patches less often because of competition with and predation by larger owls and hawks (Artuso 2009, Craighead and Craighead 1956), lower nest success, or lower population density (Artuso 2009, Gehlbach 1994). Therefore, we thought it worthwhile to test relationships other than simple linear responses and included quadratic terms in some of our models. Our candidate model set included 5 models: an intercept-only model ([.]), two 1-parameter models ([%I] and [%F]); and two quadratic models ([Q%I] and [Q%F]). Both detection and then occupancy were estimated with these models.

Model validation with SYS dataset AIC is a relative ranking of the models under consideration; the best model out of a set can still be poor if the entire set is poor overall. A relevant and well-chosen model set is an assumption of using AIC (Burham and Adnerson 2002) and ideally, models should be validated by comparing model predictions to independent data. In the case of habitat models, model-predicted probabilities should be compared to the number of actual presences and absences in a validation set collected from other locations (Fielding and Bell 1997, Verbyla and Litvaitis 1989).

Our objective of validating our CS occupancy models with new data from the CS survey became somewhat complicated because we sought to incorporate detection rate. Not all of the CS sites where we did not detect owls could be assumed to be truly unoccupied. To quantify detection rate and determine which unoccupied sites could be considered true "absences," we modeled detection rate in the SYS dataset identically to the CS dataset. The AIC_c-selected best model for p was then used to calculate p_i for each SYS site. The probability of at least one owl detection given the three visits was calculated for each site based on the model-specific detection rates ($Pfinal_i|p_i$, x surveys $= 1–(1–p_i)^x$). A site was assumed not occupied if the $Pfinal_i$ was >0.85, i.e., we were comfortable with a 15% chance at most that we would include a site with no detections that was really occupied. If this probability was <0.85, the site was removed as we concluded that there was a substantial chance that the site was occupied despite no detections. This gave us a subset of presences and absences we were confident in using as a validation set.

All CS occupancy models that performed better (i.e., had lower AIC_c scores) than the intercept-only models were considered in validation with the SYS dataset. Occupancy probabilities were calculated for each of the SYS sites; these predictions would be compared to the SYS presence and absence observations. In addition, based on the Akaike weights (w_i), we included a set of predictions based on the w_i-averaged occupancy predictions of the top models. Model-averaged parameter values were not possible because the varying response types that we modeled (linear and quadratic) would confound parameter averages (Wilson et al. 2007, Blum et al. 2004, Burnham and Anderson 2002).

To assess the predictive accuracy of a habitat model, the predicted probabilities must be converted to binary predictions of “presence” or “absence,” which are then compared to the observed presences and absences. A threshold probability must be set that groups predictions above the threshold as predicted presences and those below it are classified as predicted absences. Traditionally this threshold is set at 0.5 (Freeman and Moisen 2008*a*). However, the choice of 0.5 is arbitrary and model accuracy can vary greatly across threshold values (e.g., 0.4, 0.6, etc.). In addition, accuracy can vary greatly according to the rarity or commonness of the species across the study area (termed “species prevalence” in most habitat modeling studies; Freeman and Moisen 2008*a*, Allouche 2006, Wilson 2005). We calculated optimized threshold values so the observed prevalence – after accounting for detection – was maintained in the final predictions, as recommended by Freeman and Moisen (2008*a*).

Lastly, there are numerous methods of scoring model accuracy beyond the simple proportion of correct predictions which take chance correct predictions into account (kappa: Freeman and Moisen 2008*a*, Landis and Koch 1977; True Specific Statistic (TSS): Allouche et al. 2006), and the difference between correctly predicting presences (sensitivity) and absences (specificity; Fielding and Bell 1997, Freeman and Moisen 2008*a*). We calculated the proportion-correctly-classified (PCC; correct predictions/total sites), sensitivity (correctly predicted presences/all predicted presences), specificity (correctly predicted absences/all predicted absences), kappa (model accuracy corrected for chance) and the TSS for each occupancy model as measures of accuracy.

Finally, receiver-operating characteristics (ROC) plots allow for threshold-independent measures of model performance (Freeman and Moisen 2008*a*, Manel et al. 2001, but see also Lobo et al. 2008). An ROC plot displays true positives (sensitivity) vs. false positives (1–specificity) across a large number of threshold values. A model that performs well will asymptote at 100% sensitivity at low levels of 1 – specificity (see Fielding and Bell (1997) for examples). Thus, the area-under-curve (AUC) proportion shows how a model performs compared to randomly assigning observations (i.e., AUC = 0.5) independent of threshold as generally better models will have larger AUC's (e.g., >0.8 or >0.9). We generated ROC graphs and AUC proportions for the validation model set as additional measures of model performance. These measures of accuracy would evaluate the agreement of the 2 datasets, and thus give a measure of congruence between the citizen science data and the systematic data. Site–specific detections and occupancy predictions were estimated using Presence 3.0. Optimized thresholds, model accuracy indices, and ROC plots were calculated using the PresenceAbsence library (Freeman and Moisen 2008*b*) for R statistical software.

Results

One-hundred ninety-seven individuals attended workshops or registered online to conduct the citizen science survey. At the end of August 2010, 63 sites were usable in our analysis, i.e., these participants had submitted adequate data. Effort of these 63 participants ranged from 1 survey (12 sites) to as many as 7 surveys (2 sites) per site. Percent forest and impervious cover were similar in both studies (Table 1).

Detection during the citizen science surveys was best modeled by [p(Q%I)], a quadratic model of percent impervious cover ($AIC_w = 0.71$; $\beta_1 = 0.0978 \pm 0.0142$ (mean ± SE); $\beta_2 = -$

0.0027 ± 0.0005). Detection ranged from approximately 0.4 to 0.6 until it fell below 0.4 at 35% impervious cover. Both percent forest and impervious cover appeared in the top ψ models (Table 2). There was no evidence of overdispersion in any of the models (c-hat ≤ 1.0).

In the SYS dataset, detection was best modeled linearly using percent forest cover, [p(%F)] ($AIC_w = 0.72$). Detection increased rapidly with percent forest cover ($\beta_1 = 0.1105 \pm 0.0403$); most sites had a derived $p > 0.45$. Out of 30 sites, an owl was detected at least once in 14 sites. Based on the modeled detection probabilities, 5 out of the 16 sites with no detections had ≥85% chance of being true absences after three visits and thus were included in the model validation phase. Optimized threshold values were calculated based on 5 absent sites and 14 present sites.

Three models – [ψ(%F)]; [ψ(Q%F)]; and [ψ(%I)] – performed better than the intercept only model and were compared to the SYS validation set. These models correctly predicted the occupancy status of 89% of the sites. However, indices other than PCC should be used as the final measure of model performance. Originally developed to assess agreement between observers (Cohen 1960, Landis and Koch 1977), kappa has been widely used to validate confusion matrices of species presence-absence data. It is considered superior to PCC because it takes chance agreement between observed and predicted results into account. Kappa itself has been criticized for being biased at low and high levels of prevalence and Allouche et al (2006) recommended TSS as a prevalence-unbiased measure of accuracy. In this study, kappa and TSS agreed on the most accurate models (kappa and TSS = 0.73), the two forest cover models ([ψ(%F)] and [(ψ(Q%F)]). The model-averaged predictions also had high kappa and TSS, while the [%I] model had the lowest kappa of the four (Table 3). ROC curves were also similar, and the four predictor models all had AUC scores > 0.85.

Discussion

Implications Regarding Eastern Screech Owl Ecology

The two models with the most accurate predictions (as measured by kappa and TSS) both indicated that Screech Owl occupancy declined around >50% forest cover. These patterns were observed in the CS dataset as well (Figure 1). We had expected to find a “humped” relationship between occupancy and our chosen covariates, such that Screech Owls would tend to occupy sites with moderate levels of development and forest cover. The advantageous characteristics of suburbia include more stable climate, larger and/or concentrated food sources, and fewer large raptors (Artuso 2009, Gehlbach 1994, Smith and Gilbert 1984), although the suburban landscape has its own perils as well, e.g., secondary poisoning, vehicles, more *Procyon lotor* Linnaeus (Raccoons), *Didelphis virginiana* Kerr (Opossums; which prey on eggs and nestlings) and *Sciurus carolinensis* Gmelin (Eastern Grey Squirrels; which compete for nest cavities). Forested areas may also provide more natural nest sites and more invertebrate and/or amphibian prey.

Instead, our models seemed to predict a largely monotonically increasing relationship among Screech Owl occupancy and decreasing forest/increasing development. Taken literally, the model curves for the best supported model, [(ψ(%F)], seems to suggest that Screech Owl occupancy is nearly assured at <10% forest cover (Figure 1). The prediction curve of [(ψ(Q%F)] was nearly identical to the simpler linear model of percent forest. The [(ψ(%I)] model also suggests that occupancy approaches 1 at >50% impervious cover (Figure 2). However, the forest cover covariate we used is derived from satellite-based reflectance images and thus quantifies the landscape at a coarse level, and a forest cover of 0% by this measure does not necessarily mean the cell is devoid of trees. A given cell must have at least 20% forest cover to be classified as such, so there is ample room for some amount of overstory in a cell that is not classified as forested. In Texas, screech owls were monitored nesting in suburban areas with tree densities as low as 71 ± 9.3 trees/ha (Gehlbach 1994), which corresponds with approximately 6 trees per raster cell in the NLCD. A cell with this few trees would likely not be classified as forested. Additionally, the maximum percent impervious cover we sampled was 67%, so all sites had at least some (>30%) non-impervious cover. It seems unlikely that Screech Owl populations could persist in areas that are at the farthest end of the rural-to-urban spectrum without access to any vegetated cover, and the monotonic relationships we observed are somewhat due to the fact that the maximum impervious cover sampled in our suburban Westchester, Putnam, and Fairfield sites was around 65 – 70%. However, since the models developed from the CS dataset were still able to predict the SYS dataset well, the functional pattern of high Screech Owl occupancy in areas of less forest cover was supported across the sampled extent of forest and impervious cover. Our measure of percent forest cover seemed to fit suburbia well (ranging 0 – 99% fairly evenly), but a measure with a broader scale will be needed in more urbanized areas.

We expected that our sampling area, particularly within Westchester County, would find the upper level of urbanization at which Screech Owl occupancy would decline, as previous studies have characterized areas with tree canopy cover of 71.1 to 96.5% (Gehlbach 1994) and percent greenspace cover of 46 – 70% (Artuso 2009) as “suburban” (although in Texas, Gehlbach (1994) also reported that Screech Owls can successfully nest in areas with tree densities as low as 53/ha). We had just two usable CS sites in very urbanized cities, an occupied site in White Plains (2048.5 people/km^2) and a non-detection site in New Rochelle (2,692.5 people/km^2; U.S. Census Bureau 2010). Screech Owls are quite generalist in their habitat selection (Craighead and Craighead 1956, Gehlbach 1994), diets (Craighead and Craighead

1956, Gehlbach 1995, Marti and Hogue 1979, VanCamp and Henny 1975), and nest site selection (Belthoff and Ritchison 1990) and some developed sites likely have features on a smaller scale that make them suitable despite their higher levels of urbanization. While further research regarding the ability of dispersing owls to penetrate an urban matrix and occupancy patterns in highly urbanized areas is needed, it nevertheless appears that moderately developed urban areas (i.e., <70% impervious cover and/or 20% forested cover) can be suitable for Screech Owls. We would still expect occupancy rate to drop off at some point with increasing urbanization, and for managers interested in making predictions in suburban or urban areas, we would therefore recommend using a model that includes a measure of forest cover in a nonlinear relationship, similar to [(ψ(Q%F)].

Implications Regarding Citizen Science

A key finding of this study was the substantial agreement among the citizen–science and the systematic methodologies. In addition to the ability of our CS occupancy models to predict the SYS data, average detection rates in the CS study were almost identical (CS $p = 0.46 \pm 0.02$; SYS $p = 0.46 \pm .06$), which illustrated that our volunteer observers were as effective as our trained staff. Most avian studies require expertise in identifying species either by sound or sight. Our methodology avoided this problem first by training and supporting volunteers but – perhaps more importantly – employing a technique where the target species is easily identified (the call of the real owl the observer is listening for sounds the same as the call being broadcast). A number of volunteers also reported that the owl calls and pictures on the project web site helped them identify on the spot any other questionable birds they happened to hear (Barred Owl or *Bubo virginiensis virginiensis* Gmelin (Great Horned Owl) in a few cases, *Zenaida macroura*

Linnaeus (Mourning Doves) in others). Similarly, the occupancy analysis developed by MacKenzie et al. (2006) lends itself well to a citizen science program because it can incorporate varied numbers of surveys per site, missed surveys, multiple seasons, and incomplete covariate information. Still, at least 3 - 4 surveys per site are ideal and it was a challenge to find an adequate number of volunteers to perform multiple surveys.

Many points in our systematic study fell on private single–family residences. While most property owners allowed us on or near their property, there were several occasions where we were asked not to conduct owl calls anywhere in the neighborhood. Citizen science offers the possibility of accessing private properties by enlisting property owners as partners. Despite a potential sampling bias of using volunteers – that may have disproportionately lived near owls, were interested in owls and nature, joined because they already knew they had owls on their property, or failed to bother to report negative results – we were able to sample a similar range of habitats in the CS survey than in the SYS survey (Table 1).

The reliability of a citizen science approach to sample species distributions is particularly helpful for biologists looking to draw inferences across large scales of urbanization but may not have the resources or access they need (Dickinson et al. 2010). Citizen science certainly has implicit pitfalls and potential sampling biases must be taken into account. Researchers may not be able to find volunteers to sample in particular areas of interest; in this study we were only able to enlist a few volunteers who lived in the extremely urbanized areas of southern Westchester County, likely due to a combination of less interest and access. As well, volunteer recruitment and training, continuing correspondence, and maintenance of volunteer interest are challenging and time-consuming tasks that researchers must not take lightly if they hope to have a successful program. Employing methods that require only limited technical expertise can help greatly, as was the case in this study. All methodologies have limitations, and the advantages of citizen science may include greater amounts of data over a large geographic area (Devictor et al. 2010, Dickinson et al. 2010), access to private properties that make up the majority of the landscape in urban landscapes and are often the habitats specifically of interest to (sub)urban ecologists (Webster and Destefano 2004, Weckel et al. 2010), and partnership amongst researchers and stakeholders (Bonney et al. 2009, Cooper et al. 2007, Dickinson et al. 2010, Evans et al. 2005, Kransy and Bonney 2005).

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Table 1 –Model covariate means and sampled ranges used for occupancy estimation of Eastern Screech Owls in Westchester and Putnam, NY and Fairfield, CT counties, 2009 – 2010.

	% Impervious		% Forest	
	Citizen Science	Systematic Survey	Citizen Science	Systematic Survey
Mean	16.1	26.2	33.5	15.6
SD	14.9	17.0	31.2	24.0
Minimum	0.0	0.2	0.0	0.0
Maximum	54.3	68.0	99.3	87.9

Table 2 – $\mathrm{AIC_c}$ results for occupancy (ψ) models of Eastern Screech Owl observations using citizen science–based call–broadcast surveys in Westchester, Putnam, and Fairfield Counties, NY and CT, 2009.

Model*	k	$\Delta\mathrm{AIC_c}$	w_i	$-2\mathrm{Log}(L)$
ψ(%F),p(Q%I)	5	0	0.45	208.07
ψ(Q%F),p(Q%I)	6	1.88	0.18	207.50
ψ(%I),p(Q%I)	5	2.17	0.15	210.24
ψ(.),p(Q%I)	4	2.29	0.14	212.72
ψ(Q%I),p(Q%I)	6	3.51	0.08	209.13

*Detection (*p*) modeled as [p(Q%I)]

Table 3 – Accuracy of citizen science–based occupancy models on predicting systematic data of Eastern Screech Owl distribution in Ossining, NY, 2010.

ψ Model	OT[a]	Sens[b]	Spec[c]	PCC[d]	Kappa[e] (SE)	TSS[f] (SE)	AUC[g] (SE)
ψ(Q%F)	0.740	0.93	0.80	0.89	0.73 (0.18)	0.73 (0.20)	0.89 (0.08)
ψ(%F)	0.775	0.93	0.80	0.89	0.73 (0.18)	0.73 (0.20)	0.88 (0.09)
w_i–avg model	0.780	0.93	0.80	0.89	0.73 (0.18)	0.73 (0.20)	0.87 (0.09)
ψ(%I)	0.760	0.86	0.80	0.89	0.62 (0.20)	0.66 (0.18)	0.87 (0.10)

[a] Optimized threshold for categorizing a predicted absence or presence (Freeman and Moisen 2008*a*).

[b] Sensitivity – proportion of correctly classified presences out of all observed presences (Fielding and Bell 1997).

[c] Specificity – proportion of correctly classified absences out of all observed absences (Fielding and Bell 1997).

[d] Proportion of correctly classified observations (Freeman and Moisen 2008*a*).

[e] Proportion of correctly classified observations after accounting for the probability of chance agreement (Freeman and Moisen 2008*a*).

[f] True skill statistic: (sensitivity + specificity) – 1 (Allouche et al. 2006).

[g] Area–under–curve of receiver operator plot (Manel et al. 2001).

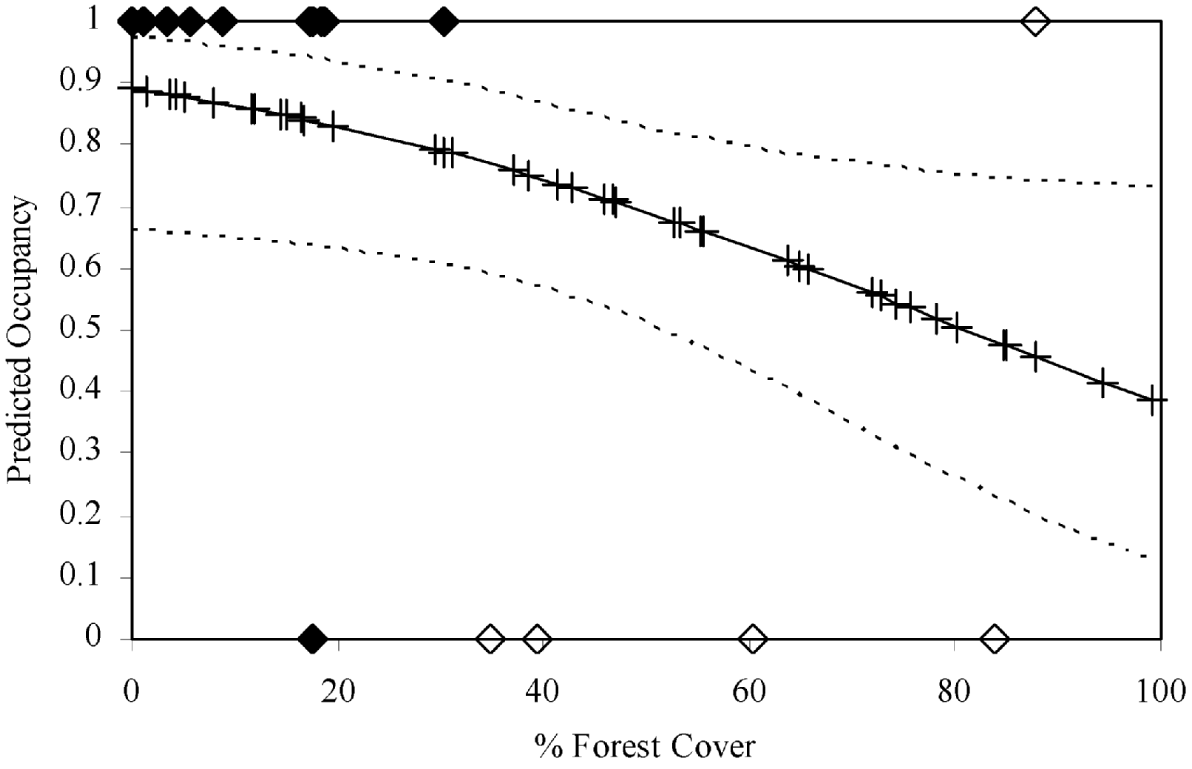

Figure 1 – Predicted occupancy of Eastern Screech Owls as a function of percent forest cover under the [ψ(%F)] model. Curvilinear lines represent predictions, lower, and upper 95% confidence intervals (β_1 = -0.0259 ± 0.0113). “+” marks along the prediction line represent citizen science sites. Filled and hollow diamond marks at ψ = 0 and ψ = 1 represent observed occupied and unoccupied SYS sites, respectively. Filled diamonds at ψ = 0 are occupied sites that were incorrectly predicted as unoccupied, and hollow diamonds at ψ = 1 are unoccupied sites that were incorrectly predicted as occupied.

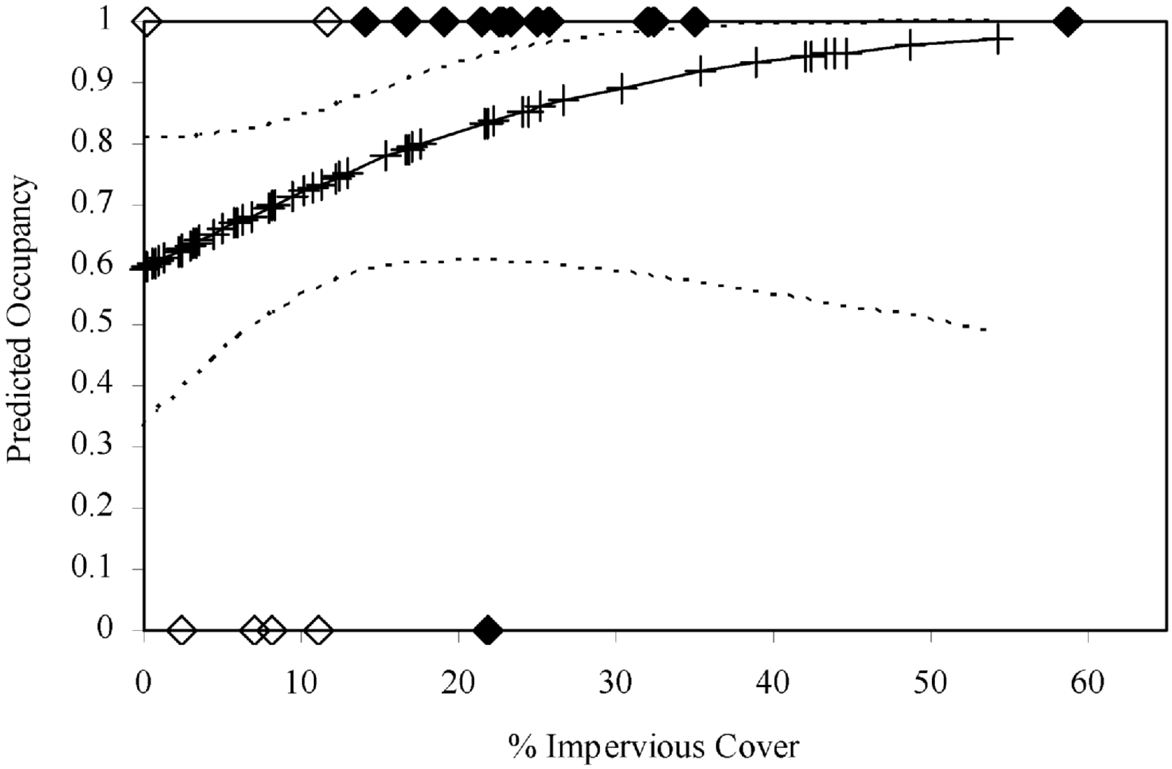

Figure 2 – Predicted occupancy of Eastern Screech Owls as a function of percent impervious surface cover under the [ψ(%I)] model. Curvilinear lines represent predictions, lower, and upper 95% confidence intervals (β_1 = -0.0569 ± 0.0402). “+” marks along the prediction line represent CS sites. Filled and hollow diamond marks at ψ = 0 and ψ = 1 represent observed occupied and unoccupied SYS sites, respectively. Filled diamonds at ψ = 0 are occupied sites that were incorrectly predicted as unoccupied, and hollow diamonds at ψ = 1 are unoccupied sites that were incorrectly predicted as occupied.

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Chapter 5: Occupancy Patterns of Eastern Screech Owls in Urban Parks in New York City and Adjacent Suburbs

Abstract

Eastern screech owls (*Megascops asio*) exist in a number of parks in New York City (NYC) and the cities of Westchester County, NY. To better inform management of urban screech owl populations, I gathered presence-absence data of screech owls in 16 urban parks in NYC and Westchester County using call-broadcast surveys. Occupancy and detection rates were modeled as functions of the presence or absence of larger native owls (barred (*Strix varia*) and great horned (*Bubo virgineanus*) owls) and eight geographic variables: total park area, total undeveloped forest area in parks, percent forest area, perimeter-area ratio of whole parks, perimeter-area ratio of forested area in parks, median percent impervious cover of a 200m buffer zone around parks, and percent forested grid cells in a 200m buffer zone around parks. Detection was best modeled by including the categorical presence or absence of larger owls. The most important covariates in terms of occupancy were percent impervious and percent forest cover of the buffer zones. The relative importance of these covariates suggests that characteristics of the areas surrounding urban parks need to be considered when managing park-dwelling screech owls. Generally, parks in less urbanized areas (low percent impervious and high percent forest cover) were more likely to contain owls, however, those parks in NYC that had owls still had >50% percent impervious cover. While screech owls can survive in parks in highly urbanized areas, there appears to be an upper limit to the amount of urbanization that can be tolerated regarding long-term population viability. This limit likely influences movement and immigration among city parks and from adjacent areas. To conserve urban wildlife with limited

dispersal ability, wildlife managers must consider the characteristics of the urban matrix and enhance inter-park or inter-greenspace movement as well as conditions within habitat islands.

Introduction

Biologists are becoming increasingly interested in how wildlife can persist and flourish in developed areas. While wildlife diversity is typically lower overall compared to more pristine areas, many species are able to take advantage of some amount of human development (Weckel and Giuliano 2001, DeStefano and DeGraff 2003, Webster and DeStefano 2004, François et al. 2008, Weckel et al. 2010). These species are often able to capitalize on anthropogenic food sources (Belant et al. 1998, Prange et al. 2003, Contesse et al. 2004), do well in early-successional habitats or habitat edges (Tigas et al. 2002, McKinney 2002), and can tolerate disturbances and stimuli (human activity, buildings, mechanical noise, fragmentation, etc.) associated with human development (VanDruff et al. 1996). However, much of what is termed "urban ecology" or "urban wildlife management" describes the population or community ecology of wildlife existing in suburban or even lightly urbanized areas (e.g., Grund et al. 2002, Lee and Miller 2003, Chace and Walsh 2006, Lopez et al. 2004, and see McIntyre et al. 2000). Ecosystem studies and a number of wildlife studies that focus on the most urban areas along the rural-to-urban spectrum have shown that ecosystem processes (McPherson et al. 1997, Savard et al. 2000) and wildlife populations (Fernandez-Juricic 2000, Grinder and Krausman 2001, Stout et al. 2006) within true cities have their own unique characteristics. Therefore, inferences regarding wildlife ecology in truly urban areas should be based on data collected in such areas – at least until broader trends are corroborated for a given species or system

The eastern screech owl (*Megascops asio*) is a small, non-migratory raptor, often found in suburban areas and can tolerate some amount of urbanization. Many studies have found that this species selects habitat that correlates with some urbanization and development (Lynch and Smith 1984, Gehlbach 1994, Nagy et al. *in press*) and screech owl populations often have higher densities and vital rates in suburban areas (Gehlbach 1994). However, barring some exceptions such as Norway rats (*Rattus norvegicus*) and rock doves (*Columba livia*), there is a point for most “urban” species where human development becomes too intense for them to persist in an area. In New York State, eastern screech owls are found in many residential neighborhoods in Westchester and Putnam Counties, NY (Nagy et al. *in press*). Yet, in the highly urbanized areas in New York City (NYC), screech owls have been found in only a handful of wooded city parks, although in the suburban borough of Staten Island, NYC, the screech owl is more common and can be found in many parks (Nagy, *unpub. data*). This pattern suggests that there is an upper limit to the screech owl’s ability to tolerate human development and thus conservation of the species within extremely urban areas is focused on managing populations within parks and other greenspaces.

Vital rate estimation and population modeling has suggested that screech owl survival is substantially higher in city parks than in more typical, rural or suburban habitat (see Chapter 2). However, the limited size of parks and their noncontiguous distribution across the urban landscape may lead to greater risk of local extinction. City-wide extinction could eventually occur if local extinctions accumulate and sites are not recolonized. Simultaneously, all parks are likely not created equal and attributes within a park – such as available forested area or habitat configuration – may affect the presence or absence of screech owls.

In this study, I estimated screech owl distribution in 16 urban parks, 13 in NYC and three in nearby cities in Westchester County (3 parks). I modeled site occupancy as a function of landscape-level variables to determine if site occupancy depended more on park size and within-park habitat availability or on the surrounding level of urbanization. If there was substantial evidence for the importance of within-park factors, then management recommendations could be applied on a park-by-park basis. If external variables such as the level of urbanization or park shape were found to be important, then managers would have to focus on larger scale measures (e.g., corridors or the establishment of new greenspaces).

Methods

Study Site Descriptions

The study took place in parks in southern Westchester County and within New York City (Figure 1). Nearly all parks consisted of developed areas (e.g., lawns, ball fields, playgrounds, etc.) as well as protected, undeveloped forest areas. The Westchester County sites were the Greenburgh Nature Center (GNC) in the town of Scarsdale; Twin Lakes Park in the city of New Rochelle; and Saxon Woods Park in the city of White Plains. These parks were located in distinctly high-suburban and urban areas in southern Westchester (population density 1,037, 2,693, and 2218 people/km^2 for Scarsdale, New Rochelle, and White Plains, respectively (U.S. Census Bureau 2010)). The landscape within the three parks primarily consisted of medium-aged eastern deciduous forest. All had large roadways and highways that bisected or ran adjacent and had public trail systems. Saxon Woods and Twin Lakes were managed by the Westchester County Parks Department; the GNC is a private non-profit preserve.

The NYC sites were parks under the management of the NYC Department of Parks and Recreation (NYCDPR). These parks typically saw substantially higher recreational use than the Westchester County Parks. Population density for the Bronx was 12,707 people/km^2 (5 parks), 26,879 people/km^2 for Manhattan (4 parks), 13,687 people/km^2 for Brooklyn (1 park), and 7,882 people/km^2 for Queens (3 parks). Undeveloped land in the NYC parks was usually medium-to-old-aged hardwood forest, but some parks (Pelham and Alley Pond) also had substantial wetland

and/or salt marsh areas. Pelham and Van Cortlandt had large golf courses within the park which were counted as forested habitat for owls in the landscape analysis (see below).

Data Collection

Call surveys for eastern screech owls were conducted in 16 urban and suburban parks in southern Westchester and the boroughs of Bronx, Brooklyn, Manhattan, and Queens, NYC. In each park, surveys were conducted along a 300m grid. Recordings of screech owl calls were broadcast for 10 minutes at each grid point. Each grid point in each park was surveyed once in the spring or summer of 2010 and each point was counted as a spatial replicate for occupancy and detection rate estimation (MacKenzie et al. 2006). The number of points in each park was based on area, with a minimum of 4 points regardless of area. Because of time constraints, Saxon Woods and Twin Lakes were surveyed at only four points each. Pelham Bay Park was the largest park and had 24 survey points.

Landscape Measurements

I was interested in what landscape variables might be associated with occupied parks. I hypothesized that a park would remain occupied over a long time frame – and thus have a good chance of being occupied at the point that I performed my surveys – if it had relatively high probabilities of immigration from other sites and of ensuring population persistence. I measured park-level variables that I thought would affect these two factors. Regarding the probability of immigration, I measured total park area (PArea), total forested area (FArea) of each park (larger parks should have a greater chance of being found by dispersing owls). Total area of the park was calculated from the Westchester (Westchester County Department of Planning 2004) and NYCDPR GIS layers (NYCDPR 2011). Forested area of each park was digitized by hand from aerial photographs and my own knowledge of the parks' layout. I also measured the median percent impervious surface and the percent of 30m x 30m raster cells that were categorized as forested in a 200m buffer zone around each park (%IB and %FB, respectively) using the 2006 National Landcover Dataset impervious surface and land-use category rasters (Fry et al. 2009). These variables were a measure of the amount of urbanization around the park. Edge effects from intense development may play a role in affecting screech owls that live in the park (either positively or negatively) or the level of urbanization around a park may affect immigration into the park. %IB and %FB measured similar characteristics – either measuring impervious cover or (the lack of) forest cover – I measured both to determine which of the two would be a better predictor of occupancy. Variables that I thought may play a role in ensuring persistence of an established screech owl population included the two area measures described above, the percent of the park that was forested (%F), the perimeter-to-area (P/A) ratio of the forested area (P/A-For), and the total park area (P/A-Park). Screech owls have been characterized as "edge predators" (Sparks et al. 1994, Gehlbach 1995) in that they often forage along forest-meadow, forest-path, and forest-water edges. My perimeter-area variables would give a measure of the "edginess" of the forest and park areas. Increased perimeter-area ratio could lead to an increased risk of extinction if screech owls are negatively affected by forest-park development or forest-urban edges. Alternatively, greater perimeter-area ratio could lead to increased habitat quality if screech owls use forest-development edge similarly to the ways they use more "natural" edges. Perimeter-area ratio was calculated as:

$$D_i = \frac{P}{2\sqrt{A\pi}},$$

where D_i is the perimeter area ratio for park i, P the perimeter and A the area of the park (Cook 2002). A circle, the shape with the lowest possible perimeter for a given area, has a $D = 1$ and shapes deviating from a circle have $D > 1$.

Lastly, I included a categorical variable that noted whether the park was typically occupied by great horned or barred owls (BigOwls), as the presence of these species may play a role in limiting screech owl abundance or habitat. Distribution data on these other species were taken from my own observations, observations by NYCDPR staff or New York State Breeding Bird Atlas records (New York State Department of Environmental Conservation 2010). The latter was used only if more site-specific observations were unavailable, as BBA plots were often larger than the individual parks I surveyed.

Analysis

Presence-absence data and the associated geographic measurements were entered into an occupancy-detection analysis using the methodology of MacKenzie et al. (2006). Maximum likelihood estimates for occupancy (ψ) and detection (p) were obtained for a set of candidate models and evaluated with Akaike's Information Criterion corrected for small sample sizes (AIC_c; Burnham and Anderson 2002). I found a best-fit model for detection first and then modeled occupancy using the supported detection parameterization (Mackenzie 2006, Negroes et al. 2010). Previous analysis (see Chapter 2) suggested that the presence of barred owls could lower the detection rate of call surveys for screech owls so detection was modeled both as a constant and with BigOwls as a covariate (with a constant model of occupancy). The supported model for detection was then used with all candidate occupancy models.

The AIC_c-selected best model was used to calculate a detection rate for each site, based on the site-specific detection rate and the number of surveys performed at the site. This yielded a probability of false negative for the whole site (i.e., the chance I missed a screech owl given the sampling effort). I expected this final detection rate to be high, based on previous work (see Chapter 2 and 3) and the large number of surveys I performed (up to 24). Prior to modeling occupancy I examined simple plots of the geographic covariates in owl-present parks versus owl-absent parks to determine the raw differences in covariates among parks with owls and those without.

Occupancy models consisted of eight linear effect models, each parameterized with one of the covariates above, and a constant occupancy model, $\psi(.)$, $p(.)$. The seven geographic covariates (i.e., all but BigOwls) were also modeled as quadratic effects to determine if their relationship with occupancy was nonlinear, e.g., occupancy might be maximized at moderate or at high and low levels of a predictor. I also tested four two-covariate models consisting of each buffer variable (%IB and %FB) with each area variable (PArea and FArea) to test the importance of both total available area and adjacent urbanization on park occupancy. Lastly, a model consisting of WArea and P/A-For was used to determine the importance of available habitat and within-park forest edge on park occupancy. Those models that performed better than the constant model and had a $\Delta \mathrm{AIC}_c < 4.0$ were considered to receive some support and examined further. Patterns of occupancy based on the supported covariates were then used to make inferences regarding screech owl distributions and potential management goals.

Geographic measurements were obtained using ArcGIS 9.1 with the Spatial Analyst (ESRI 2005), Hawth's Tools (Beyer 2006), and XTools (Data East Soft 2011) extensions. Occupancy and detection were modeled with Presence 3.0 (Hines 2006).

Results

Owls were found in three NYC parks: Riverdale, Van Cortlandt, and Inwood (Figure 1). They were also found in the three Westchester County Parks (Greenburgh Nature Center, Saxon Woods, and Twin Lakes). Detection was modeled more effectively when the presence (p = 0.31

± 0.12 (mean ± SE)) or absence ($p = 0.63 \pm 0.11$) of larger owls was included ($w_i = 0.92$). Given these detection rates, all sites had cumulative detection rates – given the number of surveys I performed at each – that were greater than 0.98. This suggested I had an approximately 2% chance of false negatives for any of the sites. Thus, comparing covariate measurements among sites with at least one detection and sites with no detections for descriptive purposes prior to explicitly modeling occupancy was appropriate. Most geographic covariates did not differ among parks where owls were detected and parks where no owls were detected (Figure 2) except for percent impervious surface and percent forested cells in the 200m buffers around parks.

Not surprisingly, these two variables were the best predictors of park occupancy by screech owls (Table 1). Percent impervious cover of the 200m buffer was included in all models that performed better than the intercept model and the %IB univariate model was the top model in the set. Percent forested cells was the second most supported model ($\Delta AIC_c = 1.78$). Both %IB and %FB measured the amount of urbanization/deforestation, so their high placement was likely due to similar effects. Some larger models appeared to perform similarly to the univariate %IB and %FB models (Table 1) but these likely did well not because of any additional fit due to additional covariates, but rather because they were paired with %IB or %FB. Occupancy was highest when the percent of impervious cover was low (%IB $\beta = -0.2737 \pm 0.1258$) and the percentage of forested cells surrounding the park was high (%FB $\beta = 0.8368 \pm 0.5702$). Generally, this indicates that higher levels of urbanization around a park led to a lower chance of the park being occupied by screech owls.

Discussion

The best predictors of screech owl site occupancy were the two variables that related to the extent of urbanization around the park in question. Impervious cover is a measure of the amount of pavement or concrete roads or buildings in a raster cell and thus is a fairly direct measure of the amount of development or urbanization that has occurred at a location; in this case, in a 200m buffer zone around each park. I included the percentage of forested cells as another indicator of general urbanization, however, for a cell to be classified as forested, it needs ≥20% forest cover. Thus forest cover up to 20% can still exist in a raster cell that is not classified as forested. Nagy et al. (*in press*) found that this measure of forest cover was slightly more accurate when predicting screech owl occupancy in suburban areas than percent impervious, although both were generally supported. In this study, impervious cover had better fit than percent forested cells. This could be because in this study I was characterizing a buffer zone rather than the specific territory of the owls I was observing (i.e., the buffer zone could be of lower quality than the territory of the owl). In any event, I interpreted these measures as indices of urbanization around the park and as general characterizations of the surrounding city. Thus, screech owl occupancy of urban parks appears to be negatively affected by greater amounts of urbanization around the park in question.

Indices of habitat quality or quantity (park or forested area, perimeter-area ratios) seemed to play little role in predicting whether a given park would have screech owls or not. This suggests that site occupancy across NYC depends on the amount of connectivity between parks, assuming dispersal is less likely through heavily urbanized areas compared to more natural corridors. Small parks did have owls (Inwood, Riverdale, and Twin Lakes), but these parks were usually within a few kilometers of another occupied site. This is not to say screech owls can live in any park regardless of the amount of forested area. Since only a limited number of sites could be surveyed, I chose parks with at least some amount of forest habitat and thus a reasonable chance of being occupied by screech owls. There are a number of parks in NYC that are completely mowed and/or paved; if these parks were included, variables such as FArea or %F might have had some support. This comparison seemed less useful, however, than comparing sites with at least some *a priori* chance of being occupied.

Prior population modeling work concluded that park area or total available habitat can have a substantial effect on population persistence (see Chapter 2). However, the area measurements seemed to have little effect in this analysis of park-level occupancy. While extinction risk is lessened in larger parks, it is not eliminated completely. The observed occupancy patterns in parks within heavily urbanized areas may be the long-term result of potentially small but nevertheless non-zero extinction probabilities combined with effectively zero re-colonization probabilities. In fact, the three parks in NYC that had screech owls (Inwood, Riverdale, and Van Cortlandt) were of varying sizes (0.49 to 4.35 km^2) but within 4 km of each other and are near the Bronx-Westchester border. These parks were also adjacent to the residential neighborhood of Riverdale. This “somewhat-less-urban” matrix may be more permeable by screech owls than the heavily developed areas of Queens and Brooklyn. Gehlbach (1994 and 1995) concluded that eastern screech owl populations can become locally extinct and in rural and suburban areas the species probably exists in metapopulations, where empty areas are recolonized by dispersing juveniles. If this framework also applies to urban parks, then recolonization and movement dynamics would be vital for the persistence of the larger city-wide population. Increased buffer urbanization could also lead to greater mortality from vehicles or possibly affect prey populations similarly though vehicle mortality or reduced occupancy (which could then affect screech owls indirectly).

A notable site was Alley Pond Park in Queens. This park was surveyed 3 times in 2007 and 1 - 2 screech owls were found there (no more than 1 detection each visit). The park was surveyed two times annually in 2008, 2009, and 2010 (the most recent data were used for this study) and no screech owls were ever detected. This park is large (246ha) and 77% of its area is undeveloped. For comparison, it is larger and has a greater percentage of forested area than the three Westchester Parks in this survey (all of which were occupied by screech owls). However, the small number of detections in 2007 and apparent extirpation between 2007 and 2008 suggest that this population was not stable. While surrounded by residential areas similar to Riverdale on some borders, Alley Pond is bisected by numerous interstates and highways and its border is 63% impervious surface.

Another large park that was unexpectedly unoccupied by screech owls was Pelham Bay Park in the Bronx. This is the largest park in NYC ($11.21km^2$) and its northern border is rather suburban, similar to Riverdale. However, a substantial portion of the park is a large golf course. I originally thought it more appropriate to include such semi-developed areas with scattered stands of trees as available habitat, since screech owls are so generalist and forage along edges (Smith and Gilbert 1984, Sparks et al. 1994, Terman 1997). This could be incorrect regarding the Pelham Bay Golf Course, and thus the true available area would be smaller than what I measured. Similarly, Van Cortlandt Park also had a lower than expected density of owls based on its area and this may have been because its actual habitat area is smaller than I measured (see Chapter 2). Previous habitat selection work in Central Park, NYC concluded that areas consisting of lawns with scattered large trees were used proportionally to their availability (Nagy 2004), while forests and forest-path edges were selected (Nagy 2004). Pelham Bay also has a large, semi-forested salt marsh along its western edge, which I chose to include as undeveloped available area, but in reality may not be, since screech owls are not typically found in salt marsh (Gehlbach 1995). Future research can further investigate the use of “urban-savannah” areas, such as golf courses and cemeteries, by screech owls. Additionally, protected greenspace in many cities is typically associated with coastal areas and it would be useful to see if urban species such as screech owls might use this historically atypical habitat, if at all.

Habitat edge, as measured by the perimeter-area ratio of the forested area (P/A-For), was also unimportant in predicting site occupancy. While screech owls may be “edge predators” (Sparks et al. 1994, Nagy 2004) the amount of edge habitat in the forested area of a park probably does not appear to affect distribution on the landscape scale. It is likely that whatever amount of edge is suitable for screech owls in those parks that support them is adequately provided by small-scale clearings and forest-path, forest-lawn, and forest-water edges.

Nagy et al. (*in press*) concluded that owl occupancy increased with increasing impervious cover in more rural northern Westchester and Putnam Counties, NY; however they noted that they only sampled up to approximately 60% impervious cover. This study sampled much higher impervious surface values and saw a decline in occupancy as %IB increased. Interestingly, the impervious cover model prediction curves of Nagy et al. (*in press*) and the prediction curve of the %IB model of this study appear to agree in the range of predictor values in which they overlap, and each may accurately describe the two ends of the response curve (Figure 3). Screech owls may be able to tolerate development up to 50 – 60% impervious coverage, but respond negatively to levels of urbanization above 60% impervious cover. Many species that can be found in urban or suburban areas eventually exhibit an upper urbanization threshold (e.g., burrowing owls (*Athene cunicularia floridana*): Millsap and Bear 2000; Cooper’s hawks (*Accipiter cooperii*): Stout et al. 2006*a*; red-tailed hawks (*Buteo jamaicensis*): Stout et al.2006*b*).

Based on these findings, eastern screech owls have a rather high threshold, if sufficient parkland is available: two of the three occupied NYC parks, Inwood Hill and Van Cortlandt, had %IB values >50% impervious cover.

Management Implications

Mark-recapture analysis (Chapter 2) on owls in occupied parks could estimate short-term vital rates but projections from these rates may not apply over many decades. In this study I sought to use park-level occupancy as an indicator of the long-term viability of urban parks: screech owls were historically present in many NYC parks until the mid-20th century (DeCandido 2005), and their absence at this time would be a result of local extinction and a lack of successful recolonization, or repeated local extinctions – either of which would imply poor viability overall.

Detection rate was substantially affected by the presence or absence of larger (barred or great horned) owls, meaning a screech owl is less likely to respond to call-broadcast surveys if it lives in a site that also has larger owls. Biologically, this indicates some amount of competition between these species and screech owls and/or that the larger owls opportunistically predate screech owls. In terms of sampling, researchers surveying for screech owls should perform more surveys in sites that also are home to barred or great horned owls. To have an >85% chance of detecting screech owls at a site where larger owls reside (or potentially reside), at least 6 surveys would be required.

Variables describing the level of urbanization surrounding a given park best predicted a park’s occupancy status. This may correlate with the chance that a given park will be recolonized after a local extinction if screech owls are less likely to successfully disperse through highly urbanized areas than through natural corridors. Additionally, in most cases the parks with higher levels of urbanization were in the interior of the city and this might further decrease the chance of immigration from non-urban areas adjacent to NYC.

The results of this study should not persuade managers of individual parks to neglect habitat restoration or enhancement. First, I did not measure micro-site habitat variables such as vegetation structure or cavity density. Such variables could certainly play a role in screech owl persistence in a park. Second, the %IB model obviously contains inherent uncertainty: Inwood Hill Park in Manhattan had a high %IB and thus a predicted occupancy probability of only 0.20. Yet this park has been consistently occupied by screech owls for at least 10 years (Nagy, *unpub. data*), possibly in part because of the contiguous undeveloped forest, installed nest boxes, and active habitat restoration efforts there. If colonization rate is low, minimizing local extinction risk can offset the low immigration rate. Third, as stated above, the parks I sampled were those that appeared to have some reasonable chance to be occupied by screech owls in the first place. In many cases, extirpation at a site may have been caused by past conditions and now suitable habitat does, or could, exist. The important factors in site occupancy appear to reside in the urban matrix outside of parks, but if and when screech owls do return (via natural dispersal or reintroduction), clearly within-site conditions will play a role in future persistence.

If the surrounding level of urbanization is important for the long-term viability of park populations, then corridors become an important research and management priority. Short-term within-park survival and persistence might depend on park area and the quality of habitat within a site (Chapter 2), but long-term persistence appears to also depend on the ability of dispersing owls to move from park to park. Despite the general difficulty in studying animal movements and dispersal, this information is important for those interested in screech owl management and ecology in highly urbanized areas. Information on corridor size, composition and density would also be valuable to urban planners and developers. In this study, occupancy sharply declined around 50 – 60% %IB. A rough guide for corridor design could be to ensure a %IB score less than 50% around the park. This could be done in two ways. First, planners could provide a few densely wooded corridors through heavily urbanized areas or, second, keep the overall amount of urbanization at moderate levels. For a given target %IB, the first option would lead to a broad range of %IB, since some places would be highly urbanized while the corridor would be near 0 impervious cover. The second option would lower the variation in %IB, since all cells would be moderately developed. Since screech owls seem to respond well in suburban environments, the latter might be more effective, although possibly more difficult to implement.

Acknowledgements

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Table 1 - AIC results for models of eastern screech owl occupancy in parks in southern Westchester County and New York City, NY, 2010. Only models with $\Delta AIC_c < 10$ shown.

Model	k	ΔAIC_c	w_i	$-2\text{Log}(L)$
ψ(%IB[a]), *p*(BigOwls[b])	4	0	0.48	60.11
ψ(%FB[c]), *p*(BigOwls)	4	1.78	0.20	61.89
ψ(%IB + PArea[d]), *p*(BigOwls)	5	2.96	0.11	58.71
ψ(%IB + FArea[e]), *p*(BigOwls)	5	3.94	0.07	59.69
ψ(Q%IB[a]), *p*(BigOwls)	5	4.33	0.06	60.08
ψ(Q%FB[c]), *p*(BigOwls)	5	5.93	0.03	61.68
ψ(%FB + FArea), *p*(BigOwls)	5	5.99	0.02	61.74
ψ(%FB + PArea), *p*(BigOwls)	5	6.12	0.02	61.87
ψ(.), *p*(BigOwls)	3	9.83	<0.01	73.58

[a] %IB: median percent impervious of all raster cells in a 200m buffer zone around park ("Q" indicates quadratic effect).

[b] BigOwls: Presence of absence of barred or great horned owls in the park.

[c] %FB: percent of raster cells categorized as forested in a 200m buffer zone around park ("Q" indicates quadratic effect).

[d] PArea: total area of park.

[e] FArea: total area of undeveloped (typically forest) sections of park, used as a measure of available screech owl habitat.

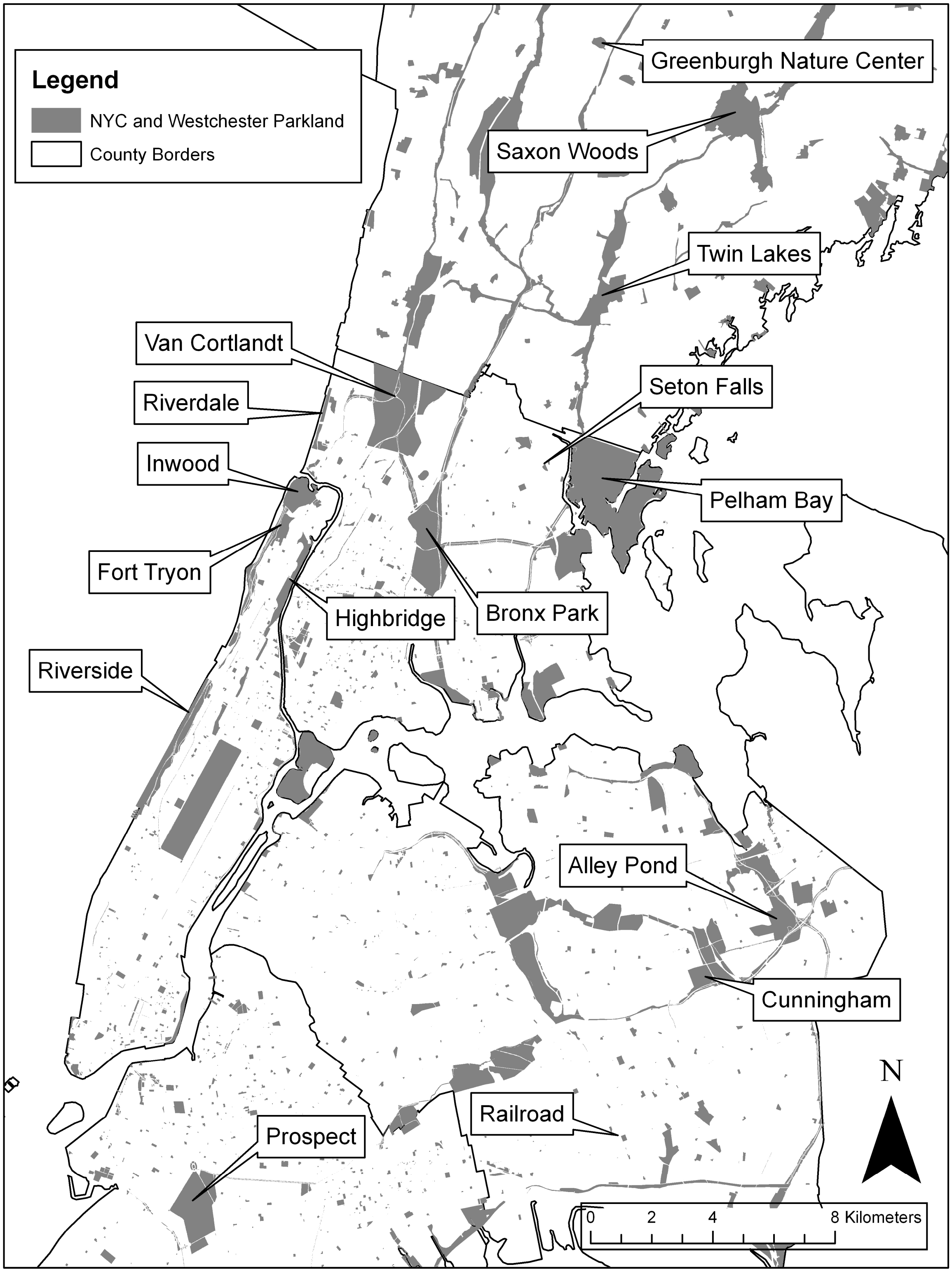

Figure 1 – Location of parks surveyed for eastern screech owls in Westchester County and the New York City boroughs of Manhattan, Queens and Brooklyn, 2010.

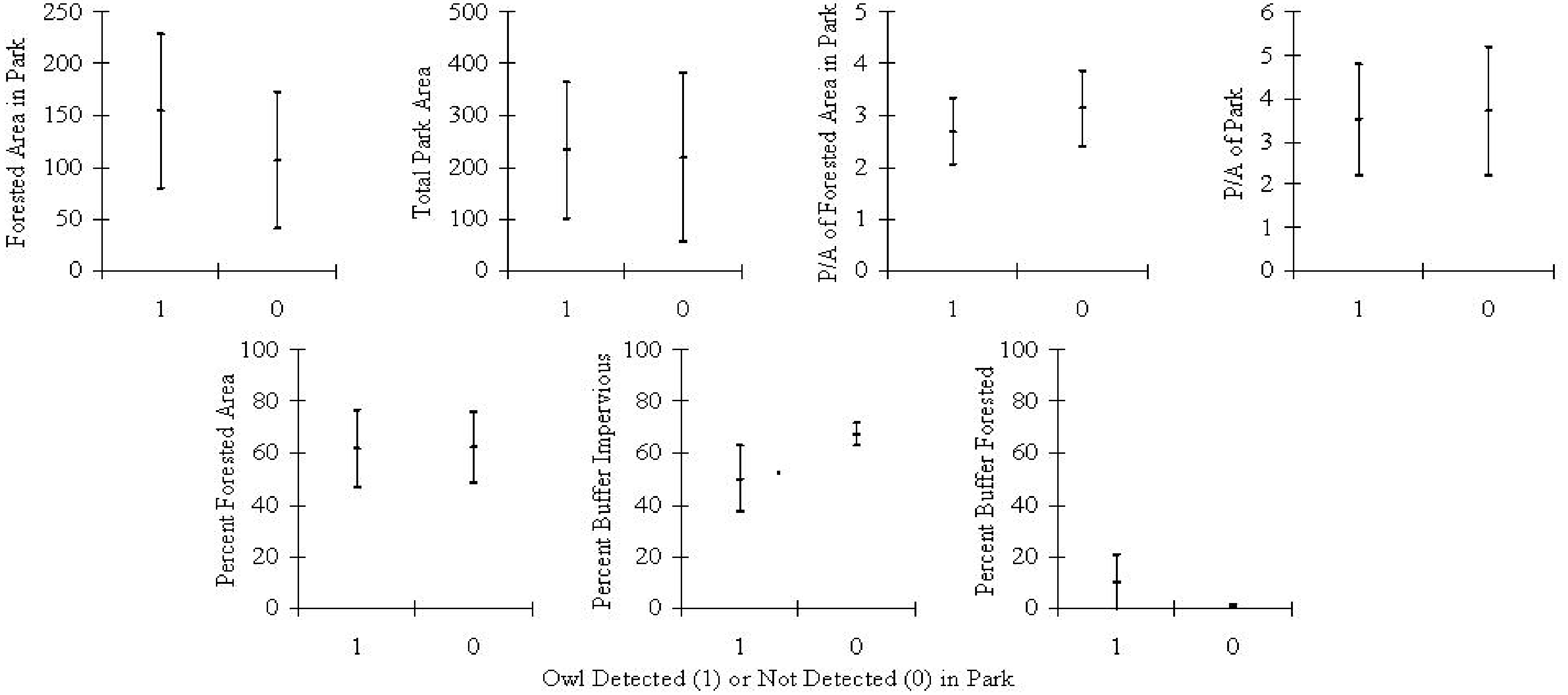

Figure 2 – Geographic variation (mean ± 95% confidence intervals) in parks in which eastern screech owls were detected (1) or not detected (0) during call-broadcast surveys, Westchester County and New York City, NY 2010. Buffer measurements based on a 200m buffer around the park boundary.

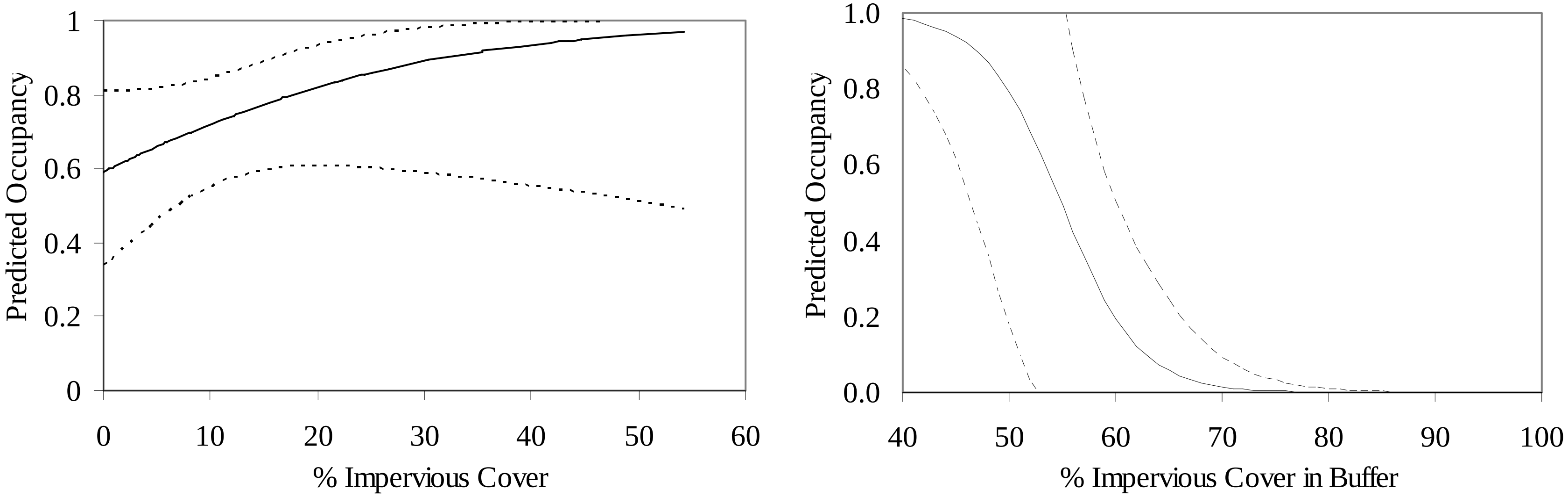

Figure 3 – Prediction curves (solid lines) and 95% confidence bands (dashed lines) for two models of eastern screech owl site occupancy based on percent impervious surface cover: Nagy et al. (*in press*) citizen-science based study in suburban Westchester and Putnam Counties, NY and Fairfield, CT (left); and the current southern Westchester and New York City Park study (right).

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Chapter 6: Conclusions

While the eastern screech owl is not threatened or endangered across its range, its fate in New York City (NYC) is somewhat uncertain. Within the greater NYC metropolitan area, it will likely persist in the suburban areas (most of Westchester and Putnam Counties, and the suburban areas of Staten Island), but in highly urbanized areas where forest stands are small and fragmented and dispersal is limited, there is a substantial chance for extirpation. One local extinction at Alley Pond was observed over the course of this study.

In the short-term and with regard to individual parks, it appears as if some urban parks provide advantages to screech owls similar to those in the suburbs. Adult survival was very high in the parks that I monitored. However, the populations can still be extirpated because of the parks' limited carrying capacities. Over the short-term and within individual parks, local abundance and persistence depends on the area of available habitat. This can be a function of total park area to some degree, but as observed by the lower-than-expected densities in Van Cortlandt and the lack of any screech owls in Pelham Bay, large areas of protected natural area (forest, riparian, and perhaps meadows) are more important than sheer park size. Ideal areas for supporting screech owls appear to be from approximately 0.6 to 3.0 km^2. Parks larger than 3.62 (Van Cortlandt) did not have any owls – it is possible that as parks get larger they begin to function similarly to rural forests, where screech owls have more predators and competitors and lower vital rates. A tried-and-true management strategy that can be easily implemented and evaluated would be to install a large number of nest boxes to enhance reproductive rates and over-winter survival. This could increase available nesting habitat in parks with fewer owls than expected given a park's size. In parks where densities are closer to what is expected (e.g., Inwood and Riverdale), nesting cavities may not be limiting, and habitat restoration or reclamation might help to increase a park's carrying capacity. Many NYC parks with any protected forest also have large tracts of unused lawns that could be restored as meadows and young forests.

No matter how large or suitable a single park is, the probability of local extinction is never zero. Over the long-term, all subpopulations are likely to hit the zero mark at some point and thus prospects for recolonization must be improved. The three populations I monitored in this study were found near the northern edge of NYC, were close to each other, and the smallest of the three had the lowest amount of urbanization around it. If corridors and/or networks of parks in close proximity to each other can be provided, then subpopulations can be supplemented or restarted by immigrants. Thus, an ideal park would be one that consisted of 1.0 – 3.0 km2 in undeveloped (forested, meadow, or riparian) habitat with ample corridors or a low level (<55%) of urbanization around it. Additionally, any one site will probably be more stable if there are other occupied sites nearby (e.g., within 5 km).

The patterns found in these eastern screech owl populations are likely illustrative of general patterns of many species of urban wildlife. Even if a species can take advantage of the urban landscape and tolerate the increased human presence, the extremely fragmented urban landscape still presents a problem for long-term persistence. Managers and researchers should address both within-park factors such as habitat quantity and quality and minimum viable area to minimize local extinction risk, as well as inter-park factors such as corridor requirements, the permeability of the urban matrix, and greenspace distribution to enable recolonization of empty parks.

Appendix 1 – Descriptive statistics and PIC values for all variables measured on calls from 10 eastern screech owls, New York and New Jersey, 2008 - 2010. Variables with PIC > 1 were considered for discriminatory value. After iterative testing with these variables, whole-call center frequency (CFall), 1st quartile frequency (Q1Fall), 3rd quartile frequency (Q1Fall), and note rate (NRall), and note rates of each call phase (NR1, NR2, and NR3) had the best discriminatory power.

	Notes_all[a]	Notes1[a]	Notes2[a]	Notes3[a]	Dur1[b]	CF1	Q1F1	Q3F1	Dur2[b]	CF2	Q1F2	Q3F2	Dur3[b]
Mean	31.9	13.1	5.1	13.7	0.95	645.2	570.8	720.8	0.45	645.3	571.9	719.9	0.81
SD	4.4	2.3	1.2	3.5	0.16	101.0	101.5	103.5	0.11	101.4	102.5	103.1	0.22
PIC	0.82	0.68	0.49	0.64	0.59	2.93	1.86	2.15	0.54	2.98	1.98	2.18	0.66

	CF3	Q1F3	Q3F3	Dur_all[b]	CFall	Q1Fall	Q3Fall	NRall	NR1	NR2	NR3	PrNotes1[c]
Mean	645.4	571.8	720.3	2.22	644.1	569.2	719.9	14.39	13.66	11.48	16.96	0.41
SD	99.3	100.1	101.5	0.28	100.6	101.4	102.8	0.81	0.81	1.02	0.97	0.08
PIC	3.05	2.03	2.36	0.82	3.17	2.00	2.28	1.68	1.23	1.86	1.05	0.65

	PrNotes2[c]	PrNotes3[c]	PrDur1	PrDur2	PrDur3	IQR1	IQR2	IQR3	IQRall
Mean	0.16	0.43	0.43	0.20	0.36	150.0	148.0	148.5	150.7
SD	0.03	0.07	0.08	0.05	0.07	33.7	32.9	33.2	33.6
PIC	0.42	0.59	0.62	0.47	0.58	0.60	0.64	0.64	0.63

[a] “Notes” = number of notes in whole call (all) or phase 1, 2 or 3.

[b] “Dur” = duration in seconds of whole call (all) or phase 1, 2, or 3.

[c] “PrNotes” = the proportion of total notes in the call in that phase (1, 2, or 3).

[d] “PrDur” = the proportion of the total call duration in that phase (1, 2, or 3).

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Biographical Data

Name: Christopher Michael Nagy

Place of Birth: Princeton, NJ

Education: City University of New York, New York, NY
Ph.D. 2012
Fordham University, New York, NY
Master of Science, Biology, 2004
SUNY Albany, Albany, NY
Bachelors of Arts, Biology, 1999

Professional Experience: Biologist, 2003 – Pres.
Mianus River Gorge Preserve, Bedford, NY
Adjunct Lecturer, 2005 and 2011
City University of New York, New York, NY
GK-12 Fellow, 2008 – 2010
City University of New York, New York, NY
Chancellor’s Fellow, 2005 – 2008
City University of New York, New York, NY

Publications:

Nagy, C. and R.F. Rockwell. *In press*. Identification of individual Eastern Screech-Owls (Megascops asio) via vocalization analysis. Bioacoustics.

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