Landscape and Urban Planning, 14 (1987) 481-495
Elsevier Science Publishers B. V., Amsterdam - Printed in The Netherlands

CHARACTERISTICS OF URBAN WOODLANDS AFFECTING BREEDING BIRD DIVERSITY AND ABUNDANCE

NANCY G. TILGHMAN[1]

USDA Forest Service, Northeastern Forest Experiment Station, Holdsworth Hall, University of Massachusetts, Amherst, MA 01003 (U.S.A.)

(Accepted for publication 18 March 1987)

ABSTRACT

Tilghman, N. G., 1987. Characteristics of urban woodlands affecting breeding bird diversity and abundance. Landscape Urban Plann., *14: 481-495.*

Breeding bird communities were studied in 32 forest islands surrounded by urban development. These isolated woodlands in Springfield, Massachusetts, provided breeding habitats for a wider variety of birds (77 species) than previously described for other urban habitats (e.g. four times as many species as found in urban residential areas in the same city in a previous study). The size of the woodland was the primary influence on bird diversity in these woodlands, explaining 79 and 75% of the variation in total species richness and the Shannon-Weaver index of bird species diversity, respectively. Other woodland characteristics that played a significant role in determining the variety of bird species were the density of buildings in the area immediately adjacent to the woods, density of shrubs within the woods, distance to the nearest trail, distance to the nearest body of water and average canopy height. Percentage of coniferous tree cover was the most important variable in explaining the variation in the number of birds detected at a sampling point (R^2=0.26). Information on the distance to the nearest trail, distance to the nearest body of water and distance to the nearest extensive forest area were also important in determining the number of bird sightings. The size of the woodland (1-69 ha) played an important role in the distribution of individual bird species. About half of all species observed in these woodlands were more commonly found in the larger woods (43-69 ha). Eight species were more abundant in the smallest woodlands (1-5 ha), and a few others were apparently insensitive to the size of the woodland. Specific recommendations are made to improve the design and management of urban woodlands for enrichment of the avifauna within a city.

[1]Present address: Redwood Sciences Laboratories, 1700 Bayview Drive, Arcata, CA 95521, U.S.A.

INTRODUCTION

Wildlife can be found in many habitats within the city. Typical urban species are associated with high-density industrial or residential areas. Many of these species are exotics that have capitalized on the presence of man-made nest sites (e.g. roof eaves, building ledges) and food sources (e.g. garbage, bird feeders). Remnants of natural communities of the region can often be found in isolated patches of undeveloped habitat. One of the most important types of undeveloped habitat for wildlife in the city is the woodland. Tregay (1979) defines urban woodlands as wooded landscapes ranging in size from large forests to small patches. The lower size limit may vary, but he suggests that an urban woodland may be as small as 0.5 ha as long as there is a minimum of disturbance to its flora and fauna. The role that these small ecosystems play in providing the urban dweller with a "biological, psychological and romantic link with nature" is significant (Tregay, 1979, p. 294).

Several studies have shown that people who live in cities appreciate the chance to see wildlife, especially the opportunity to observe birds (Dagg, 1970; Brown and Dawson, 1978; Witter et al., 1981; Yeomans and Barclay, 1981). Development of an appreciation of nature in early childhood can lead to years of enjoyment of the out-of-doors and a more environmentally concerned citizenry. Bird-watching is enjoyed by a wide range of people and is considered a sport by some and a form of nature study by others. Therefore, from both a recreational and educational viewpoint, it should be the goal of municipal and state agencies to provide urban dwellers with nearby natural areas that meet the habitat requirements of a variety of wildlife, including birds. This study was designed to determine the characteristics of urban woodlands that support the greatest diversity and abundance of breeding birds in Springfield, Massachusetts. Secondarily, this study attempts to demonstrate the relationship between individual bird species and the size of the woodlands.

STUDY AREAS

This study was conducted in Springfield (Hampden County), Massachusetts (42°07'N, 72°35'W), in the Connecticut River valley. Springfield is a city of 152 000 people and covers about 85 km^2. The city is part of a larger urban complex with three other cities (Chicopee, Holyoke and West Springfield), having a total population of about 310 000 people (MacConnell, 1975). The average winter temperature is - 2°C and the average summer temperature is 22°C; mean annual precipitation is 112 cm (Mott and Swenson, 1978).

Forests cover about 65% of Hampden County. These forests lie in the transition zone between the northern hardwood forest of northern New England and the oak-hickory forest of southern New England. Urban development occurs in 13% of the county and is mainly concentrated in the area in and around Springfield (MacConnell, 1975). Although presettlement vegetation was primarily forest, only 18% of the city remains in forest cover; much of this has been extensively altered. Thirty-two urban woodlands, ranging in size from 1 to 69 ha, were selected from these remnant patches of wooded habitat (Fig. 1). All mixed hardwood stands larger than 1 ha were included in the study. Manicured woods in which the understory had been eliminated and replaced by lawn cover were not used. Woodlands that were not isolated from the extensive forests of the region by urban development were also not included.

Study sites included portions of city parks, natural areas set aside by the local conservation commission, wooded school land and a few privately owned woodlands (Tilghman,

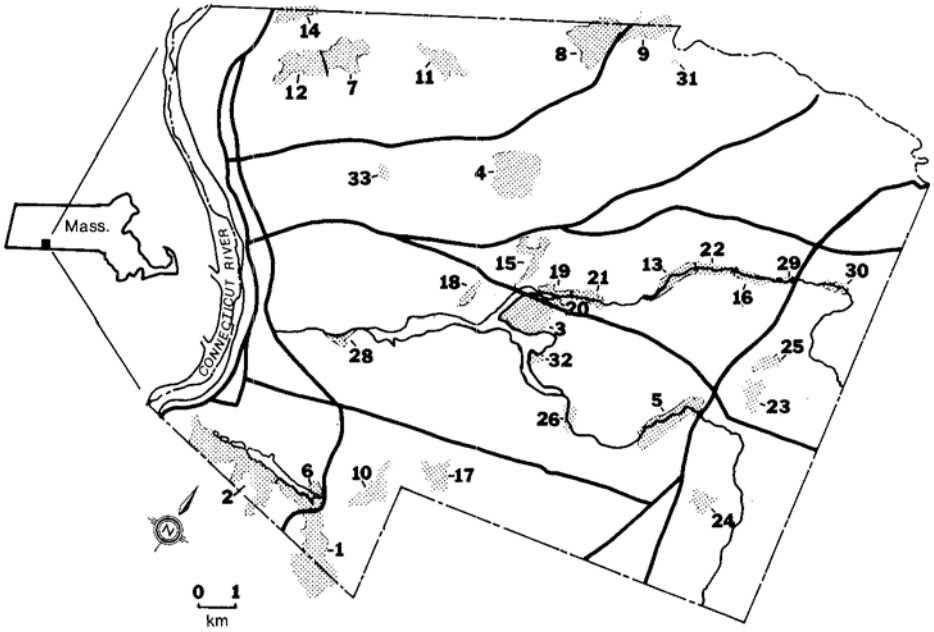

Fig. 1. Location of study areas in Springfield, Massachusetts.

1983). Many of the remnant woods were located on land unsuitable for urban development, such as steep-sided ravines, and comprised a mixture of upland and lowland forest types. The major upland tree species were northern red oak (*Quercus rubra*), black oak (*Q. velutina*), eastern hemlock (*Tsuga canadensis*) and eastern white pine (*Pinus strobus*), occurring on both flat sites and on the steep slopes of the ravines. Red maple (*Acer rubrum*) and American elm (*Ulmus americana*) dominated the stream bottoms and drainage areas.

Although these areas did not include manicured parklands, many of the study sites were subject to heavy human use. Trails of various widths were common in several of the woods. A few of the woodlands had paved roadways, but most of these were blocked off. Motorized traffic in the form of dirt bikes used the trails in some woodlands, but most human travel was on foot. Neighborhood children often played in and explored the woodlands. People living near the woodlands used theme as dump sites for lawn and garden refuse and junk metal. Young people sometimes used certain areas for beer drinking, target practice, fishing and other recreational activities.

METHODS

Birds in each woodland were sampled three times during each breeding season for 2 years. Surveys were conducted from 25 May to 30 June 1980 and from 1 to 30 June 1981 on clear calm mornings from sunrise to 09.00 EDT. Sampling was conducted at systematically-located points in each woodland. All points were at least 100 m apart and 50 m from the nearest edge. The detection area associated with each sampling point covered approximately 0.8 ha. As many sampling points as could be fitted into each woodland were used up to a maximum of 10. In woodlands > 10 ha, sampling points were evenly distributed throughout the woods so that samples were independent and all portions of the woods were sampled. Thus, a uniform proportion of each woodland was

sampled in woodlands < 10 ha, but because we were limited to only 10 sampling points per morning in woodlands > 10 ha, sampling intensity in these large woodlands varied. Observers were selected from experienced birdwatchers and trained in the sampling technique prior to the field season. The training period included field exercises in which all observers counted birds at the same point at the same time. Differences in results were discussed and problems in identification of species and individuals were highlighted. Four observers counted birds on a total of 193 sampling points each year, recording all birds heard or seen during a 20-min period. Fly-overs, obvious migrants, or birds outside the woods were not included. Care was taken to prevent double records of individuals at the same or adjacent sampling points.

The number of different bird species observed in each woodland was determined from all three visits. In an effort to adjust for differences in sampling intensity in woodlands > 10 ha, a jackknife procedure (Miller, 1964) was applied to the number of bird species observed. This procedure produced an estimate of the number of bird species that would have been observed in each woodland if an unlimited number of bird sampling points had been located. The jackknife estimator of the number of species in a woodland was used as a dependent variable in the multiple regressions described below, but since use of this artificial variable did not improve the predictability of the number of species present, these results will not be included in further discussions. An index of bird species diversity (H') was calculated (Shannon and Weaver, 1949) using natural logarithms. At each sampling point and for each year, an index of the abundance of each species was taken to be the highest number of individuals recorded on any one visit. The average number of sightings per point was calculated for each species in each woodland; these values were also combined to give the average number of bird sightings per point for each woodland. The estimates of the average number of sightings do not give density estimates, but they were used as an index to bird abundance in each woodland. The hazard of adding averages for bird species of different detectabilities was recognized, but preliminary examination of data for highly detectable and less detectable species showed no relationship between average sightings of these species and the major independent variables. Thus, the average number of birds detected per point for all points in a woodland was used as an index to bird abundance.

Various measures of the size, isolation, vegetation characteristics and human activity were determined for each of the 32 urban woodlands. The area and perimeter of each woodland were determined from aerial photographs. In addition to using the area (size in ha) as a variable by itself, information on the area and perimeter of each woodland were combined into another variable indicating the relative amount of edge present (Patton, 1975). Patton's formula for this edge index (DI) is $DI = TP/[2\ (A\pi)^{0.5}]$, where TP is the total perimeter of the woodland and A is the area. The distance (m) to the nearest extensive woods (>400 ha) was also measured from aerial photographs and represented the degree of isolation of these urban woodlands from the nearest natural forest bird community that might serve as a source for immigrating individuals. The distance (m) to the nearest body of water (e.g. lake, pond, stream or creek) was measured at each sampling point and the overall soil moisture of each woodland was classified into one of three classes (1 =wet, 2= intermediate, 3 =dry) based on information on the depth to the high-water table as reported by Mott and Swenson (1978).

Several variables characterizing the vegetation were measured in 0.04-ha plots centered on the bird-sampling points. In an effort to better characterize the vegetation in the smallest woodlands, a minimum of four vegetation plots were taken in those woods with less than

four bird-sampling points. Tree density (No. ha^{-1}) was determined by the point-centered quarter method (Cottam and Curtis, 1956). The height (m) of each of the sampled trees was measured by means of a Haga altimeter or telescoping pole, and the percentage of trees that were coniferous was recorded. Shrub density (No. ha^{-1}) was measured on two 0.002-ha strips at each plot (James and Shugart, 1970; James, 1978). A spherical densiometer was used to estimate percentage canopy closure at five locations on each plot. The structure of the vegetation in each woodland was also determined at these five sampling points on each 0.04-ha plot. At each point, three layers (0-0.6 m, 0.6-6.1 m, > 6.1 m) were evaluated for presence or absence of vegetation. Thus an index of the amount of layering of the vegetation was calculated as a value from 0 to 300 based on the sum of the percentage of points that had some form of vegetation in each of the three layers (after Karr, 1968).

One major difference between these woodlands and forests outside the city is the increased human activity in and around each wood. Because of the large number of urban woodlands involved in this study, the human activity associated with each woodland was measured indirectly. An index of the degree of human disturbance within each woodland was established as the distance (m) from each bird-sampling point to the nearest trail or to the edge of the wood, whichever was closer. The level of human activity in the area immediately adjacent to the wood was defined as the density of buildings (No. ha^{-1}) in a 90-m strip around the wood.

Multiple regression techniques were employed to examine the relationship between the independent habitat variables and the dependent bird variables. Simple regressions of every combination of habitat and bird variables were used to detect those habitat variables having significant association with the dependent variables, and to investigate the form of that relationship (straight line or curvilinear). For each habitat variable, the simple regression with the highest R^2 dictated the form used as an independent variable in the multiple regression analyses. Dependent variables included two measures of bird diversity — the number of bird species observed (S), and bird species diversity (H') — and one measure of bird abundance — the average number of birds detected per sampling point (NMBIRDS).

The average number of sightings of individual bird species in urban woodlands of different sizes served to demonstrate the degree of sensitivity of the species to "island" size. Species that were observed fewer than six times in a single year were not included in this analysis. Regression analyses of the abundance indices of each of the remaining bird species on the corresponding size of urban woodland suggested the direction and significance of this relationship. Significant regression equations that explained a high proportion of the variation in a species' abundance and had a positive slope indicated that the species was more common in large woodlands; significant regressions with a negative slope indicated that the species were more common in smaller woodlands.

RESULTS

Bird communities

Seventy-seven different bird species were observed during the breeding season in the 32 study areas (Table 1). On average, 32.5 species (SD = 8.5, N = 64; 193 sampling points X2 years) were observed in any one woodland in one season. The average number of species observed per sampling point was 20.7 (SD = 4.0, N = 386); the average number of birds observed per point was 48.1 (SD =10.7, N= 386). Although typical urban bird species were found in these woodlands, several species associated with more rural habitats were also found (mostly insectivores, e.g. the cuckoos, pileated woodpecker, some of the flycatchers, brown

TABLE I

Abundance indices' for breeding birds in urban woodlands of different sizes

Species[2]		Woodland size-class[3] (ha)				Simple correlation coefficient[4] (*r*)
Common name	Scientific name	1-5 (*N*=22)	6-17 (*N*=24)	18-42 (*N*=14)	43-69 (*N*=4)	
Birds observed six times or more in a single year						
Broad-winged hawk[5]	*Buteo platypterus*	0	0.01	0.03	0.08	0.34**
Ring-necked pheasant	*Phasianus colchicus*	0.19	0.66	0.59	0	0.23
Mourning dove	*Zenaida macroura*	0.88	0.58	0.54	0.40	-0.27*
Black-billed cuckoo[5]	*Coccyzus*	0.19	0.21	0.14	0.25	0.01
Yellow-billed cuckoo[5]	*Coccyzus americanus*	0.38	0.43	0.55	0.80	0.18
Belted kingfisher[5]	*Ceryle alcyon*	0.10	0.03	0	0	-0.16
Downy woodpecker	*Picoides pubescens*	1.28	1.57	1.51	2.35	0.36**
Hairy woodpecker	*Picoides villosus*	0.21	0.71	0.74	1.03	0.54**
Northern flicker	*Colaptes auratus*	1.62	1.61	1.38	1.60	-0.15
Eastern wood-pewee	*Contopus virens*	0.41	0.77	0.94	1.60	0.32**
Least flycatcher[5]	*Empidonax minimus*	0	0.04	0.07	0.05	0.18
Eastern phoebe	*Sayornis phoebe*	0.26	0.42	0.24	0.15	0.03
Great crested flycatcher	*Myiarchus crinitus*	0.67	0.96	1.72	2.10	0.56**
Eastern kingbird	*Tyrannus tyrannus*	0.30	0.23	0.48	0.10	-0.04
Blue jay	*Cyanocitta cristata*	1.62	1.66	1.82	1.80	0.18
American crow	*Corvus brachyrhynchos*	0.54	1.24	1.49	1.25	0.46**
Black-capped chickadee	*Parus atricapillus*	1.16	2.37	2.41	2.85	0.48**
Tufted titmouse	*Parus bicolor*	2.24	2.72	2.70	3.20	0.31
White-breasted nuthatch	*Sitta carolinensis*	0.78	1.18	1.25	1.55	0.29*
Brown creeper	*Certhia americana*	0	0.14	0.30	0.75	0.50**
House wren	*Troglodytes aedon*	0.68	0.83	1.55	1.00	0.18
Blue-gray gnatcatcher[5]	*Polioptila caerulea*	0	0	0.09	0	0.19
Veery[5]	*Catharus fuscescens*	0	0.04	1.11	2.65	0.53**
Wood thrush	*Hylocichla mustelina*	1.73	1.95	2.14	2.08	0.23
American robin	*Turdus migratorius*	2.96	2.86	2.17	1.55	-0.35**
Gray catbird	*Dumetella carolinensis*	2.50	2.14	2.19	1.70	-0.14
Northern mockingbird	*Mimus polyglottos*	0.58	0.43	0.12	0.05	-0.37**
Brown thrasher	*Toxostoma rufum*	0	0.22	0.25	0.13	0.33**
Cedar waxwing	*Bombycilla cedrorum*	0.09	0.10	0.36	0.54	0.37**
European starling	*Sturnus vulgaris*	1.57	1.59	1.39	0.63	-0.18
Warbling vireo	*Vireo gilvus*	0.62	0.18	0.38	0.05	-0.33**
Red-eyed vireo	*Vireo olivaceus*	1.01	1.42	1.96	1.90	0.46**
Blue-winged warbler	*Vermivora pinus*	0.04	0.05	0.30	0.93	0.37**
Yellow warbler	*Dendroica petechia*	0.06	0.25	0.53	0.80	0.39**
Chestnut-sided warbler[5]	*Dendroica pensylvanica*	0	0.01	0.03	0.20	0.38**
Black-throated green warbler[5]	*Dendroica virens*	0	0.03	0.09	0.10	0.26*
Prairie warbler[5]	*Dendroica discolor*	0.03	0.07	0.11	0.05	0.18
Black-and-white warbler[5]	*Mniotilta varia*	0	0.10	0.25	1.33	0.52**
American redstart	*Setophaga ruticilla*	0.10	0.18	0.38	0.55	0.38**
Ovenbird	*Seiurus aurocapillus*	0	0.09	0.05	1.38	0.42**
Louisiana waterthrush[5]	*Seiurus motacilla*	0	0.05	0.01	0.15	0.18
Common yellowthroat	*Geothlypis trichas*	0.81	0.85	1.36	1.60	0.30*
Canada warbler[5]	*Wilsonia canadensis*	0	0	0.08	0.25	0.34**
Scarlet tanager	*Piranga olivacea*	0.04	0.45	0.40	1.25	0.49**
Northern cardinal	*Cardinalis cardinalis*	2.09	2.00	1.98	1.93	-0.10
Rose-breasted grosbeak	*Pheucticus ludovicianus*	0.67	0.60	0.67	1.20	0.12
Indigo bunting[5]	*Passerina cyanea*	0.05	0.11	0.17	0.20	0.26*
Rufous-sided towhee	*Pipilo erythrophthalmus*	0.06	0.63	0.90	0.25	0.33**

TABLE I (continued)

Species		Woodland size-class[3] (ha)				Simple correlation coefficient[4] (*r*)
Common name	Scientific name	1-5 (*N*=22)	6-17 (*N*=24)	18-42 (*N*=14)	43-69 (*N*=4)	
Chipping sparrow	*Spizella passerina*	0.22	0.30	0.17	0.20	-0.13
Field sparrow	*Spizella pusilla*	0	0.01	0.11	0	0.22
Song sparrow	*Melospiza melodia*	2.47	2.16	1.66	2.23	-0.25*
Swamp sparrow	*Melospiza georgiana*	0.09	0	0.04	0	-0.18
Red-winged blackbird[5]	*Agelaius phoeniceus*	2.29	1.25	2.41	1.73	-0.09
Common grackle	*Quiscalus quiscula*	2.46	1.55	1.96	1.50	-0.29*
Brown-headed cowbird	*Molothrus ater*	0.87	1:04	1.20	1.80	0.26*
Northern oriole	*Icterus galbula*	1.88	1.45	1.63	1.53	-0.23
Purple finch	*Carpodacus purpureus*	0.11	0.01	0	0.05	-0.24
House finch	*Carpodacus mexicanus*	1.03	0.62	0.73	0.43	-0.30*
American goldfinch	*Carduelis tristis*	0.22	0.18	0.43	0.43	0.07
House sparrow	*Passer domesticus*	1.77	1.52	0.09	0.55	-0.45**
Species observed fewer than six times in a single year; not included in analysis						
Green-backed heron[5]	*Butorides striatus*					
Ruffed grouse[5]	*Bonasa umbellus*					
Rock dove	*Columba livia*					
Eastern screech-owl[5]	*Otus asio*					
Barred owl[5]	*Strix varia*					
Pileated woodpecker	*Dryocopus pileatus*					
Alder flycatcher[5]	*Empidonax alnorum*					
Willow flycatcher[5]	*Empidonax traillii*					
Tree swallow	*Tachycineta bicolor*					
Red-breasted nuthatch	*Sitta canadensis*					
Carolina wren[5]	*Thryothorus ludovicianus*					
Winter wren[5]	*Troglodytes troglodytes*					
Eastern bluebird[5]	*Sialia sialis*					
Solitary vireo[5]	*Vireo solitarius*					
Yellow-throated vireo[5]	*Vireo flavifrons*					
Nashville warbler[5]	*Vermivora ruficapilla*					
Pine warbler[5]	*Dendroica pinus*					

[1]The average number of individuals of a given species detected per point for all woodlands in a particular size-class.
[2]Common and scientific names follow the checklist of the American Ornithologists' Union, 1983.
[3]For presentation of the data, woodlands were grouped into size-classes on the basis of natural breaks in the distribution of sizes studied. The number of cases in each size-class represents the number of woods of that size times 2 years' data. Regressions were run on data from each woodland, not on grouped means.
[4]Regression of abundance indices for a particular species on the size of the woodland. Significance of relationship: *=$P< 0.05$; **=$P< 0.01$.
[5]Species not observed in nearby urban or suburban residential areas (DeGraaf and Wentworth, 1981).

creeper, winter wren, Carolina wren, blue-gray gnatcatcher, solitary vireo, various warblers, scarlet tanager, plus broad-winged hawk, ruffed grouse, barred owl, belted kingfisher, wood thrush, veery and eastern bluebird; see Table I for the scientific names of bird species).

Relationship of bird diversity to woodland characteristics

In regression analysis, size of woodland was by far the most important variable affecting the number of bird species observed (*S*) and bird

species diversity (H'). For S, coefficients of determination (R^2) were 0.58 for the linear and 0.79 for the curvilinear (logarithm of size) regressions. For H', the correlation coefficients were 0.51 for the linear and 0.75 for the curvilinear regressions. The largest woodlands had nearly twice as many species as did the smallest woodlands, and bird species diversity exhibited a similar range in values (Table II).

Examination of a plot of the curvilinear regression for S indicates that the number of bird species increased rapidly as the size of woodland increased from 1 to 25 ha; thereafter, the increase was more gradual (Fig. 2). At 25 ha, about 0.75 of the maximum number of species were represented.

In addition to size of woodland, number of adjacent buildings, density of the shrub layer and proximity of trails were significantly related to both S and H'. Canopy height and distance to water were also significant in the H' regression. However, addition of these variables in various combinations to the simple regression models containing woodland size increased the amount of variation explained by only 7-10% (Table III) .

TABLE II

Effect of size of urban woodland on two measures of bird diversity

Dependent variable	Woodland size-class (ha)			
	0.9-5 (N=11)	6-17 (N=12)	18-42 (N=7)	43-69 (N=2)
S	24.0 A[1]	33.0 B	41.1 C	46.2 C
H'	3.00 A	3.26 B	3.43 C	3.56 C

[1]Means in a row not followed by the same letter are significantly different (P< 0.001, Duncan's new multiple range test).

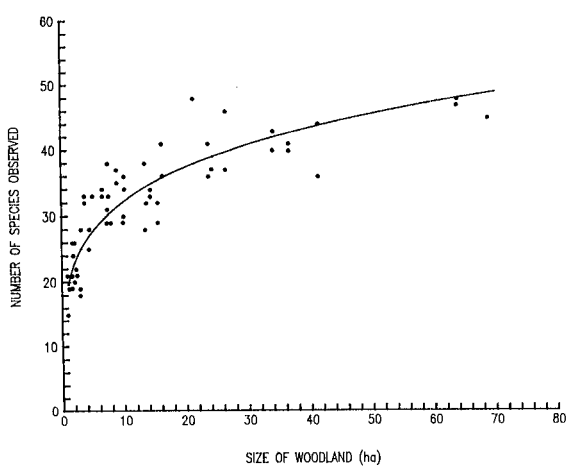

Fig. 2. Relationship of number of bird species observed (S) to size of urban woodland.

Large numbers of buildings reduced the number of bird species and bird species diversity, while a well-developed shrub layer increased the number of species and diversity. Taller trees in the canopy resulted in lower diversity, but did not significantly affect the number of bird species (Table III). Woods with less edge (more compact in shape) and woods on dryer sites supported a greater variety of bird species as measured by H' but not by S. These two variables did not appear in the two best multiple regressions of H', being non-significant in the presence of one or more of the other variables.

Distance to trails appeared in multiple regressions for both S and H' (Table III), but affected these dependent variables in different ways depending upon the other variables in the equation. When number of buildings was not included in combination with distance to trails, both bird species diversity and number of bird species were low in close proximity to trails, but when buildings and trails were both included in the regressions, the number of bird species (but not H') was highest in close proximity to trails. Since both trails and buildings are measures of human disturbance, it is not surprising that they are correlated (r=0.50). This, plus the fact that both buildings and trails are only weakly correlated with the dependent variables, probably accounts for the shifts in the direction of the relationship between trails and S. I do not believe this shift has any biological significance.

Relationships of bird abundance to woodland characteristics

Percentage coniferous tree cover and size of

TABLE III

Regression coefficients for multiple regression models' relating measures of bird diversity and abundance to characteristics of urban woodlands

Independent variables[2]	Dependent variables			
	S	*H'*[3]	*H'*[3]	NMBIRDS
Log (size of woodland)	14.65	0.35	0.33	-
Building density	-1.25	-0.015	-0.017	-
Shrub density	0.0003	-	-	-
Log (shrub density)	-	-	0.16	-
Distance to trails	-0.13	-	-	-
1/(Distance to trails)	-	-0.27	-0.25	-17.02
1/(Canopy height)	-	3.88	-	-
Distance to water	-	-0.0002	-0.0002	-0.014
Log (% coniferous cover)	-	-	-	7.58
Isolation of woodland	-	-	-	0.0009
Y-intercept	22.12	2.745	2.404	37.902
R^2	0.86	0.85	0.85	0.48

[1]Only independent variables whose regression coefficients were significantly different from zero ($P \leq 0.05$) were included in the models.
[2]Transformations are as indicated: Log=logarithmic transformation (base 10); 1 /=hyperbolic transformation.
[3]Two regression models for *H'* are included in this table since both explained the greatest amount of variation in *H'*.

woodland explained similar amounts of the variation in the number of birds present (simple R^2s of 0.26 and 0.25, respectively). However, these two independent variables were not both significant when both were present in multiple regressions. A close examination of the data set showed few data for small woodlands with > 10% coniferous tree cover and for large woodlands with <2% coniferous tree cover. This resulted in a high correlation between the two independent variables (r=0.51) that only allowed one of them (percentage coniferous tree cover) to enter into the multiple regression model. It appears that woods with scattered patches of pines and hemlocks tended to have greater numbers of birds. It is unclear, however, that larger urban woodlands would have supported higher densities of birds had these woods not also had a higher percentage of coniferous trees in the overstory; the relationship may have been an artifact of sampling.

The multiple regression model for NMBIRDS was much less powerful in its ability to explain the variation in bird abundance (R^2 =0.48) than were the models for the two measures of bird diversity. There was no single variable that could account for a large proportion of the differences in bird abundance. The model indicates that woods with a greater proportion of coniferous trees in the overstory and water in or near them tended to have higher bird densities. These high bird abundances were also associated with more isolated urban woodlands, located far from the nearest extensive forest. Woods with trails close to the sampling points tended to have fewer birds (Table III).

Relationship of individual bird species to size of woodland

Nearly half of the species examined for association with size of woodland were significantly more abundant in the larger woodlands (Table I). Of the 27 species more commonly found in larger woods, nine were never observed in woods smaller than 5 ha (broad-winged hawk, brown creeper, veery, brown thrasher, black-and-white warbler, chestnut-sided warbler, black-throated green warbler, ovenbird and Canada warbler). On the other

hand, eight bird species were most abundant in the smallest woodlands (especially American robin, northern mockingbird, warbling vireo and house sparrow). Several species did not seem to be sensitive to the size of the woodland at all (Table I). Some of these species, such as the northern flicker, blue jay and northern cardinal, might be considered ubiquitous. Other species such as the swamp sparrow and red-winged blackbird are more obviously limited by other factors (e.g. nearness to water).

DISCUSSION

Most studies of birds in urban environments have indicated that these areas are relatively poor in number of species compared to more rural habitats, but rank high in density of individuals (Pitelka, 1942; Woolfenden and Rohwer, 1969; Emlen, 1974; Guthrie, 1974; Walcott, 1974; DeGraaf, 1978). The present study has shown that the variety of breeding-bird species in urban woodlands can be much greater than is typical of other urban habitats. Urban woodlands in the present study had about 50% more bird species than DeGraaf and Wentworth's (1981) suburban residential areas and about four times as many species as their urban residential areas (also in Springfield). The additional species found in urban woodlands (indicated in Table I) were primarily wetland species, ground-nesting and -foraging species, insectivores and carnivores. The presence of these species in the more natural woodlands is probably due to the greater variety of food and relatively undisturbed nest sites found there. In a study of bird habitat relationships in a New England suburb, DeGraaf and Wentworth (1986) demonstrated that certain insectivorous species were not present except in nearby natural forest stands. In urban areas where large natural forests are distant, urban woodlands can provide habitat for many species that might otherwise only be found in the native forests of the region. Indeed, the numbers of breeding bird species in the largest urban woodlands surveyed were about the same as found in a study of forest birds in a 4650-ha wooded preserve located about 40 km from Springfield (R.M. DeGraaf, personal communication, 1986). However, all urban woodlands are not alike in their ability to attract and support a variety of breeding bird species. Bird diversity and abundance in these areas differ with the physical characteristics of the woodlands (size, shape and isolation), the variety of microhabitats provided (by layers and composition of the vegetation) and the level of human activity in and around the woods.

Size of woodland was by far the most important variable in explaining differences in both the number of bird species and bird species diversity in urban woodlands. These results support the idea that "habitat islands" in an urban setting follow some of the basic concepts of island biogeography (MacArthur and Wilson, 1963, 1967), especially the species-area relationship that has held true in many bird studies of fragmented forests (Moore and Hooper, 1975; Forman et al., 1976; Galli et al., 1976; Tilghman, 1977; Robbins, 1979; Whitcomb et al., 1981). Davis and Glick (1978) and Samson (1980) have suggested that the isolated nature of urban parklands should make them suitable for conservation strategies based on island biogeographical theory. Previous studies of bird communities of urban parks and woodlands have provided data that might be used as evidence of the insular qualities of urban woodlands, but none have examined this relationship with so many woodlands or over such a broad range of sizes (Luniak, 1974; Gavareski, 1976; Alonso and Purroy, 1979).

In a review of several studies dealing with island biogeography or its application to "habitat islands", Gilbert (1980) concurs that area (or size) is usually the major factor contributing to the number of species. The importance of size of woodland in this study supports the idea that nature reserves or parks should be as large as possible if the entire complement of

naturally occurring fauna is to be maintained (Terborgh, 1974; Diamond, 1975; Sullivan and Shaffer, 1975; Whitcomb et al., 1976; Faaborg, 1979; Hounsome, 1979). Although the urban woodlands examined in this study are generally much smaller than would be recommended for a nature reserve, their role in increasing the diversity of bird life in the city is important.

Size of woodland may have been important in determining bird abundance, but interpretation of the results is difficult because of the correlation between size of woodland and percentage coniferous cover mentioned previously. If, however, the positive association between size of woodland and bird numbers is real, these results directly contradict a study conducted in Europe (Oelke, 1966). It may be that larger woods have a greater variety of desirable microhabitats and can accommodate a large number of individuals, attracting birds from the surrounding residential areas.

Variations in the shape or configuration of these urban woodlands were measured by an edge index. While it is well documented that species richness tends to increase in the ecotones between habitat types, the relative amount of edge associated with these urban woodlands played only a minor role in determining the variety of birds within them. The relative unimportance of edge in this study is probably due to the placement of the bird sampling points at least 50 m from the nearest edge, in an effort to reduce the chance of recording birds that were actually outside the woodland.

Increased isolation of urban woodlands from the nearest probable source of colonizing individuals ("mainland" woods) had a positive effect on bird abundance, but did not play a role in the models for bird diversity. Other studies of bird communities on habitat islands have indicated that increased isolation may decrease the variety of bird species, especially forest interior species (MacClintock et al., 1977; Butcher et al., 1981; Whitcomb et al., 1981; Opdam et al., 1984). In the present study, however, the degree of isolation (4-11 km) was probably negligible relative to the dispersal ability of birds. The positive relationship between isolation and bird numbers has been described in a few island studies, but usually in terms of niche expansion and density compensation in the face of reduced competition from a reduced number of species (MacArthur et al., 1972). As mentioned previously, this is the typical finding of bird studies in the more developed portions of the city where local avifaunas are dominated by a few species occurring at extremely high densities. In these urban woodlands, however, no relationship was detected between the degree of isolation and number of species, so density compensation does not appear to be a suitable explanation for the increased numbers of birds. Rather, these more isolated woods may be far more attractive to birds from the surrounding urban habitats than are urban woodlands that are closer to the extensive forests outside the city. Birds that depend on shrubs and trees for breeding and foraging sites may find it advantageous to move into these woods where they must tolerate increased competition from their neighbors, but where food and nest sites are also more plentiful.

Of the various measures of the vegetation and microhabitats available in these woodlands, the variables that predicted bird diversity were indicators of the horizontal and vertical complexity of the woods. Lower canopy height may have been associated with an increase in the variety of birds present, if shorter average canopy heights represented increased horizontal heterogeneity with more openings in the woodlands. Woods with streams flowing through them or lakes adjacent to them added a dimension to the microhabitats available and thus had a greater bird species diversity and total bird abundance. Birds such as green-backed herons, belted kingfishers, veeries, Louisiana waterthrushes, common yellowthroats, red-winged blackbirds and swamp sparrows found suitable nesting

and foraging sites that were not available in woods without water nearby. Rich food supplies and dense vegetation that are often associated with these wetland areas probably allowed a greater density of birds to nest in and around the wetlands than in the remainder of the woodlands. Urban woodlands with patches of coniferous cover were able to support higher densities of birds. This habitat type may have been sufficiently rare in the city as a whole to attract birds to these woods from neighboring habitats.

Several studies have demonstrated the relationship between vertical vegetation complexity and bird species diversity (MacArthur and MacArthur, 1961; MacArthur et al., 1962, 1966; Recher, 1969; Karr and Roth, 1971). In urban habitats, the presence of shrub layers has been shown to be particularly important to the variety of bird species in parks (Linehan et al., 1967; Burr and Jones, 1968; Gavareski, 1976). In the present study, the presence of a well-developed shrub layer provided habitats for low-nesting or shrub-feeding species and, by increasing the vertical dimension of the woods, increased the variety of niches available.

Differences in the size of urban woodlands and changes in vegetation cannot explain all the differences in their bird communities. Historical factors such as man's influence on the system need to be considered. In this study, the density and proximity of buildings to the woodlands were used as an index to the level of urbanization adjacent to the woods. This index had an overall negative effect on bird diversity and, to a lesser extent, bird abundance. Batten (1972) and Butcher et al. (1981) have also documented declines in the total number of bird species present and noted qualitative changes in the kinds of species in isolated wooded areas as the level of urbanization increased around them.

In the present study, the direct effect of human disturbance *within* urban woodlands was measured by the distance between bird sampling points and the nearest trails. Although the impact of this variable on the two measures of bird diversity was confusing, it appears that the level of disturbance associated with trails in the woods did not have a great effect on bird species diversity. The shape of the curve relating trails to diversity suggests that traffic along trails limits the variety and numbers of birds in the area immediately adjacent to the trail, but that there is little or no effect beyond this point. The type of trampling disturbance suggested by Whitcomb (1977) did not play a major role in determining the breeding bird communities of these areas. Linehan et al. (1967) found human activity in urban woodlands in Delaware had little effect on the bird community when a sufficient shrub layer was present. Other researchers (Nasmith, 1975; Cooke, 1980) have commented on the tolerance of urban and suburban birds to moderate levels of human activity. Once birds have established their territories and built their nests, it takes a great amount of direct disturbance by man or predators associated with areas of human habitation to cause the birds to desert their nests.

Several researchers have demonstrated that size of forest tract can be a limiting factor in the distribution of individual forest-dwelling bird species (Forman et al., 1976; Galli et al., 1976; Robbins, 1979; Whitcomb et al., 1981). The trend in abundance indices of the bird species that were found in this study indicates that certain bird species are size-limited in their distribution in urban woodlands. In some instances, the species associated with larger urban woodlands are the same as those found to be intolerant of forest fragmentation in more suburban areas of central Maryland (e.g. hairy woodpeckers, red-eyed vireos, black-and-white warblers, ovenbirds and scarlet tanagers). Other species that seemed to show no real affinity for large forests in the Maryland study were significantly associated with larger urban woodlands in this study (e.g. downy woodpeckers, great crested flycatchers, eastern wood-pewees, American crows and rufous-

sided towhees; Whitcomb et al., 1981). Some of these associations with large urban woodlands may be more in response to greater isolation from surrounding urban activity than to the need for a large tract of forest habitat per se. The species that were more common in the smaller woods were typical urban species usually found in residential or industrial habitats. Small urban woodlands were often reminiscent of residential habitats in both vegetation structure and human activity and thus probably attracted similar bird species.

MANAGEMENT RECOMMENDATIONS

The results of this study should be useful to urban land managers in the northeast who are involved in the acquisition and management of natural areas within the city. Specific recommendations are listed below.

(1) Large woodlands (> 25 ha) are necessary to maintain a high bird species diversity and thus provide urban dwellers with the opportunity to see a wide variety of birds typical of more rural forests of the region.

(2) Maintenance of natural vegetation in the shrub layer can provide an increased number of niches for an increase in number of bird species.

(3) Woodlands with a variety of microhabitats, such as small scattered openings and some form of water in or adjacent to the woods, can provide nesting and feeding sites for a variety of birds. Patches of pines or hemlocks and wetland areas within the woods can also increase the number of birds in the area.

(4) Wherever possible, buildings immediately adjacent to the woodlands (within 90 m) should be kept to a minimum.

(5) Trail systems should be limited in scope. Instead of a fine network of trails throughout the woods, a few well-marked trails providing human access to particular portions of the woods should be maintained.

In the past, urban conservation land has not been purchased as wildlife habitat; recreation has been the major motivation for land acquisition (Gray et al., 1979). But urban woodlands can provide both a variety of wildlife habitats and the recreational opportunity for residents of our larger cities to experience nature and its diversity.

ACKNOWLEDGEMENTS

This study was funded by the U.S. Forest Service, Northeastern Forest Experiment Station, and the University of Massachusetts at Amherst. I thank R.M. DeGraaf for his advice and encouragement throughout the study, and D.A. Marquis for his help in the final analysis and revision of the manuscript. This study also benefitted from the advice of J. S. Larson, W. E. Dodge, W.B. Nutting and D.E. Kroodsma. D.L. Fischer, J.J. Green, Jr., S.D. Surner, G.M. Witman, P.H. Yaukey and M.D. Ziomek assisted with the field work. Thanks to R.A. Damon, J.T. Finn, T.A. Hosmer, G.S. Walton and D.W. Seegrist for their advice on statistical analyses, and to C.H. Nilon, Jr., B.R. Noon and L.W. VanDruff for suggestions for improving the manuscript. Special thanks to the Springfield Parks Department, the Springfield Conservation Commission, and several private landowners for their hospitality.

REFERENCES

Alonso, J.A. and Purroy, F.J., 1979. Avifauna de los parques de Madrid. Naturalia Hispanica, No. 18, Instituto Nacional Para la Conservacion de la Naturaleza, Madrid, 109 pp.

American Ornithologists' Union, 1983. Check-list of North American Birds. 6th edn. American Ornithologists Union, Lawrence, KS, 877 pp.

Batten, L.A., 1972. Breeding bird species diversity in relation to increasing urbanisation. Bird Study, 19: 157-166.

Brown, T.L. and Dawson, C.P., 1978. Interests, Needs and Attitudes of New York's Metropolitan Public in Relation to Wildlife. Cornell Univ. Agric. Exp. Stn., Nat. Resour. Res. Ext. Serv. No. 13, 53 pp.

Burr, R.M. and Jones, R.E., 1968. Influence of parkland hab-

itat management on birds in Delaware. Trans. North Am. Wildl. Nat. Resour. Conf., 33: 299-306.
Butcher, G.S., Niering, W.A., Barry, W.J. and Goodwin, R.H., 1981. Equilibrium biogeography and the size of nature preserves: an avian case study. Oecologia, 49: 29-37.
Cooke, A.S., 1980. Observations on how close certain passerine species will tolerate an approaching human in rural and suburban areas. Biol. Conserv., 18: 85-88.
Cottam, G. and Curtis, J.T., 1956. The use of distance measures in phytosociological sampling. Ecology, 37: 451-460.
Dagg, A.I., 1970. Wildlife in an urban area. Nat. Can., 97: 201-212.
Davis, A.M. and Glick, T.F., 1978. Urban ecosystems and island biogeography. Environ. Conserv., 5: 299-304.
DeGraaf, R.M., 1978. Avian communities and habitat associations in cities and suburbs. In: C.M. Kirkpatrick (Editor), Wildlife and People. Purdue Univ., Dep. For. Nat. Resour., Lafayette, IN, pp. 7-24.
DeGraaf, R.M. and Wentworth, J.M., 1981. Urban bird communities and habitats in New England. Trans. North Am. Wildl. Nat. Resour. Conf., 46: 396-413.
DeGraaf, R.M. and Wentworth, J.M., 1986. Avian guild structure and habitat associations in suburban bird communities. Urban Ecology, 9: 399-412.
Diamond, J.M., 1975. The island dilemma: lessons of modern biogeographic studies for the design of nature reserves. Biol. Conserv., 7: 129-146.
Emlen, J.T., 1974. An urban bird community in Tucson, Arizona: derivation, structure, regulation. Condor, 76: 184-197.
Faaborg, J., 1979. Qualitative patterns of avian extinction on neotropical land-bridge islands: lessons for conservation. J. Appl. Ecol., 16: 99-107.
Forman, R.T.T., Galli, A.E. and Leck, C.F., 1976. Forest size and avian diversity in New Jersey woodlots with some land use implications. Oecologia, 26: 1-8.
Galli, A.E., Leck, C.F. and Forman, R.T.T., 1976. Avian distribution patterns in forest islands of different sizes in central New Jersey. Auk, 93: 356-364.
Gavareski, C.A., 1976. Regulation of park size and vegetation to urban bird populations in Seattle, Washington. Condor, 78: 375-382.
Gilbert, F.S., 1980. The equilibrium theory of island biogeography: fact or fiction? J. Biogeogr., 7: 209--235.
Gray, G.G., Larson, J.S. and Braunhardt, D.A., 1979. Urban conservation leadership and the wildlife resource. Urban Ecol., 4: 1-9.
Guthrie, D.A., 1974. Suburban bird populations in southern California. Am. Midl. Nat., 92: 461-466.
Hounsome, M., 1979. Bird life in the city. In: I.C. Laurie (Editor), Nature in Cities. Wiley, New York, pp. 179-201.
James, F.C., 1978. On understanding quantitative surveys of vegetation. Am. Birds, 32: 18-21.
James, F.C. and Shugart, H.H., Jr., 1970. A quantitative method of habitat description. Audubon Field Notes, 24: 727-736.
Karr, J.R., 1968. Habitat and avian diversity on strip-mined land in east-central Illinois. Condor, 70: 348-357.
Karr, J.R. and Roth, R.R., 1971. Vegetation structure and avian diversity in several New World areas. Am. Nat., 105: 423-435.
Linehan, J.T., Jones, R.E. and Longcore, J.R., 1967. Breeding-bird populations in Delaware's urban woodlots. Audubon Field Notes, 21: 641-646.
Luniak, M., 1974. The birds of park biotopes in small towns of central-eastern Poland. Acta Ornithol., 14: 99-143.
MacArthur, R.H. and MacArthur, J.M., 1961. On bird species diversity. Ecology, 42: 594-598.
MacArthur, R.H. and Wilson, E.O., 1963. An equilibrium theory of insular zoogeography. Evolution, 17: 373-387.
MacArthur, R.H. and Wilson, E.O., 1967. The Theory of Island Biogeography. Princeton University Press, Princeton, NJ, 203 pp.
MacArthur, R.H., MacArthur, J.W. and Preer, J., 1962. On bird species diversity. II. Prediction of bird census from habitat measurements. Am. Nat., 96: 167-174.
MacArthur, R.H., Recher, H. and Cody, M., 1966. On the relation between habitat selection and species diversity. Am. Nat., 100: 319-332.
MacArthur, R.H., Diamond, J.M. and Karr, J.R., 1972. Density compensation in island faunas. Ecology, 53: 330-342.
MacClintock, L., Whitcomb, R.F. and Whitcomb, B.L., 1977. Evidence for the value of corridors and minimization of isolation in preservation of biotic diversity. Am. Birds, 31: 6-16.
MacConnell, W.P., 1975. Remote Sensing 20 Years of Change in Hampden County, Massachusetts, 1952-1972. Mass. Agric. Exp. Stn. Bull. 628, Amherst, MA, 99 pp.
Miller, R.G., Jr., 1964. A trustworthy jackknife. Ann. Math. Stat., 35: 1594-1605.
Moore, N.W. and Hooper, M.D., 1975. On the number of bird species in British woods. Biol. Conserv., 8: 239-250.
Mott, J.R. and Swenson, E.I., 1978. Soil Survey of Hampden County, Massachusetts, Central Part. USDA Soil Conserv. Serv., Mass. Agric. Exp. Stn., Amherst, MA, 199 pp. Nasmith, E., 1975. Bird life in a city ravine. In: G.B. McKeating (Editor), Nature and Urban Man. Can. Nat. Fed., Spec. Publ. No. 4, Ottawa, pp. 35-43.
Oelke, N., 1966. 35 years of breeding bird census work in Europe. Audubon Field Notes, 20: 635-642.
Opdam, P., van Dorp, D. and ter Braak, C.J.F., 1984. The effect of isolation on the number of woodland birds in small woods in The Netherlands. J. Biogeogr., 11: 473-478.
Patton, D.R., 1975. A diversity index for quantifying habitat "edge". Wildl. Soc. Bull., 3: 171-173.
Pitelka, F.A., 1942. High population of breeding birds within an artificial habitat. Condor, 44: 172-174.
Recher, H., 1969. Bird species diversity and habitat diversity in Australia and North America. Am. Nat., 103: 75-80.
Robbins, C.S., 1979. Effect of forest fragmentation on bird populations. In: R.M. DeGraaf and K.E. Evans (Editors), Workshop Proceedings: Management of North Central and Northeastern Forests for Nongame Birds. USDA For. Serv. Gen. Tech. Rep. NC-51, pp. 198-212.
Samson, F.B., 1980. Island biogeography and the conservation of nongame birds. Trans. North Am. Wildl. Nat. Resour. Conf., 45: 245-251.
Shannon, C.E. and Weaver, W., 1949. The Mathematical

Theory of Communication. University of Illinois Press, Urbana, IL, 117 pp.

Sullivan, A.L. and Shaffer, M.L., 1975. Biogeography of the megazoo. Science, 189: 13-17.

Terborgh, J., 1974. Preservation of natural diversity: the problem of extinction prone species. BioScience, 24: 715-722.

Tilghman, N.G., 1977. Problems in sampling songbird populations in southeastern Wisconsin woodlots. M.S. Thesis, University of Wisconsin, Madison, WI, 50 pp.

Tilghman, N.G., 1983. Breeding birds of urban woodlands. Ph.D. Dissertation, University of Massachusetts, Amherst, MA, 132 pp.

Tregay, R., 1979. Urban woodlands. In: 1.C. Laurie (Editor), Nature in Cities. Wiley, New York, pp. 267-295.

Walcott, C.F., 1974. Changes in bird life in Cambridge, Massachusetts from 1860 to 1964. Auk, 91: 151-160.

Whitcomb, R.F., 1977. Island biogeography and "habitat islands" of eastern forests. I. Introduction. Am. Birds, 31: 3-5.

Whitcomb, R.F., Lynch, J.F., Opler, P.A. and Robbins, C.S., 1976. Island biogeography and conservation: strategy and limitations. Science, 193: 1030-1032.

Whitcomb, R.F., Robbins, C.S., Lynch, J.F., Whitcomb, B.L., Klimkiewicz, M.K. and Bystrak, D., 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. In: R.L. Burgess and D.M. Sharpe (Editors), Forest Island Dynamics in Man-dominated Landscapes. Springer, New York, pp. 125-205.

Witter, D.J., Tylka, D.L. and Werner, J.E., 1981. Values of urban wildlife in Missouri. Trans. North Am. Wildl. Nat. Resour. Conf., 46: 424-431.

Woolfenden, G.E. and Rohwer, S.A., 1969. Breeding birds in a Florida suburb. Bull. Fla. State Mus., 13: 1-83.

Yeomans, J.A. and Barclay, J.S., 1981. Perceptions of residential wildlife programs. Trans. North Am. Wildl. Nat. Resour. Conf, 46: 390-395.