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# Application of Remote Sensing to Examine Changes in Bird Communities Over a Gradient of Urbanization

John E. Northeimer

# Application of Remote Sensing to Examine Changes in Bird Communities Over a Gradient of Urbanization

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In partial fulfillment of
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Geobiophysical Modeling

by

John E. Northeimer

Dr. Ralph E. Oberly, Committee Chairperson
and Thesis Advisor
Dr. James Brumfield, Committee Member
Dr. Frank Gilliam, Committee Member
Dr. Thomas Pauley, Committee Member

Marshall University

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ABSTRACT

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Interest in urban ecology and the impact of urbanization on natural resources has increased over the last decade. Studies have related degradation of water quality and loss of biodiversity to increased urbanization. Avian species comprise an important part of the urban ecology. Surveys of bird populations can provide insight into the effects of urbanization on species composition, diversity, and distribution. A search of available literature revealed no published comprehensive avian surveys completed during the breeding season within the city of Huntington, West Virginia. The purpose of this study was to provide an initial characterization of land bird populations during the breeding season within Huntington, West Virginia, by defining distributions of individual species, and comparing species richness and species diversity over a gradient of urbanization. Results showed a decline in species richness and diversity and an impoverishment of community structure with increasing urbanization.

Key Words: urbanization, urban gradient, bird species richness, bird species diversity, impervious surface, feature extraction.

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# CHAPTER I: INTRODUCTION

Interest in urban ecology and the impact of urbanization on natural resources has increased over the last decade. Studies have related degradation of water quality and loss of biodiversity to increased urbanization. Interest in urban ecology is best reflected in the addition of Long-Term Ecological Research sites, established by the National Science Foundation in two urban environments—Phoenix, Arizona, and Baltimore, Maryland (Collins et al., 2000).

It is important to consider the specific characteristics of the local urban system to understand the impact of continuing urbanization on plant and animal communities (Pickett & Cadenasso, 2006). Recent studies have focused on defining changes along an urbanized gradient to determine the relationship of various landscape metrics to species distribution and to changes in species richness and diversity. Crooks, Suarez, and Bolger (2004) examined a gradient along a highly fragmented landscape. Other studies have examined diversity in relation to landscape complexity (Melles, Glenn, & Martin, 2003) and the homogenizing effects of urbanization (Clergeau, Croci, Jokimäki, Kaisanlahta-Jokimäki, & Dinetti, 2006; Devictor, Julliard, Couvet, Lee, & Jiguet, 2007). Donnelly and Marzluff (2004) examined the effects of reserve size on urban bird conservation. Collins et al. (2000) emphasized the need to include the human community in the mix of variables affecting ecological system modeling.

Pickett et al. (2001) suggest the need to not only look at the urban core but to also examine the gradient of urbanization from the urban core outward. Collins et al. (2000) and Blair (1996) view this gradient as one where human activities substantially alter ecosystems at the urban center but become less dominant as one moves out to the undisturbed landscape.

Avian species comprise an important part of the urban ecosystem. Surveys of bird populations can provide insight into the effects of urbanization on species composition, diversity, and distribution. The urban and suburban areas of Huntington have been included within the count circle of the Huntington Audubon Christmas Bird Count each winter since 1940 (available at http://www.audubon.org/Bird/cbc/), and at least one species-specific study on the establishment of the house finch in the Huntington area has been completed (Slack, 1986). However, a search of available literature revealed no published comprehensive avian surveys completed during the breeding season and no examination of bird species distribution in relation to the intensity of urban development within the city of Huntington.

The purpose of this study was to provide an initial characterization of land bird populations during the breeding season within Huntington, West Virginia, by comparing species distribution, species richness, species diversity, and community characteristics over a gradient of urbanization.

This gradient was defined by the percent of impervious surface cover that is measurable and can be extracted from either satellite or aerial imagery. The amount of impervious surface coverage has been used as a measure of urban expansion and an indicator of the quality of the urban environment (Arnold & Gibbons, 1996; Walsh, Waller, Gehling, & MacNally, 2007).

This gradient extends outward from the central industrial/commercial area of Huntington to the suburban forest. Bird species distribution, richness, diversity, and community characteristics were compared within five zones of development along this gradient—industrial/commercial, high intensity, moderate intensity, low intensity, and suburban forest.

The study was comprised of two parts: the extraction of three landscape features—impervious surface, grass cover, and tree canopy cover—from color infrared aerial photography taken leaf-on in 2007, and the completion of avian point counts at sampling stations established within the study area.

## General Description of Huntington

Huntington, West Virginia, is located in Cabell County in the southwestern region of the state. It has a population of approximately 50,000 and covers an area of 29 $km^2$. The urban landscape of Huntington is characterized by heterogeneity with an interspersed distribution of artificial structures (residential, commercial, and industrial), pavement (roads, parking lots), vegetation, water bodies, and disturbed land.

The landscape changes from the Ohio River south through an urbanized gradient representing different types of land cover and differing patterns of land use, beginning with industrial and commercial sites bordering the Ohio River, and progressing through residential, suburban, and finally suburban forest areas to the south.

This urban gradient is illustrated by the tasseled cap transformation (Figure 1) combining three images representing scene brightness, vegetation greenness, and wetness (ER Mapper 6 Level One Training Workbook for Land Information Applications, 1999). Red areas represent high brightness or reflectance (bare ground, structures), blue areas represent water bodies (rivers, streams, and impounded water) and also surfaces with similar reflectance qualities (artificial structures and surfaces), yellow areas represent grass cover, and light green represents woodlands and forests.

The tasseled cap transformation and the 2001 percent impervious National Land Cover Dataset were used for initial characterization of the gradient. They were also used to define the boundaries of the study area, based on the maximum area that could be covered with desired density of stations and with equal representation of different levels and patterns of urbanization (development).

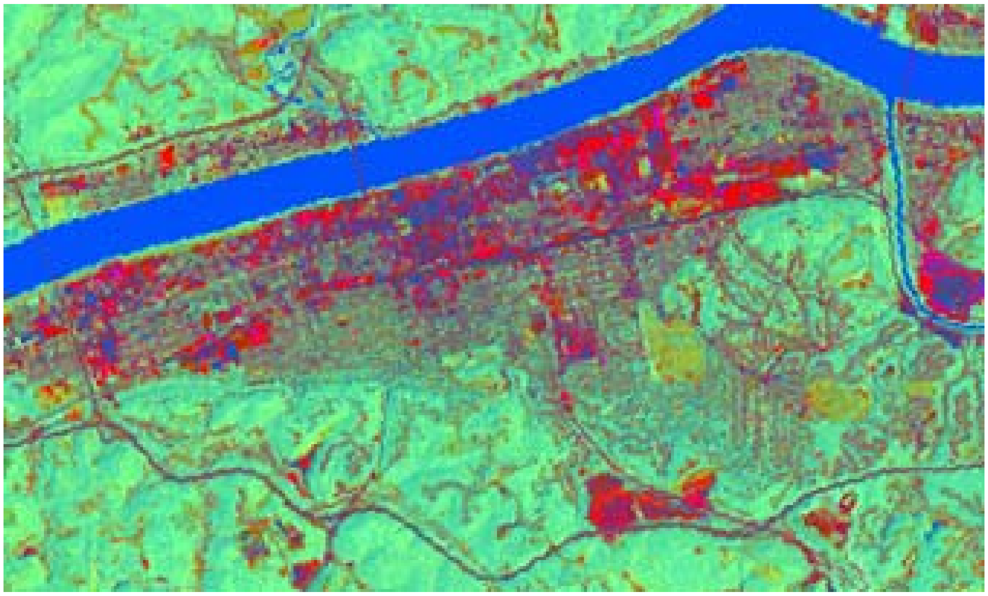


Figure 1. Landsat ETM tasseled cap transformation with DOQ sharpening.

Each urban area is unique, represented by a different degree of landscape alteration. Huntington is no different. Alterations have occurred over time that have modified the landscape by changing the type of land use (flood plain to plantation to residential and commercial development), altering the hydrologic regime (creation of a flood wall and construction of locks for river navigation), and redistributing and modifying the composition of animal and plant communities.

Other alterations include a change in ground and air temperatures caused by the “heat island” or “heat dome” effect. Increased pavement area absorbs, stores, and re-radiates solar energy at a higher level than surrounding undisturbed areas of forested land (Smith & Smith, 1998). Analysis of Landsat ETM thermal band data showed a continuous decrease in blackbody temperatures (unadjusted for emissivity) from the urban center of Huntington outward into the surrounding forested landscape.

## Study Area

The study area includes approximately 2,873 hectares within the urban and suburban areas of Huntington, West Virginia (Figure 2). The area is bounded by the Ohio River on the north, Interstate 64 on the south, the Guyandotte River on the east, and West 16th Street on the west. The area includes the industrial and commercial centers, varying degrees of residential development, and areas of suburban development.

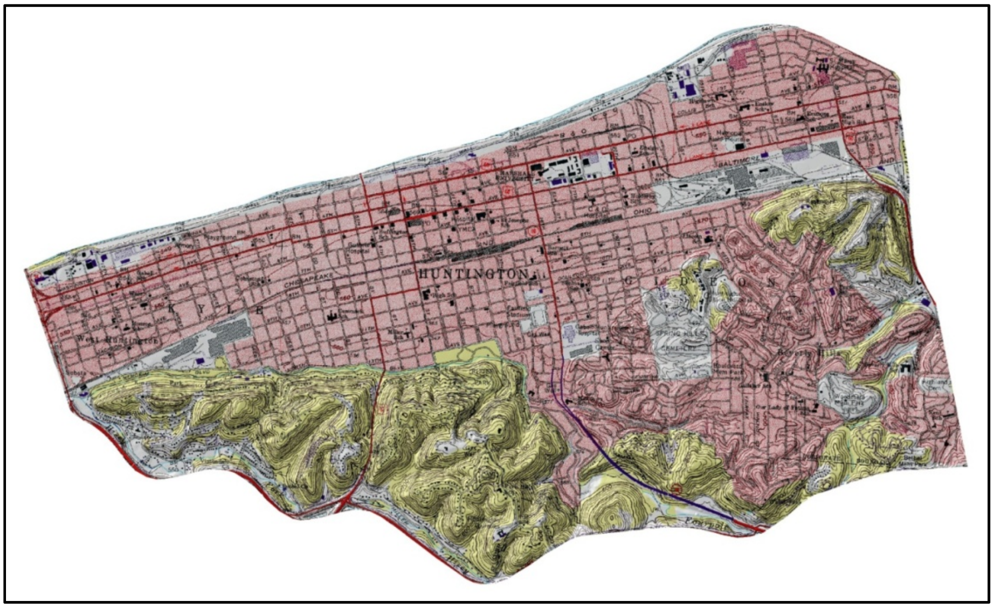



Figure 2. Map of study area with topographic overlay.

## Definition of the Urban Gradient

The study area was divided into five development zones based on the amount of impervious surface cover and the pattern of landscape development. These five development zones, described in order of increasing impervious surface cover and representing an increasingly urbanized landscape, were designated suburban forest, low intensity, moderate intensity, high intensity, and industrial/commercial (Figures 3-7).

### *Suburban Forest Development Zone*

Large continuous tracts of forest composed of native tree species dominate the suburban forest with a mean tree canopy cover area of 69.1% (Figure 3). Roadways follow ridgelines, valleys, or hillside contours. There is a relatively low ratio of edge to forest interior area. The majority of structures are primary residences surrounded by a narrow buffer of maintained turf grasses and ornamental shrubs and trees. Most surface water runoff from impervious surfaces is directed to surrounding areas of vegetation. Natural drainage patterns remain intact.

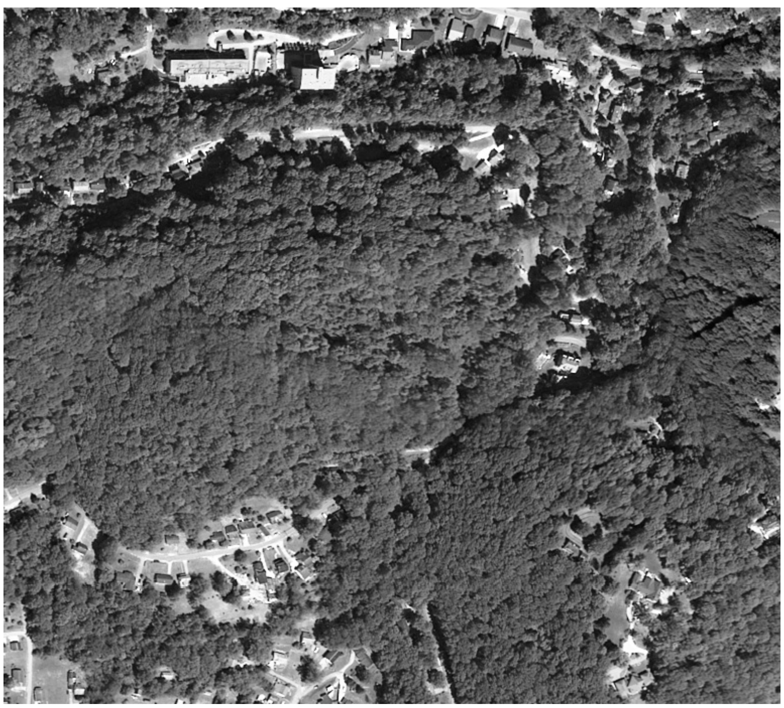


Figure 3. Aerial view of landscape features within the suburban forest development zone including percent impervious surface and tree canopy cover estimates extracted from imagery.

| Cover Class | Mean | Minimum | Maximum |
|---|---|---|---|
| Impervious Surface | 7.9% | 0% | 15.0% |
| Tree Canopy | 69.1% | 3.5% | 99.7% |

***Low Intensity Development Zone***

The low intensity development zone maintains some large tracts of forest but also contains smaller isolated patches (Figure 4). Percent impervious cover increases along with the areas covered by maintained turf grass. Habitat fragmentation increases with larger tracts of open land and a reduction in interior forest area size. There is an increased use of ornamental shrub and tree species around residential structures, replacing native tree species. Surface water runoff from impervious surfaces is discharged to surrounding vegetation or adjacent water bodies.

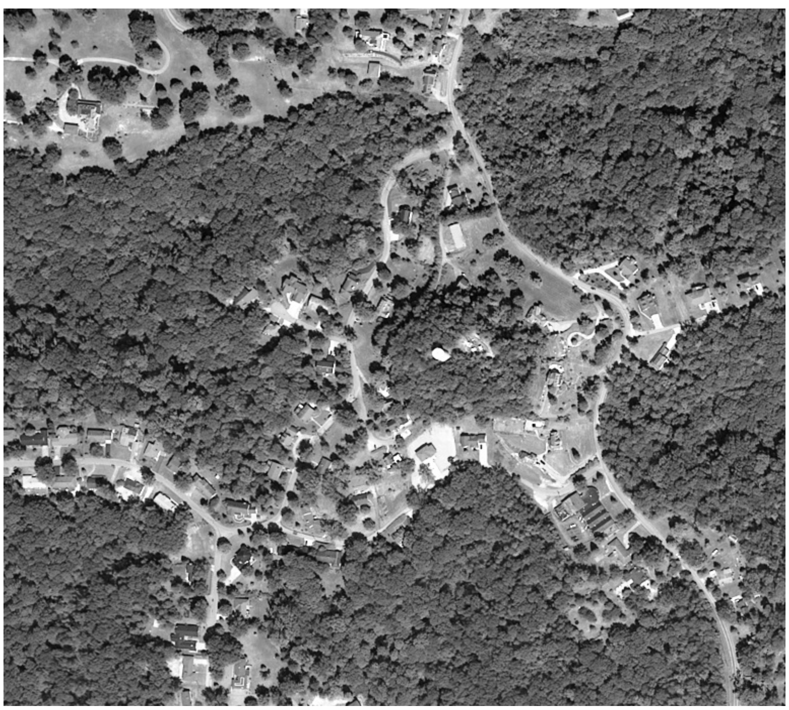


Figure 4. Aerial view of landscape features within the low intensity development zone including percent impervious surface and tree canopy cover estimates extracted from imagery.

| Cover Class | Mean | Minimum | Maximum |
|---|---|---|---|
| Impervious Surface | 22.9% | 15.1% | 32.5% |
| Tree Canopy | 48.8% | 15.2% | 86.9% |

### *Moderate Intensity Development Zone*

Large forest tracts have been eliminated with remnants occurring as row-like stands or isolated patches (Figure 5). Some areas have been developed in a block-like pattern with some structures occurring in rows. There is an increase in planted ornamental shrubs and trees. Structures are a mix of primary residences and small to medium businesses. Mean impervious surface area increases to greater than 40%. Surface water runoff from impervious surfaces is directed to storm water drains. Natural stream channels are altered through use of culverts or channel hardening (paving, gabions).

Figure 5. Aerial view of landscape features within the moderate intensity development zone including percent impervious surface and tree canopy cover estimates extracted from imagery.

| Cover Class | Mean | Minimum | Maximum |
|---|---|---|---|
| Impervious Surface | 43.4% | 32.6% | 55.1% |
| Tree Canopy | 24.8% | 1.9% | 50.7% |

### ***High Intensity Development Zone***

Block structure dominates. Impervious surface is represented by a higher proportion of paved parking areas and barren areas (Figure 6). Industry consists of medium to heavy manufacturing. Vegetation cover area is greatly reduced, occurring as small patches of maintained turf grasses and isolated trees. Natural surface drainage has been interrupted with most surface water runoff directed to storm drains.

Figure 6. Aerial view of landscape features within the high intensity development zone including percent impervious surface and tree canopy cover estimates extracted from imagery.

| Cover Class | Mean | Minimum | Maximum |
|---|---|---|---|
| Impervious Surface | 66.4% | 56.8% | 75.4% |
| Tree Canopy | 9.4% | 0.5% | 16.8% |

***Industrial/Commercial Development Zone***

The industrial/commercial development zone is dominated by large contiguous blocks of impervious surface with small tracts of grass and scattered trees interspersed (Figure 7). Land use includes industrial and manufacturing sites bordering the Ohio River, commercial enterprises, educational institutions, and rail transportation maintenance facilities. Mean impervious cover is greater than 85%. Vegetation is restricted to maintained turf, ornamental tree and shrub plantings, and native tree species in small green areas or bordering buildings and roadways. Surface water runoff is directed almost entirely to storm water drains, excluding natural infiltration.

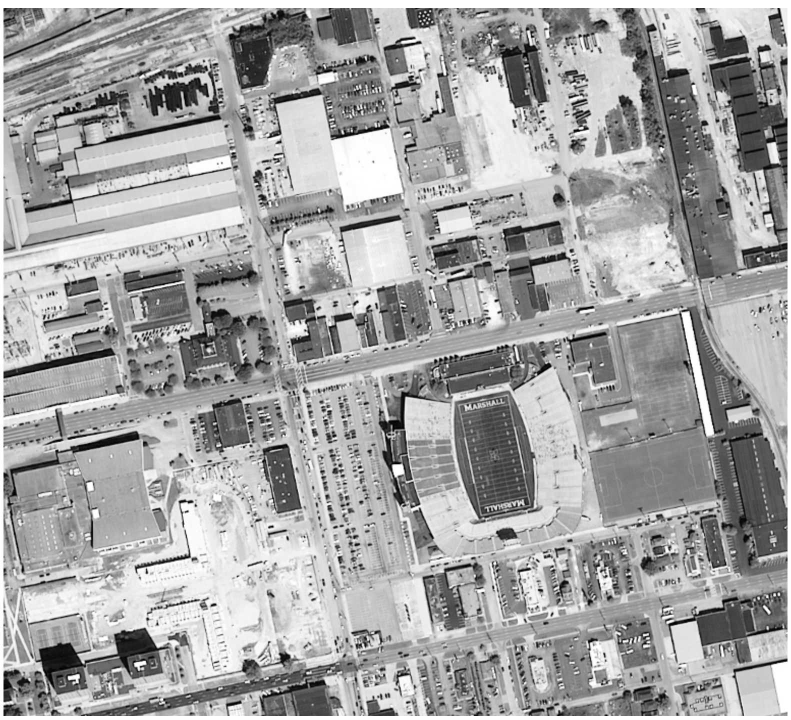



Figure 7. Aerial view of landscape features within the industrial/ commercial development zone including percent impervious surface and tree canopy cover estimates extracted from imagery.

| Cover Class | Mean | Minimum | Maximum |
|---|---|---|---|
| Impervious Surface | 88.2% | 76.3% | 99.8% |
| Tree Canopy | 2.6% | 0% | 8.1% |

The amount of impervious surface within each zone generally increases with a decrease in residential lot size and an increase in commercial and industrial development. This trend and the corresponding mean percentage of impervious surface extracted for each development zone closely follows the results of studies by the City of Olympia (1995) and the Natural Resources Conservation Service (1986). The pattern or "texture" of the landscape also changes.

The aerial extent of each development zone within the study area is outlined in Figure 8.

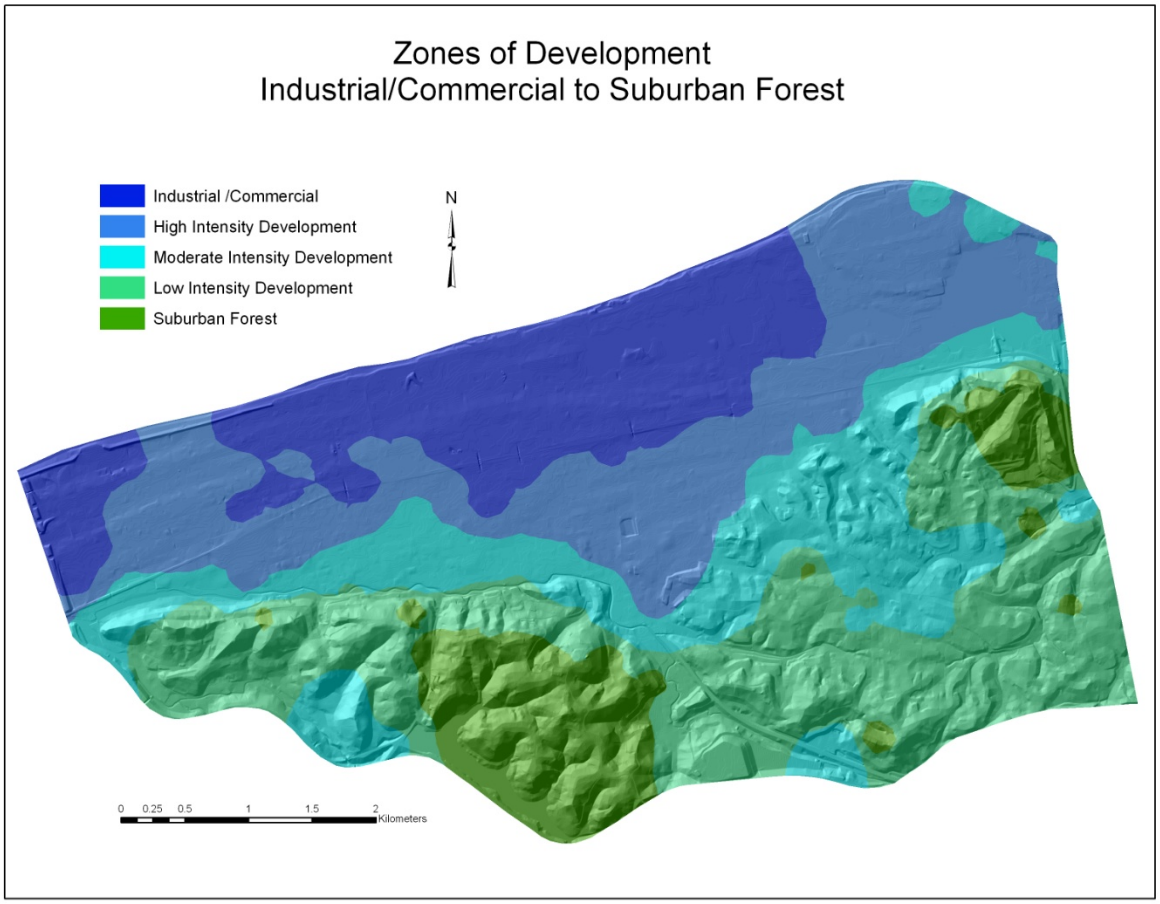



Figure 8. Development zones location map.

### *Sample Station Locations*

Sample stations were located within the study area to obtain data on landscape characteristics and bird species composition. Each station represents a circle with a radius of 100 meters and an area of 3.14 hectares. Two-hundred and five stations were established and sampled during 2008 (Figure 9).

Station circles were used to "clip" or cut out individual station land cover maps from the features extracted from aerial imagery. Sampling frame design, sampling methods, and extraction techniques are fully described in Chapters II and III.

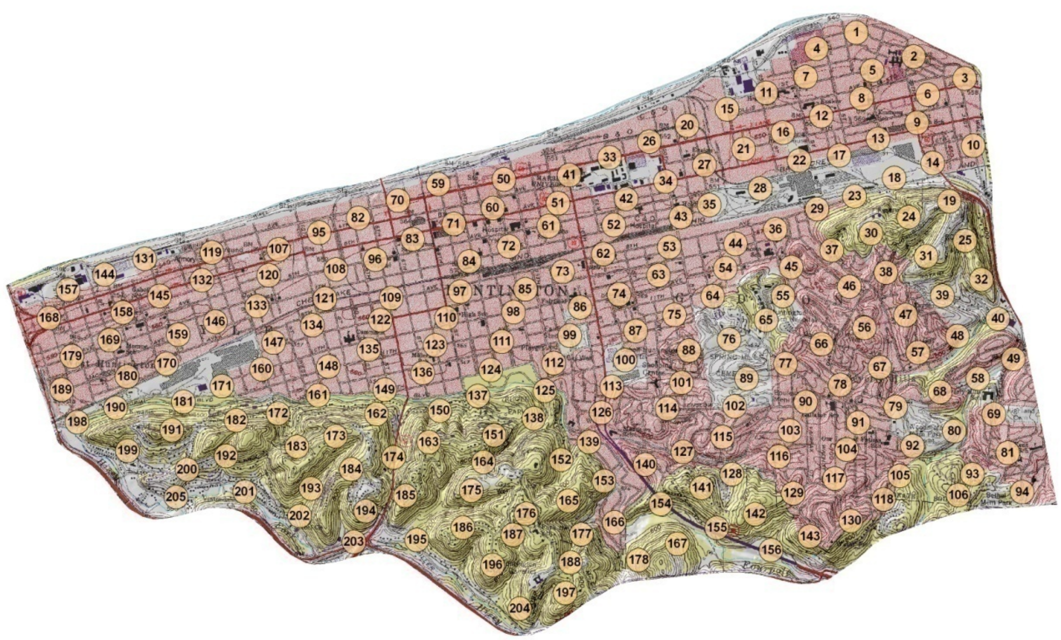


Figure 9. Study area map with topographic overlay showing the locations of established sample stations.

# CHAPTER II: FEATURE EXTRACTION FOR LANDSCAPE CHARACTERIZATION

## Introduction

### *Imagery Selection and Usefulness*

Characterizing urban habitat using remote sensing can be difficult as the landscape is a heterogeneous mixture of features. Imagery with low resolution may have pixels that encompass more than one cover type. Landsat ETM imagery has a pixel size of 30 m and Aster imagery has a pixel size of 15 m. Borders between cover types would not be well defined and in some cases may be obscured within a single pixel at these resolutions.

Imagery obtained from airborne cameras or sensors can provide small pixel size (IFOV) and higher resolution, allowing landscape patterns to be extracted, but may not contain the thematic information provided by Landsat and Aster images to separate different cover classes or distinguish different land uses. Researchers mapping urban vegetation most often use a combination of hyperspectral and high spatial resolution imagery such as AVIRIS and IKONOS (Buddenbaum, Schlerf, & Hill, 2005; Mehner, Cutler, Fairbairn, & Thompson, 2004). These images provide the spatial (1–4 meter) resolution and spectral (229 bands) resolution needed to characterize the complex urban landscape.

Researchers have applied many forms of sub-pixel classification to try to separate different class elements occurring within a single pixel. These include linear mixture modeling (Lee & Lathrop, 2005), expert system rules (Myint, 2006), spectral mixture analysis (Small, 2001), and super-resolution pixel swapping (Thornton, Atkinson, & Holland, 2006).

The author conducted a pilot mapping project at Rotary Park within the study area to evaluate the usefulness of linear mixture sub-pixel classification using both Aster and Landsat ETM imagery. The results indicated that this technique would provide useful landscape feature information but that it would not suffice for delineation of features at the scale used in this study.

Time of imagery acquisition also affects its usefulness. Imagery obtained leaf-on can be used to estimate vegetation cover (horizontal area – canopy cover). Imagery obtained leaf-off can reveal boundaries of features that would otherwise be obscured by vegetative cover (highways, streets, paved areas, buildings).

Imagery should also be contemporary with or as close as possible to the date of bird species field data collection (Gottschalk, Huettmann, & Ehlers, 2005). Land use change, which can occur over a short period, may substantially alter the habitat characteristics of the area within or adjacent to survey stations. Figure 10 and Figure 11 show two areas of post-survey modifications of the land surface in areas that overlap established sampling stations. These modifications include changes to the local topography, hydrologic regime, and vegetation cover type.

Figure 10. Change in land cover and land use within the study area. The area in the foreground was covered by shrubs and small trees during the count period. All vegetation was removed post survey.

Figure 11. Change in hydrologic regime within study area. The area was filled following the survey period, eliminating a wetland and altering the drainage pattern.

***Geospatial Data and Imagery***

Imagery for this project was limited to open source distribution centers.

1. DOQQ (CIR 2007 USDA-NAIP) Leaf-on.

   *Source:* West Virginia GIS Technical Center Web site.

   *Derivatives*: Classification of land cover to determine percent of impervious, tree, and grass cover. Reference for defining boundary edge between multiple land cover classes. Used as a color draping and data fusion layer.

2. LANDSAT ETM+ (5/22/2002) Leaf-on.

   *Source:* USGS Global Visualization Viewer Portal – Earth Resources Observation and Science Center

   *Derivatives*: General classification of land cover, thermal to blackbody conversions.

3. National Land Cover Dataset (NLCD) 2001 – Percent Impervious

   Source: West Virginia GIS Technical Center Web site.

   Derivatives: Comparison with impervious surface cover extracted from imagery, and definition of study area boundaries.

4. Digital natural color orthophotography for the state of West Virginia

   *Source:* WV Statewide Addressing and Mapping Board (SAMB) 2003 Leaf-off.

   *Derivatives*: Base map, reference for defining boundary edge between multiple land cover classes, and definition and positioning of human-constructed features.

5. Digital Raster Graphics (DRG) from Scanned USGS Topographic Maps (1:24,000)

   Source: West Virginia GIS Technical Center Web site.

   Derivatives: Base map overlay.

6. DEM raster elevation data at 3-m resolution compliant with National Elevation Dataset standards (UTM Zone 17 Projection, horizontal datum NAD 83, vertical datum NAVD88).
   *Source:* West Virginia GIS Technical Center Web site.
   *Derivatives*: Surface features including hillshade, contours, elevation, slope, aspect, and color-draping height layer.

### *Software for Data Management and Image Processing*

Four software platforms were used for data management and feature extraction. Individual software modules were used to classify imagery for feature extraction.

ArcGIS® 9.2 Desktop software with ArcGIS Spatial Analyst™ and ArcGIS 3D Analyst™ extensions from ESRI, Inc. (ArcGIS). ArcGIS was used to establish the grid of potential sampling stations, define the study area, perform final classifications on features extracted and imported from image processing software, store raster and vector data in a geodatabase format, and create layers and interpolated surfaces from bird species data.

Storage and manipulation of station location coordinates were managed with Expert GPS software (Copyright 2007 Topografix). Expert GPS stores coordinate information in a GPS Exchange File format (.gpx) that can be shared with other GPS software. Coordinate information can also be exported or imported in a comma delimited file format that is compatible with Microsoft Excel and Microsoft Access. Coordinates generated in ArcGIS were uploaded to the GPS unit for field location of sampling stations using Expert GPS.

Image processing and feature extraction were performed using ER Mapper Professional 7.1 Desktop Software from Earth Resources Mapping (ER Mapper) and Idrisi Andes Software from Clark Labs (Idrisi). The tasseled cap transform and maximum likelihood supervised classification were completed within ER Mapper. Unsupervised classification, thermal to blackbody conversion, and generation of vegetation indexes were performed in Idrisi.

Various file formats were used for import and export of data from one image processing platform to another. The geoTIFF file format proved to be the best format for exchange between programs. The Andes version of Idrisi allows the import of ESRI shapefile format through a conversion process to Idrisi vector format. Idrisi vector files can also be exported in ESRI shapefile format.

# Methods

### *CIR Imagery*

Impervious surface, grass, and tree canopy land cover classes were selected to be extracted from USDA DOQQ CIR (leaf-on) 1-m IFOV aerial photography taken during 2007 (Figure 12). This imagery was readily available and obtained close to the date of collection of avian population data. It also provided the spatial resolution necessary for feature extraction at the desired scale.

CIR imagery can be used to separate vegetation from impervious or barren surfaces and identify the contact between land and water (U.S. Army Corps of Engineers, 1995). However, film-based CIR imagery does present certain limitations including difficulty in extracting and interpreting shadows and providing a reduced range of recordable reflected infrared response compared to other imaging sensors (Jensen, 2005; Sabins, 2007).

Three different classification methods were initially used to determine which one would provide the most accurate output from extracted impervious surface, grass cover, and tree canopy cover: unsupervised classification (Idrisi), supervised classification using a maximum likelihood classifier (ER Mapper), and the Ratio Vegetation Index (Idrisi).

Only the horizontal area of coverage was defined. Accordingly, tree cover preempted both grass and impervious features as the imagery used was leaf-on. A more accurate definition of grass and impervious surface could be derived by classifying leaf-off imagery that is contemporary with and characteristically identical to the leaf-on imagery. Unfortunately, no such imagery was available.

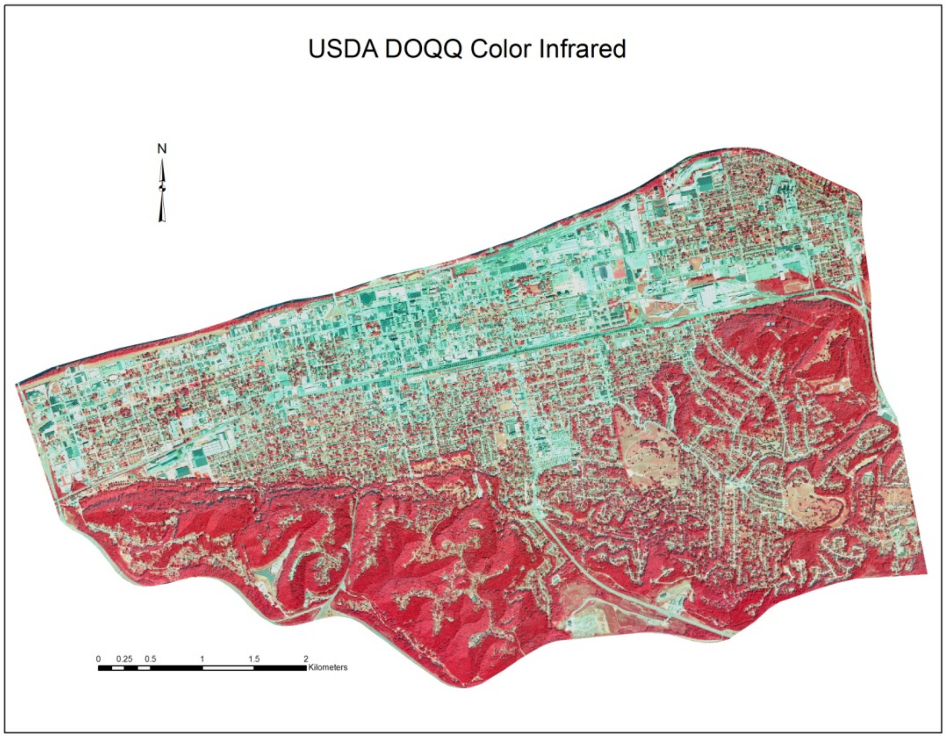



Figure 12. 2007 CIR DOQQ image of study area.

### ***Unsupervised Classification***

*Idrisi Andes Isoclust*

The Idrisi Andes Isoclust module is an iterative self-organizing unsupervised classifier and makes use of three modules: Cluster, Makesig, and Maxlike (Eastman, 2006). The Cluster module was used to examine the band data in the image prior to using Isoclust. The initial output of the cluster module recognized 26 clusters and provided their relative ranks. Using the higher number of clusters produced too complex an image for interpretation. Using a lower number of clusters did not adequately separate impervious surface from other land cover classes. Unsupervised classification was not pursued beyond this point.

### ***Supervised Classification***

*ER Mapper Maximum Likelihood*

The ER Mapper Maximum Likelihood supervised classification module uses statistics from training sites to classify an image. A cell is assigned to a class by considering the distance weighted by the covariance matrix of the means, and the prior probability that the cell belongs to it (ER Mapper Professional User Guide Version 7.1 2006).

Training site selection is critical to successful delineation of landcover features using supervised classification. Training sites must include a sufficient number of pixels within each cover type. Careful selection and delineation of training sites using unadjusted image data can produce classifications that are superior to those performed on enhanced or transformed image data (Landgrebe & Biehl, 2001). Supervised classification was completed on unadjusted image data.

Training sites were created for each cover type of interest for use with the supervised classifier. Four different training areas were defined: impervious surface, tree canopy cover, grass cover, and shadows. Impervious surface training sites included buildings, paved areas, bare ground, roof tops, roadways, and industrial and commercial storage areas. Grass cover training sites included lawns, fields, and natural recreational turf. Tree cover training sites included woodlands, forests, residential plantings, and shrub lands. Training sites for roadways included all pavement types (concrete, asphalt, brick, and gravel) and different roadway orientations (aspects). The shadow training class included those cast by buildings, trees, and topographic features (steep slopes).

Multiple iterations were necessary to adequately define training sites so that each targeted land cover class could be extracted while minimizing errors of omission and commission.

Accuracy of each new classified image was determined by placing the classified image over the original CIR imagery and visually assessing how well features were separated. Natural color, leaf-off, and orthophotoquads were also used to help delineate the impervious land cover class (Figure 13).

Figure 13. Visual assessment of classified image showing impervious surface cover class overlaid on a leaf-off natural color aerial orthophotograph.

Scattergrams were generated after each iteration and used to adjust training areas for maximum separation of the land cover classes. Figures 14, 15, and 16 show 95% confidence ellipses for training areas within the scattergrams for impervious, grass, and tree cover classes respectively. Some overlap occurred between the tree canopy cover and grass cover classes with each iteration, causing confusion in assignment of pixels to the proper cover class.

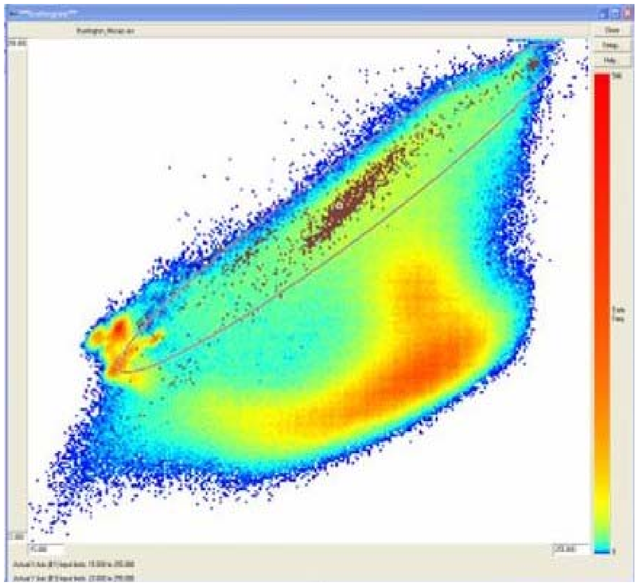


Figure 14. Scattergram (Bands 1 and 3) with the 95% confidence ellipse for the impervious surface cover class training area.

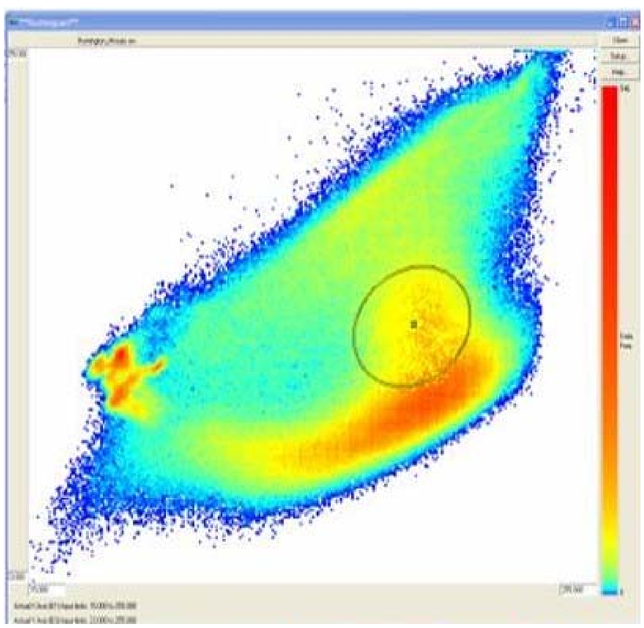


Figure 15. Scattergram (Bands 1 and 3) with the 95% confidence ellipse for the grass cover class training area.

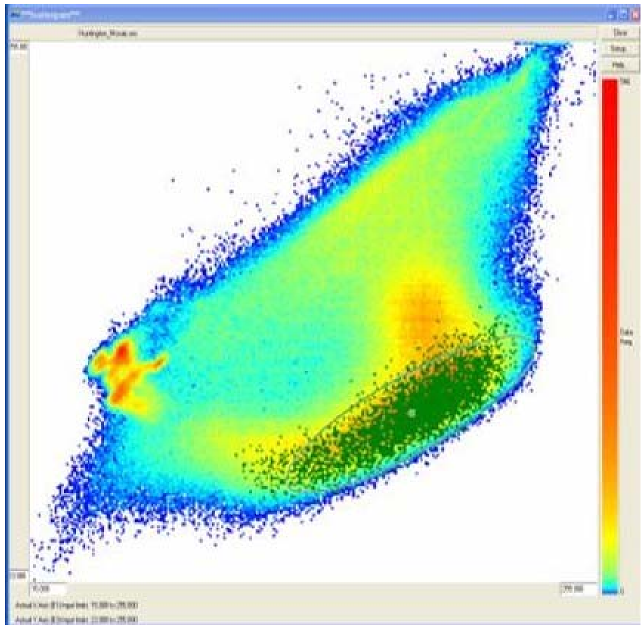


Figure 16. Scattergram (Bands 1 and 3) with the 95% confidence ellipse for the tree canopy cover class training area.

Initial supervised classification attempts dropped out some brick road sections due to inadequate training site definition. Brick roadways posed several problems for separation of all three cover types of interest (See Results and Discussion this chapter).

The final result of the maximum likelihood classification using equal prior probabilities (unweighted) placed up to 13% of the image pixels within the shadow class. These shadow areas encompassed all three of the desired landscape features: impervious surface cover, tree canopy cover, and grass cover. To force the classifier to place these pixels in either of the three desired cover classes, the prior probability for the shadow feature class was set to zero. The proportion of each of the other classes from the final unweighted classification (equal prior probability) was used to set the weighted prior probabilities for impervious cover, tree canopy cover, and grass cover in the new algorithm.

### *RVI Vegetation Index*

The Idrisi Andes Ratio Vegetation Index Model (RVI) was used to produce an image based on a band ratio. The RVI vegetation index model compares the red and near infrared (NIR) bands as a simple ratio (Eastman, 2006):

$$RVI = \frac{NIR}{Red}$$

Bare soil and impervious surface have low values. Values increase with NIR response to increasing vegetation density. NIR response would also be dependent upon vegetation type, condition, texture, and moisture content. This model was used to separate impervious surface and barren areas from vegetation. The initial RVI output image was reclassified by adjusting the division between each cover class of interest within the histogram of ratio values. This produced a sharp boundary between the impervious surface cover and the two vegetation cover classes.

## Results and Discussion

### *Classified Image Maps*

Classified image maps were created from the output of the unweighted and weighted maximum likelihood classifications and the RVI model. Individual cover maps were first created for each of the three landscape features—impervious surface, grass cover, and tree cover—extracted from the imagery. These raster images were saved in geoTIFF format and imported into ArcGIS. Each separate cover class raster image was reclassified, converted to polygons, and dissolved into a single, multipart polygon shapefile. The individual cover class shapefiles were then merged into a single study area shape file. Figure 17 shows the completed map for the unweighted maximum likelihood classification.

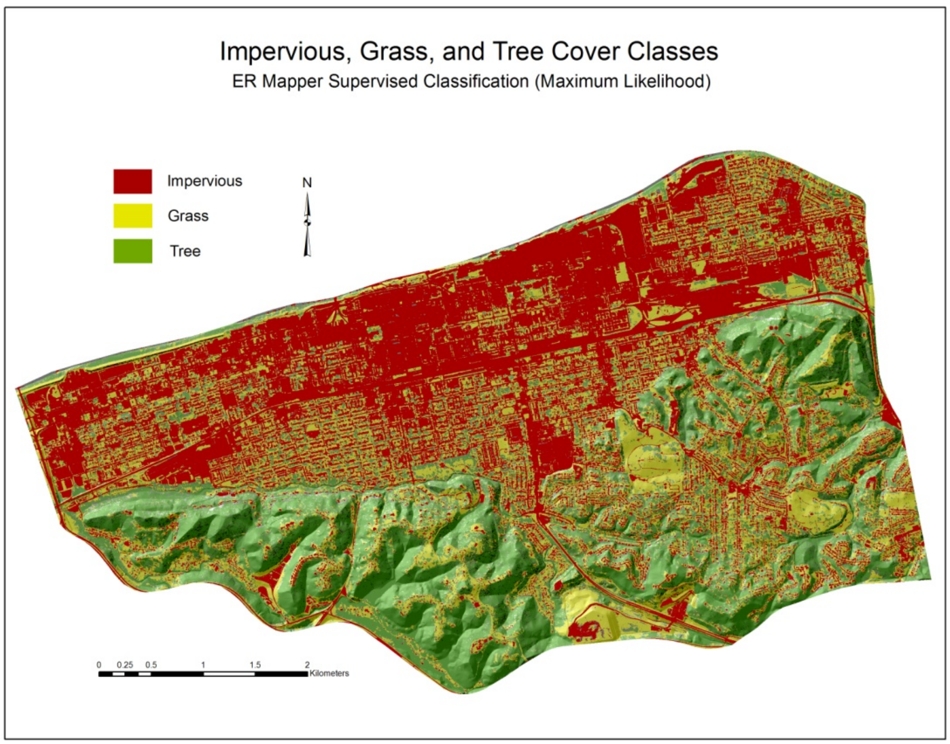



Figure 17. Impervious, grass, and tree cover class map derived from feature extraction using the maximum likelihood classifier in ER Mapper.

### *Classification Image Accuracy Assessment*

Most approaches to accuracy assessment include image differencing where one image is compared against another to determine the difference between areas occupied by each feature class. This is typically used in temporal studies where change is to be quantified between images obtained at different times (Jensen 2005).

To determine the accuracy of features extracted from imagery used in this study, a reference image would have to be used that was contemporary with and of similar characteristics to the image from which the classified image was extracted. No such image was available. Image differencing could be used to indicate change in classification between iterations of classification attempts, but as no reference image was available, image differencing could not provide a measure of accuracy for land cover class area.

The confusion matrix feature of ER Mapper is used to assess the accuracy of classification. A ground truth sample file is created in ASCII points format and then imported into ER Mapper (ER Mapper Professional User Guide Version 7.1, 2006). The resulting vector file is georeferenced to the classified image data set and a comparison is made between the classified image and each control point. However, this would only indicate the accuracy of classifying an individual pixel correctly but would provide no information on the accuracy of each extracted land class cover area.

The accuracy of each of the final three classified images was determined by comparison with a digitized land cover map comprised of a random sample of 20 sample stations selected from the total 205 stations within the study area. Each land cover class (impervious surface, grass cover, and tree canopy) was visually identified and digitized directly from the original

DOQQ image used for classification. Shadows were classified within the land cover class to which they belonged.

These same 20 stations were used to clip the corresponding areas from each of the final classified images. The clipped station sections from the classified images were then compared against the digitized image sections graphically by examining $r^2$, intercept, slope, and standard error for the correlation (Tables 1-3 and Figures 18-20). The Cross Class and Error Matrix modules in Idrisi were used to determine Kappa statistics and errors of omission and commission (See Appendix A for complete results).

Table 1
Correlation of extracted with digitized impervious surface cover.

| Statistic | Maximum Likelihood (unweighted) | Maximum Likelihood (weighted) | RVI |
|---|---|---|---|
| r | 0.988 | 0.993 | 0.995 |
| $r^2$ | 0.976 | 0.986 | 0.99 |
| intercept | -2931.076 | -2130.13 | -110.7967 |
| slope | 1.0368 | 1.0446 | 1.0501 |
| SE | ±1472.1164 | ±1127.0835 | ±955.9531 |

Table 2
Correlation of extracted with digitized tree canopy cover.

| Statistic | Maximum Likelihood (unweighted) | Maximum Likelihood (weighted) | RVI |
|---|---|---|---|
| r | 0.957 | 0.979 | 0.949 |
| $r^2$ | 0.916 | 0.958 | 0.901 |
| intercept | -841.9044 | -195.4529 | 1105.5431 |
| slope | 0.8465 | 0.994 | 0.9802 |
| SE | ±2116.9933 | ±1718.3119 | ±2683.4181 |

Table 3
Correlation of extracted with digitized grass cover.

| Statistic | Maximum Likelihood (unweighted) | Maximum Likelihood (weighted) | RVI |
|---|---|---|---|
| r | 0.902 | 0.897 | 0.836 |
| $r^2$ | 0.814 | 0.805 | 0.699 |
| intercept | 2173.0833 | 2361.8503 | 1213.8891 |
| slope | 0.9253 | 0.9255 | 0.6551 |
| SE | ±2048.6346 | ±2108.7093 | ±1990.7363 |

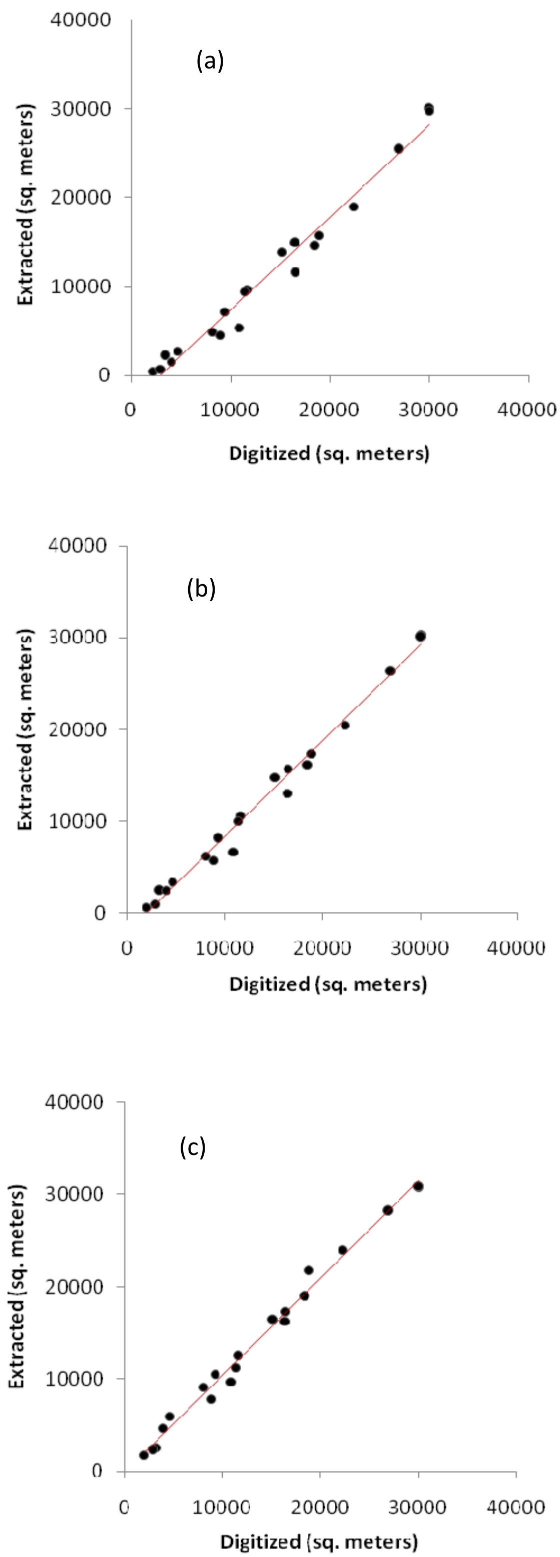



Figure 18. Comparison of extracted area against digitized area for impervious surface. (a) maximum likelihood unweighted, (b) maximum likelihood weighted, and (c) RVI.

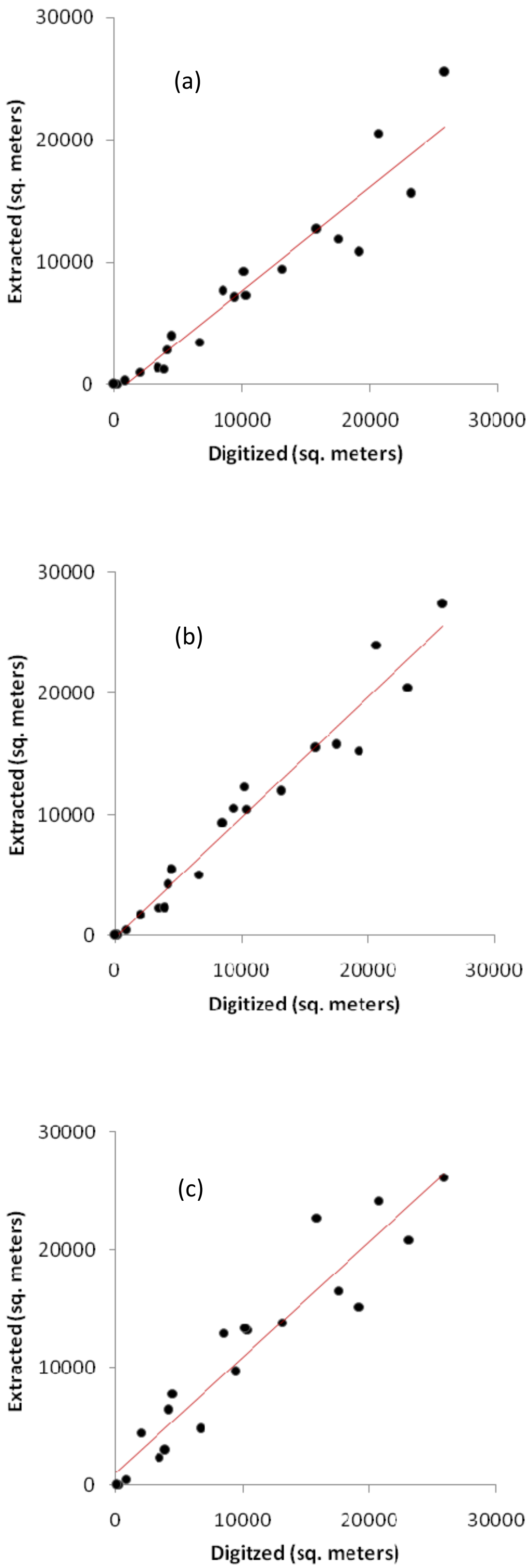



Figure 19. Comparison of extracted area against digitized area for tree canopy cover.
(a) maximum likelihood unweighted,
(b) maximum likelihood weighted, and
(c) RVI.

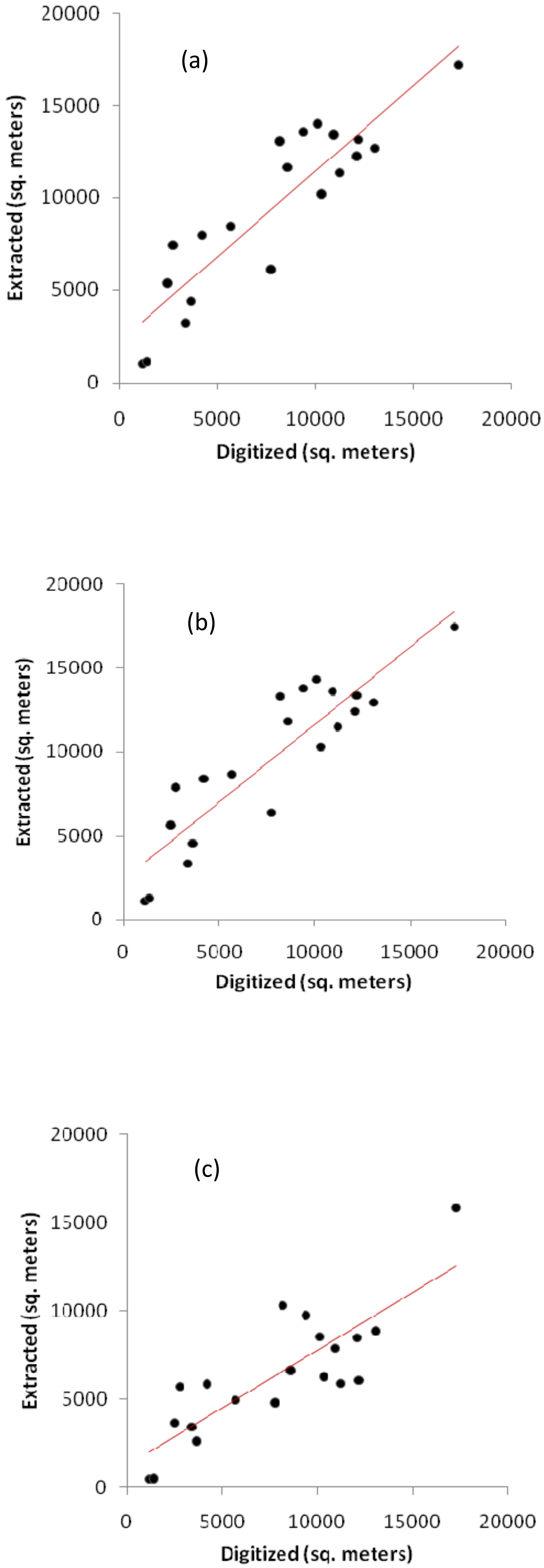



Figure 20. Comparison of extracted area against digitized area for grass cover.
(a) maximum likelihood unweighted,
(b) maximum likelihood weighted, and
(c) RVI.

Impervious surface cover area was underestimated by both the unweighted (equal prior probability) and weighted settings for the maximum likelihood classification, although accuracy did improve for the weighted algorithm. The RVI model proved to be the most accurate approach. This index produced an 83.1% pixel for pixel agreement with the digitized map for impervious surface and a Kappa Index of Agreement of 0.86. Error of omission was 7.4% and error of commission was 11.0%. Some finer details (narrow sidewalks) were dropped out but the RVI produced clean boundaries between impervious surface and the two vegetation cover classes (Figure 21).

Tree canopy cover was underestimated by the unweighted maximum likelihood classification and overestimated by the RVI. The weighted maximum likelihood classifier produced the most accurate output with a 72.9% pixel for pixel agreement with the digitized map for tree canopy cover and a Kappa Index of Agreement of 0.75. Error of omission was 17.1% and error of commission was 14.7%.

Grass cover area was overestimated by the unweighted and weighted maximum likelihood classifications and underestimated by the RVI model. Grass cover class assignment also showed the greatest overall variation from the digitized maps. No acceptable measure of grass cover area was obtained through the classification process.

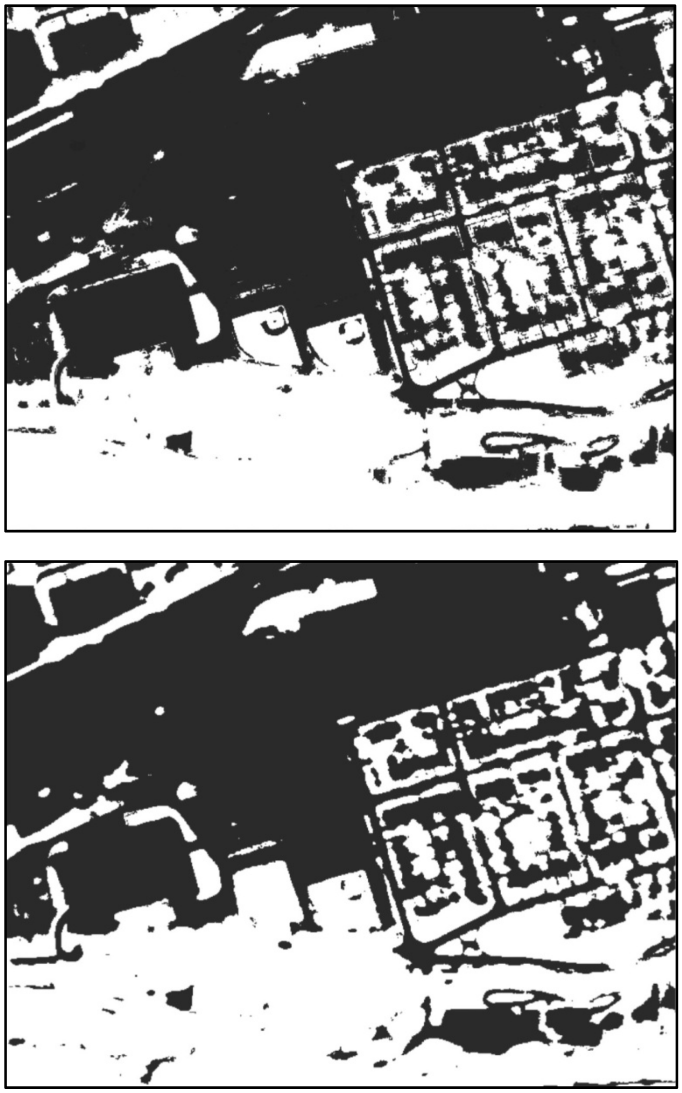


Figure 21. Comparison of impervious surface cover class definition between the unweighted maximum likelihood classification (upper image) and the RVI model (lower image) results.

***Sources of Error***

Narrow tree-lined streets and isolated residential structures surrounded by overhanging tree canopy were responsible for errors of omission for impervious surface. Shadows cast by the crowns of trees in the canopy of woodlands and forests and the intra-crown shadows of individual trees were responsible for most of the confusion between the tree canopy and grass cover classes.

Confusion was also caused by brick roadways between the impervious surface and grass cover classes. Bricks are made from clay and this could cause confusion with bare or sparsely vegetated ground. Brick roadways also have a unique texture created by the individual orientation of each brick in the pavement matrix. This can affect the reflectance characteristics of the road surface from location to location within the image.

The greatest difficulty encountered with brick roadways was the presence of interstitial vegetation. Brick roadways are generally side roads with low use, allowing vegetation to persist (Figure 22). The vegetation is usually heavier at the road margin and absent or sparse at the center, creating a gradient rather than a distinct edge between the road surface and the surrounding vegetation cover classes. (Figure 23).

Figure 22. Interstitial vegetation in brick roadway.

Figure 23. Gradient of interstitial vegetation decreasing from edge to center of roadway.

# CHAPTER III: MEASURING AVIAN POPULATIONS

## Introduction

The available time to complete surveys was a factor in designing the sampling frame. Data collection was limited to a single breeding season (2008). A decision had to be made concerning the number of sample stations to be established, the number of times each station was visited, and the spatial distribution of stations within the study area.

Maximizing the total number and spatial distribution of sample stations was considered to be more important than selecting a fewer number of stations so that repeat visits could be made. The urban matrix is patchy with abrupt changes in cover type over short distances. Capturing those changes within the sampling framework was considered essential. Both Melles et al. (2003) and Bolger, Scott, and Rotenberry (1997) considered replication in space to be more important (provided greater certainty) than repeat visits to a fewer number of sampling stations when deriving associations between species and habitat. Smith et al. (1993) found that sampling a larger number of stations once better described the bird community than when a smaller number of stations were sampled more than once.

A single visit also allowed the time spent at each station to be increased from five minutes to eight minutes. The proportion of species present during a count that are detected generally increases with a longer count period (Hutto, Pletschet, & Hendricks, 1986; Lynch, 1995). However, counts longer than 10 minutes can add variability and are less efficient at sampling the bird community (Smith et al., 1993).

Sampling bird populations in an urban environment presented several challenges. Noise is an unavoidable condition. Noise comes from artificial sources (traffic, industrial, and commercial activities) and natural sources (wind, rain, and insects). Survey design parameters were selected to minimize the effects of noise on bird detection. If transient artificial noise (garbage collection, wood chipping, lawn mowing) interrupted a count in progress, the count was either restarted upon cessation of the noise or the station was skipped and picked up at the end of the route.

The summer of 2008 experienced a large number of periodic cicadas. These insects can produce a noise level that can interfere with detection of birds, particularly in species with soft vocalizations and at increasing distances. Cool morning temperatures kept cicada-related noise within acceptable levels until routes were completed.

## Methods

### *Avian Sampling Frame Design*

A 250-m grid was overlaid on the study area. The grid was oriented by selecting a random point on the map and rotating the grid a random number of degrees using the initial point as the axis. The centers of the grids were established as potential sampling stations. Sample points were then selected systematically (every other point) using a random start. Sample stations were not stratified by land cover type or use.

Selected points falling within inaccessible areas (on top of buildings, private property) or open water were either skipped in the selection process or were offset from the grid center to the closest accessible point. Agreements were reached with selected landowners to gain access to stations that if omitted would have left large gaps in the spatial coverage of sampling stations. In no case was a sample station count area allowed to overlap with that of another station.

Two-hundred and five sample stations were selected within the study area. UTM coordinates were generated for each sampling station and each station was located in the field using a GPS receiver, topographic features, and aerial photographs. Stations were grouped into 15 routes of 12–14 stations each. Order of route completion was randomly selected. All stations were sampled once between May 28 and June 11, 2008. Counts were constrained within the time interval from dawn to four hours after dawn.

Bird species and numbers present were recorded during an eight-minute period divided into two consecutive periods of five minutes and three minutes at each station using a 100-m fixed-radius point count protocol (Hutto et al., 1986; Ralph, Sauer, & Droege, 1995; Hamel et al., 1996). An independent double observer protocol was used to address the question of detectability—the probability of detecting a bird that was present during the station survey period (Nichols et al., 2000). Thompson (2002) and Pendleton (1995) outlined the importance of using point counts that are adjusted for detection probability when calculating densities.

The location of each bird detected was marked within four concentric circles on a field data sheet (See Appendix B). The circles represented a distance of 10 m, 25 m, 50 m, and 100 m from the center of the sample station. Each of the two observers independently recorded birds on a separate field sheet. Individual birds recorded by both observers were noted, as well as birds recorded by a single observer (the individual observer was identified). Birds flushed while approaching the station were recorded if they were within the 100 m distance from the station center. Counts for aerial species, such as chimney swift, common nighthawk, and swallows, were based on the highest number observed at one time during the count period for each observer. Juveniles of all species were excluded from the count.

### *Avian Data Analysis*

Species richness, species diversity, percent abundance, and community similarity indexes were generated using the Abundance Curve Calculator by Dr. James A. Danoff-Burg and X. Chen (27 April 05). This calculator is based on the instructions given in the worked examples of Magurran (1988).

Sampling stations were treated individually and also as replicates within each development zone (41 stations per development zone). Species richness values were calculated from the total number of species detected at each individual sampling station and also from the cumulative number of species detected from all points within each development zone. Shannon diversity and Shannon evenness were calculated per point and also cumulatively within each development zone by summing the number of individuals detected for each species from all points within that zone.

The Sorenson Similarity Index (Krebs, 1989) was used to derive qualitative values of species composition similarity between the five development zones. This index uses presence/absence data to calculate similarity. It does not consider relative species abundance (Smith & Smith, 1998). A value of 1 indicates that species from both sites being considered are the same and a value of 0 indicates no similarity (Nur, Jones, & Geupel, 1999). The Renkonen Index was used to calculate percent similarity between each development zone. Percent similarity uses relative abundance of species in each community (Smith & Smith, 1998).

The double observer point count data were analyzed using DOBSERV software (Hines, 2000) from Patuxent Wildlife Research Center Software Archive to generate detectability estimates. DOBSERV uses counts, by species, of individuals detected by both observers, and counts of individuals detected by each observer as the input file. Estimates are based on six different models that are selected based on the differences in detection probabilities between observers and between species. The model selected was based on the lowest A.I.C. score. DOBSERV outputs the standard error for the detectability estimate and an estimated population size with standard error and 95% confidence intervals.

## Results and Discussion

A cumulative total of 4,163 birds, representing 63 species and 28 families (Appendix C), was counted over 205 sample stations during the survey period. The top five ranked birds in total detections were the European starling, house sparrow, American robin, chimney swift, and northern cardinal (See Appendix D for a complete listing).

Densities were calculated for 18 species. These species were selected based on acceptable detection probabilities, total number detected within the study area, and overall distribution across the gradient. Detection probabilities were calculated for each species within each of the five development zones to account for differences in detectability within each zone. Appendix D contains a complete listing of species distribution across all development zones.

Three groups were identified by their response to development along the gradient. Forest and woodland associated species including acadian flycatcher, eastern towhee, wood thrush, yellow-throated warbler, red-bellied woodpecker, and red-eyed vireo occurred in greatest densities within the suburban forest development zone and gradually decreased with increased development along the urbanized gradient (Figure 24). No detections for these species occurred within the industrial/commercial development zone with the exception of the acadian flycatcher. This single detection occurred in nonbreeding habitat.

Habitat generalists and those species that have successfully exploited increasing urbanization occurred in higher densities in the low to high intensity development zones (Figure 25). These areas are characterized by a more uniform mix of grass cover and residential structures where foraging and nesting sites are available. These species included the Carolina chickadee, northern cardinal, song sparrow, house finch, American robin, and northern mockingbird.

Urban associated species included mourning dove, house sparrow, common grackle, European starling, chimney swift, and rock pigeon (Figure 26). These species reached their highest densities in the high intensity and industrial/commercial development zones. Three in this group—house sparrow, European starling, and rock pigeon—are introduced, non-native species. Densities of these three species decreased rapidly from the high intensity development zone through the suburban forest zone. No detections for the rock pigeon occurred within the suburban forest zone.

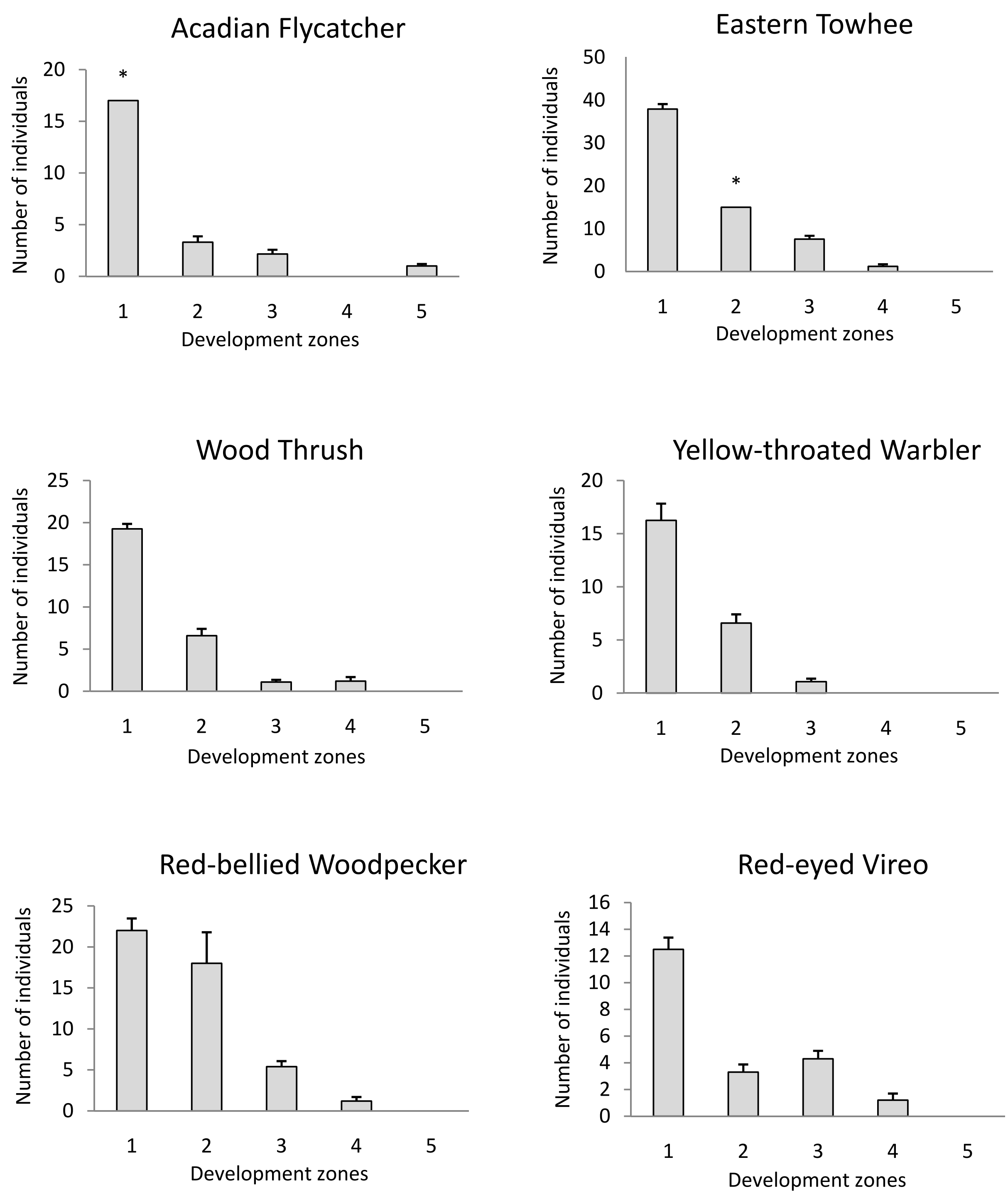



Figure 24. Species population estimates based on detectability (with standard error bars) for each development zone. Development zone 1 = suburban forest, 2 = low intensity, 3 = moderate intensity, 4 = high intensity, 5 = industrial/commercial. Each development zone aggregated sample area = 128.7 hectares (41 stations x 3.14 hectares). *Detection probability 1.0, no variance calculated.

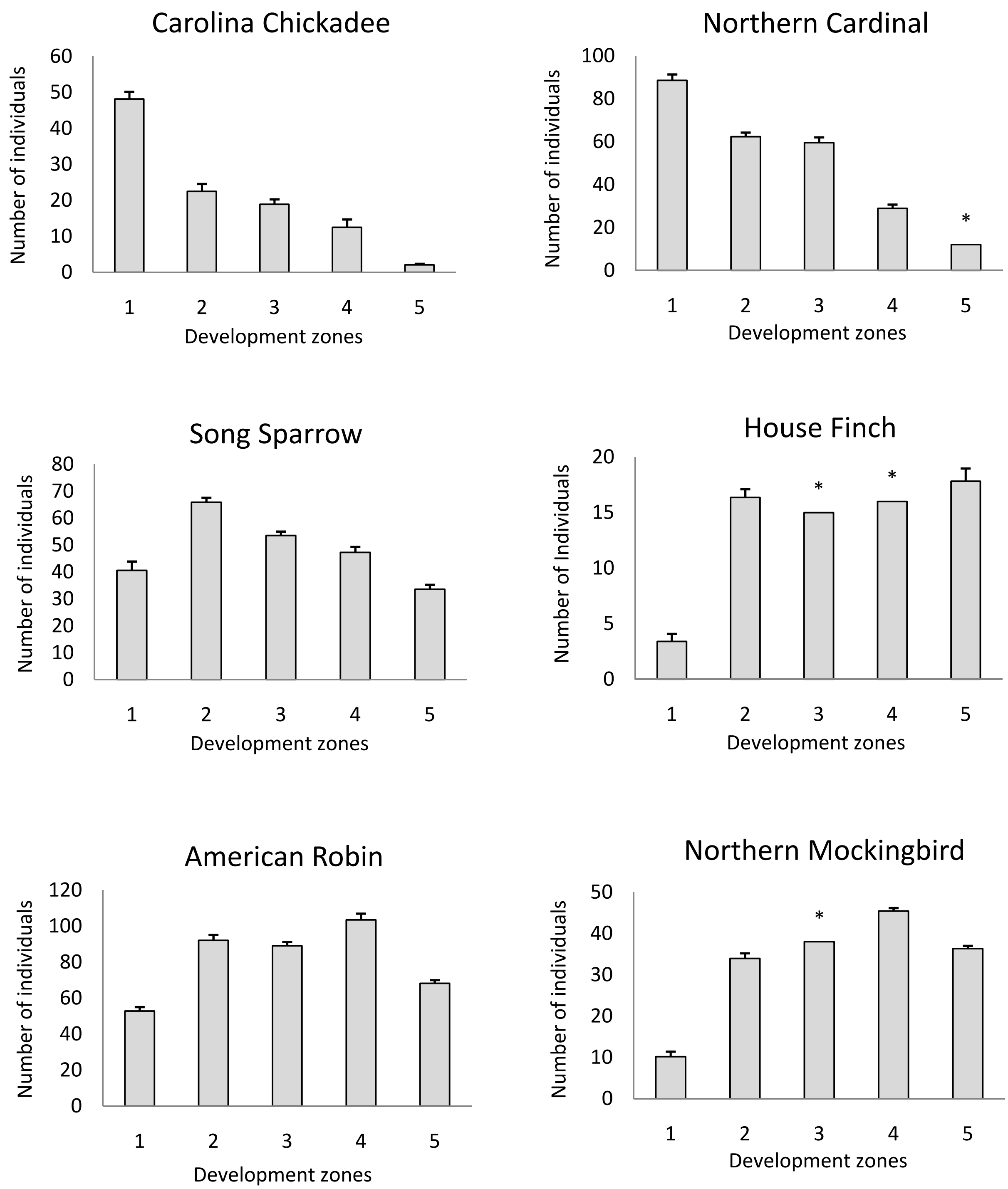



Figure 25. Species population estimates based on detectability (with standard error bars) for each development zone. Development zone 1 = suburban forest, 2 = low intensity, 3 = moderate intensity, 4 = high intensity, 5 = industrial/commercial. Each development zone aggregated sample area = 128.7 hectares (41 stations x 3.14 hectares). *Detection probability 1.0, no variance calculated.

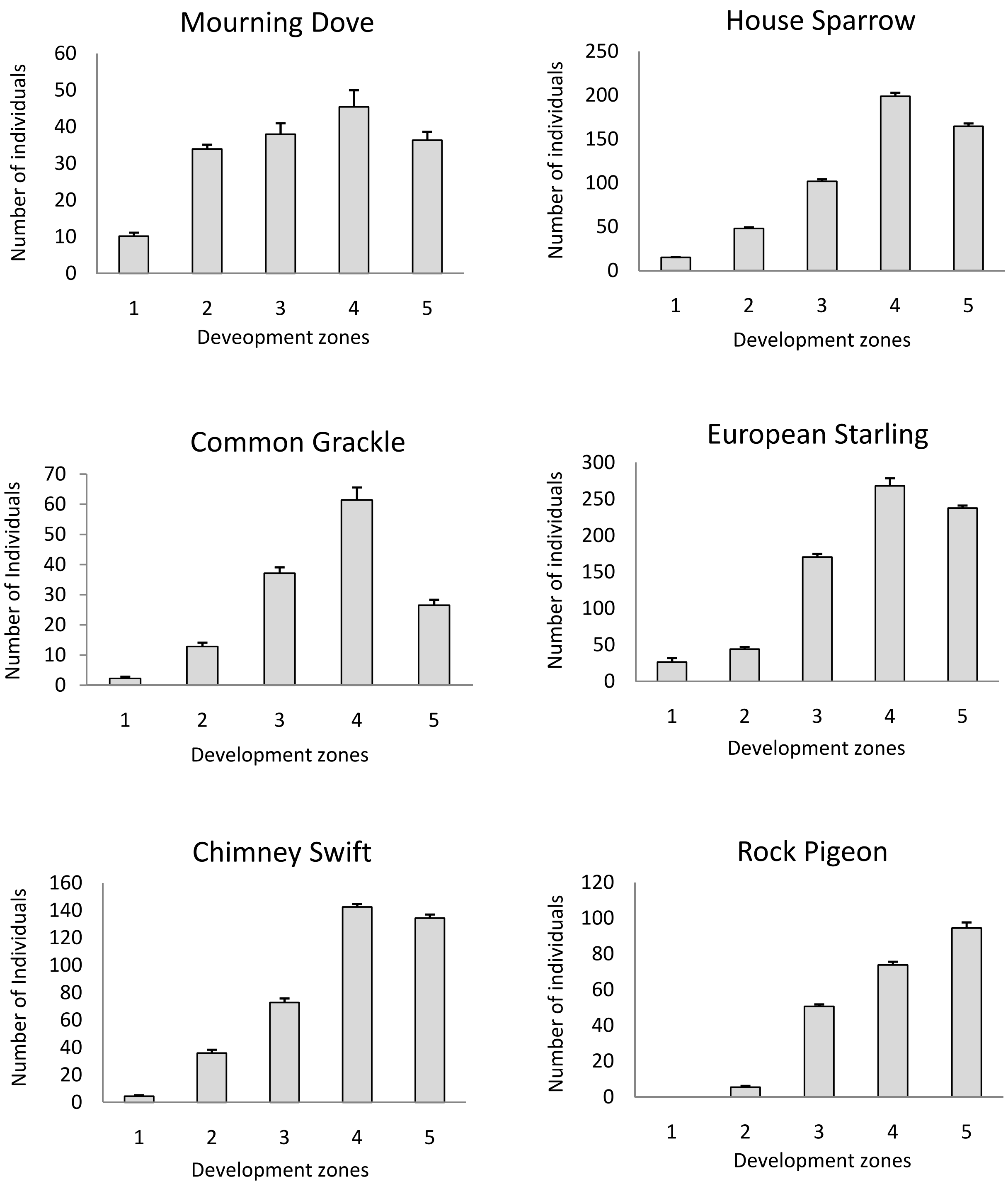



Figure 26. Species population estimates based on detectability (with standard error bars) for each development zone. Development zone 1 = suburban forest, 2 = low intensity, 3 = moderate intensity, 4 = high intensity, 5 = industrial/commercial. Each development zone aggregated sample area = 128.7 hectares (41 stations x 3.14 hectares). *Detection probability 1.0, no variance calculated.

Species richness decreased across the gradient in the direction of increasing development, with the greatest declines occurring within the transition from moderate intensity development (50 species) to high intensity development (40 species) to the industrial/commercial center (30 species). The number of individuals increased across the gradient, reaching the highest number in the high intensity development zone. Evenness decreased through the high intensity development zone and then leveled off. Species diversity (Shannon H´) decreased uniformly across the gradient (Table 4). These trends suggest a decline in species richness, diversity, and evenness due to the dominance of a fewer number of species at the urban end of the gradient.

Table 4
Comparison of number of individuals, species richness, species diversity, and evenness across development zones.

| | **Suburban Forest** | **Low Intensity** | **Moderate Intensity** | **High Intensity** | **Industrial/ Commercial** |
|---|---|---|---|---|---|
| Number of Individuals | 672 | 653 | 871 | 1057 | 910 |
| Number of Species | 52 | 50 | 50 | 40 | 30 |
| Shannon Diversity (H) | 3.3814 | 3.1833 | 2.9236 | 2.5032 | 2.3358 |
| Shannon Evenness (E) | 0.8558 | 0.8137 | 0.7473 | 0.6786 | 0.6868 |
| Shannon Maximum Value ($H_{max}$) | 3.9511 | 3.9121 | 3.9122 | 3.6887 | 3.4009 |
| Shannon Variance (H) | 0.0013 | 0.0016 | 0.0015 | 0.0012 | 0.0012 |

One-way ANOVA was completed for species richness and species diversity across all five development zones (Table 5). Tukey HSD (Figure 27) showed a significant difference ($p < 0.05$) in mean species richness between the suburban forest development zone and the moderate and high intensity zones. The difference was significant at the $p < 0.01$ level for all zones compared with the industrial/commercial zone. There was no significant difference between the suburban forest and the low intensity zone or between the three intermediate development zones.

A significant difference ($p < 0.01$) in mean species diversity was found between the suburban forest development zone and the moderate and high intensity zones. Unlike species richness, there was a significant difference ($p < 0.01$) in species diversity between the low intensity zone and the moderate and high intensity zones. The difference was significant at the $p < 0.01$ level for all zones compared with the industrial/commercial development zone. There was no significant difference between the suburban forest and the low intensity zone or between the moderate and high intensity development zones.

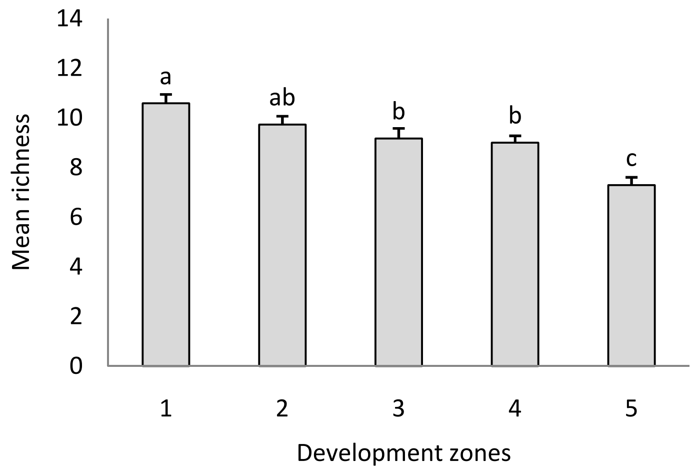
Table 5
One-way ANOVA results for species richness and diversity across development zones.

Richness

| Source of Variation | SS | df | MS | F | P-value |
|---|---|---|---|---|---|
| Between Groups | 240.712 | 4 | 60.178 | 12.719 | <.0001 |
| Within Groups | 946.293 | 200 | 4.731 | | |
| Total | 1187.005 | 204 | | | |

Diversity

| Source of Variation | SS | df | MS | F | P-value |
|---|---|---|---|---|---|
| Between Groups | 8.031 | 4 | 2.008 | 22.608 | <.0001 |
| Within Groups | 17.762 | 200 | 0.089 | | |
| Total | 25.793 | 204 | | | |



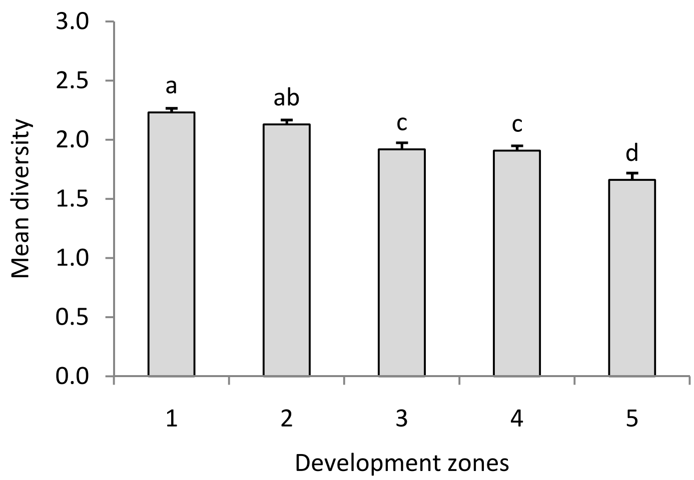




Figure 27. Mean richness and mean diversity for each development zone (with standard error bar). Development zone 1 = suburban forest, 2 = low intensity, 3 = moderate intensity, 4 = high intensity, 5 = industrial/commercial. Each development zone aggregated sample area = 128.7 hectares (41 stations x 3.14 hectares). Different letters indicate significant differences in means between development zones.

Avian community structure changed across the gradient. The suburban forest development zone was compared with all other zones to determine the degree of similarity in species composition. The suburban forest zone shared 44 species with the low intensity zone, 42 species with the moderate intensity zone, 33 species with the high intensity zone, and 26 species with the industrial commercial zone. The Sorenson index of similarity as well as Renkonen percent similarity showed a steady decline in avian community similarity between the suburban forest and all other zones along a gradient of increasing development (Figure 28).

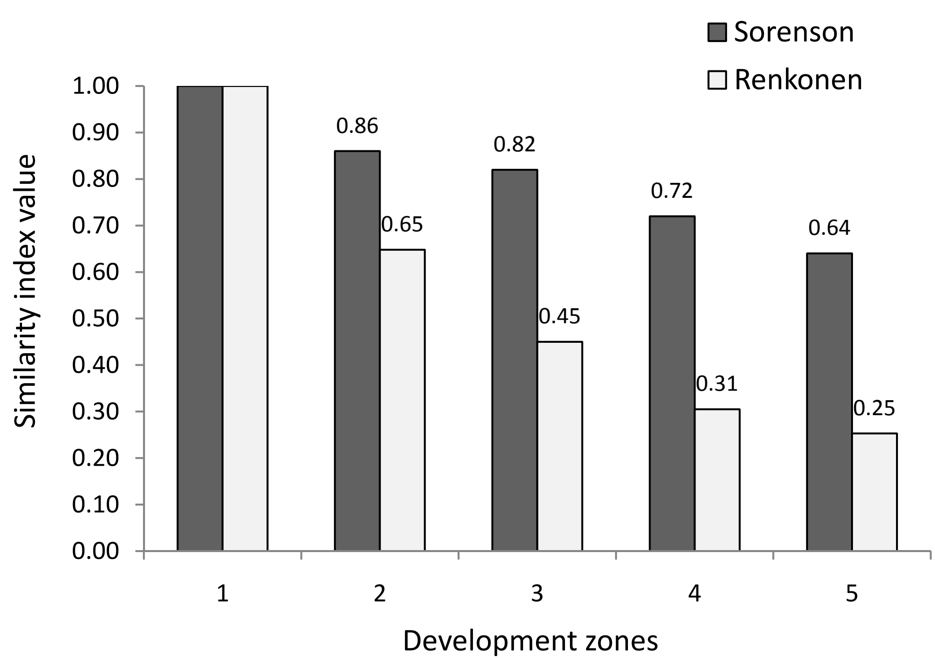



Figure 28. Comparison of Sorenson and Renkonen similarity index values for all development zones against suburban forest. Development zone 1 = suburban forest, 2 = low intensity, 3 = moderate intensity, 4 = high intensity, 5 =

This gradual impoverishment or depauperization of species richness, species diversity, and community structure follows that described in studies conducted in North America and Europe. Clergeau et al. (2006) describe a gradient where there is a reduction in breeding bird species when moving from the periurban sector to the town center. Miller, Niemi, Hanowski, and Regal (2007) show a significant negative relationship with development for 11 neotropical migrants. Blair (1996) found that in areas of high urbanization, bird communities were comprised mainly of generalist species.

Most studies examining urbanized gradients have found the greatest level of species diversity occurring at moderate levels of disturbance or development (Blair, 1996; Bolger et al., 1997; Crooks et al., 2004; Tratalos et al., 2007; & Chapman & Reich, 2007). The gradient described in this study may be truncated as it does not include an undisturbed habitat component. Incomplete sampling of environmental gradients can cause misinterpretations of changes along the gradient (Weins, 1989). However, it appears that even with the addition of an undisturbed habitat component (undisturbed forest) where species diversity may decrease relative to the suburban forest, the peak in species diversity would still occur at the low intensity end of the gradient. This is an area of research that should be pursued.

# CHAPTER IV: SUMMARY

Study results generally reflected those found in the published literature that examined avian population response along a gradient of urbanization. However, the literature indicates the need for specific studies within each individual urban area (Pickett & Cadenasso, 2006). This study represents an initial characterization of bird communities along a gradient of urbanization specific to Huntington, West Virginia.

The use of impervious surface as an indicator of urbanization proved to be useful for study purposes. Extraction results from the RVI model allowed definition of the gradient used for comparison of bird communities across the five identified development zones. Accuracy of the extraction results for impervious surface was excellent considering the heterogeneity of the urban landscape and the scale at which the study was completed.

Separating other landscape features proved difficult with the available imagery. Although extraction of tree canopy cover produced useful results, accuracy was less than desired. Extraction of grass cover was unsuccessful with all three classification techniques utilized. These two landscape metrics would be of interest in determining the drivers of individual bird species' response to urbanization. Imagery with higher spatial (sub-meter) and spectral resolution would increase landscape feature extraction success. Other extraction techniques may also improve results.

Results clearly show a decline in avian species richness and species diversity along the gradient in the direction of increasing urbanization. The change in community composition from the suburban forest to the industrial and commercial urban center resulted in a loss of half of the original bird species. This was accompanied by an increase in urban adapted species. Introduced, non-native species, in particular the European starling and house sparrow, dominated the urban landscape resulting in an uneven species community composition.

Urban parklands comprised of native habitat can be negatively impacted and reduced in size by continuing urbanization. The Greater Huntington Park and Recreation District maintains and administers 11 parks and memorial sites ranging in size from less than 1 hectare to a maximum of 53 hectares. These parklands provide a wide variety of recreational opportunities including organized outdoor sports (baseball, basketball, tennis, and soccer), general family activities, picnicking, walking, running, and bicycling. These areas provide tangible benefits to visitors and to the community. Kuo and Sullivan (2001) found that lower crime rates were associated with areas of vegetation.

The larger parks (Ritter and Rotary) include areas of intact vegetation, providing a noticeable contrast with the surrounding urban landscape. These larger parks provide a wider variety of habitats than the surrounding urban areas and, because of size, could maintain populations of local forest-dependent species (Donnelly & Marzluff, 2004).

Rotary Park (53 hectares) is comprised primarily of unbroken tracts of forest with smaller areas of maintained fields. It is disjunct from the surrounding suburban forest, being separated by areas of low to moderate intensity development. Four forest dependent species—yellow-throated vireo, wood thrush, northern parula, and scarlet tanager—were detected within Rotary Park.

The impervious surface map and avian population data generated by this study can be applied to other research and used for planning purposes. There has been increased interest in urban planning that reduces the impact of expanding development both within the urban centers and on the outer expanding edge (City of Olympia, 1995). Continued research focused on the impacts of urbanization and incorporation of the results into urban planning within the Huntington area should be pursued.

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# Appendix A

Error assessment output from Idrisi CrossClass and Error Matrix Analysis modules for extracted land cover classes using weighted maximum likelihood classification and the RVI model.

CrossClass – TRUTH (digitized) against MAXWEIGHT

Area on file: C:\Documents and Settings\Owner\My Documents\John\Thesis\Kappa_Stats\CrossClass2.rst

| Category | Square Meters | Legend |
|---|---|---|
| 1 | 57579334.0000000 | 1 \| 1 |
| 2 | 1075.0000000 | 2 \| 1 |
| 3 | 469.0000000 | 3 \| 1 |
| 4 | 922.0000000 | 4 \| 1 |
| 5 | 1073.0000000 | 1 \| 2 |
| 6 | 229127.0000000 | 2 \| 2 |
| 7 | 9901.0000000 | 3 \| 2 |
| 8 | 1260.0000000 | 4 \| 2 |
| 9 | 965.0000000 | 1 \| 3 |
| 10 | 36437.0000000 | 2 \| 3 |
| 11 | 122296.0000000 | 3 \| 3 |
| 12 | 31893.0000000 | 4 \| 3 |
| 13 | 855.0000000 | 1 \| 4 |
| 14 | 5290.0000000 | 2 \| 4 |
| 15 | 23185.0000000 | 3 \| 4 |
| 16 | 165438.0000000 | 4 \| 4 |

Legend Codes
1 - Background
2 - Impervious Surface
3 - Grass
4 - Tree Canopy

Impervious Surface Comparison

| | Area (sq m) | Percent |
|---|---|---|
| Agreement | 229127 | 80.9 |
| Commission | | |
| Grass | 9901 | 4.1 |
| Tree | 1260 | 0.5 |
| Omission | | |
| Grass | 36437 | 13.4 |
| Tree | 5290 | 1.9 |
| No Class | 1075 | 0.4 |

Error Matrix Analysis of **TRUTH** (columns : truth) against **MAXWEIGHT** (rows : mapped)

0 - Unclassified
2 – Impervious Surface
3 – Grass
4 – Tree Canopy

| | **2** | 3 | 4 | Total | **ErrorC** |
|---|---|---|---|---|---|
| 0 | 1075 | 469 | 922 | 2466 | 1.0000 |
| **2** | **229127** | 9901 | 1260 | 240288 | **0.0464** |
| 3 | 36437 | 122296 | 31893 | 190626 | 0.3585 |
| 4 | 5290 | 23185 | 165438 | 193913 | 0.1468 |
| Total | 271929 | 155851 | 199513 | 627293 | |
| **ErrorO** | **0.1574** | 0.2153 | 0.1708 | | **0.1760** |

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = 0.0008 (0.1753 - 0.1768)
95% Confidence Interval = 0.0009 (0.1751 - 0.1770)
99% Confidence Interval = 0.0012 (0.1748 - 0.1773)

KAPPA INDEX OF AGREEMENT (KIA)

Using MAXWEIGHT as the reference image ...

| Category | KIA |
|---|---|
| 0 | 0.0000 |
| 2 | 0.9180 |
| 3 | 0.5231 |
| 4 | 0.7847 |

Using TRUTH as the reference image ...

| Category | KIA |
|---|---|
| **2** | **0.7449** |
| 3 | 0.6907 |
| 4 | 0.7528 |

**Overall Kappa = 0.7333**

CrossClass Output - TRUTH (digitized) against RVI

Area on file: C:\Documents and Settings\Owner\My Documents\John\Thesis\Kappa_Stats\CrossClass.rst

| Category | Square Meters | Legend |
|---|---|---|
| 1 | 32633922.0000000 | 1 \| 1 |
| 2 | 357.0000000 | 2 \| 1 |
| 3 | 147.0000000 | 3 \| 1 |
| 4 | 189.0000000 | 4 \| 1 |
| 5 | 327.0000000 | 1 \| 2 |
| 6 | 251696.0000000 | 2 \| 2 |
| 7 | 26315.0000000 | 3 \| 2 |
| 8 | 4818.0000000 | 4 \| 2 |
| 9 | 135.0000000 | 1 \| 3 |
| 10 | 18860.0000000 | 2 \| 3 |
| 11 | 83549.0000000 | 3 \| 3 |
| 12 | 23811.0000000 | 4 \| 3 |
| 13 | 478.0000000 | 1 \| 4 |
| 14 | 1016.0000000 | 2 \| 4 |
| 15 | 45840.0000000 | 3 \| 4 |
| 16 | 170695.0000000 | 4 \| 4 |

Legend Codes
1 - Background
2 - Impervious Surface
3 - Grass
4 - Tree Canopy

Impervious Surface Comparison

| | Area (sq m) | Percent |
|---|---|---|
| Agreement | 251696 | 83.1 |
| Commission | | |
| Grass | 26315 | 9.3 |
| Tree | 4818 | 1.7 |
| Omission | | |
| Grass | 18860 | 6.9 |
| Tree | 1016 | 0.4 |
| No Class | 357 | 0.1 |

Error Matrix Analysis of **TRUTH** (columns : truth) against **RVI** (rows : mapped)

0 - Unclassified
2 – Impervious Surface
3 – Grass
4 – Tree Canopy

| | **2** | 3 | 4 | Total | **ErrorC** |
|---|---|---|---|---|---|
| 0 | 357 | 147 | 189 | 693 | 1.0000 |
| **2** | **251696** | 26315 | 4818 | 282829 | **0.1101** |
| 3 | 18860 | 83549 | 23811 | 126220 | 0.3381 |
| 4 | 1016 | 45840 | 170695 | 217551 | 0.2154 |
| Total | 271929 | 155851 | 199513 | 627293 | |
| **ErrorO** | **0.0744** | 0.4639 | 0.1444 | | **0.1935** |

ErrorO = Errors of Omission (expressed as proportions)
ErrorC = Errors of Commission (expressed as proportions)

90% Confidence Interval = 0.0008 (0.1926 - 0.1943)
95% Confidence Interval = 0.0010 (0.1925 - 0.1944)
99% Confidence Interval = 0.0013 (0.1922 - 0.1947)

KAPPA INDEX OF AGREEMENT (KIA)
------------------------------

Using RVI as the reference image ...

| Category | KIA |
|---|---|
| 0 | 0.0000 |
| 2 | 0.8057 |
| 3 | 0.5502 |
| 4 | 0.6842 |

Using TRUTH as the reference image ...

| Category | KIA |
|---|---|
| **2** | **0.8645** |
| 3 | 0.4192 |
| 4 | 0.7789 |

**Overall Kappa = 0.6997**

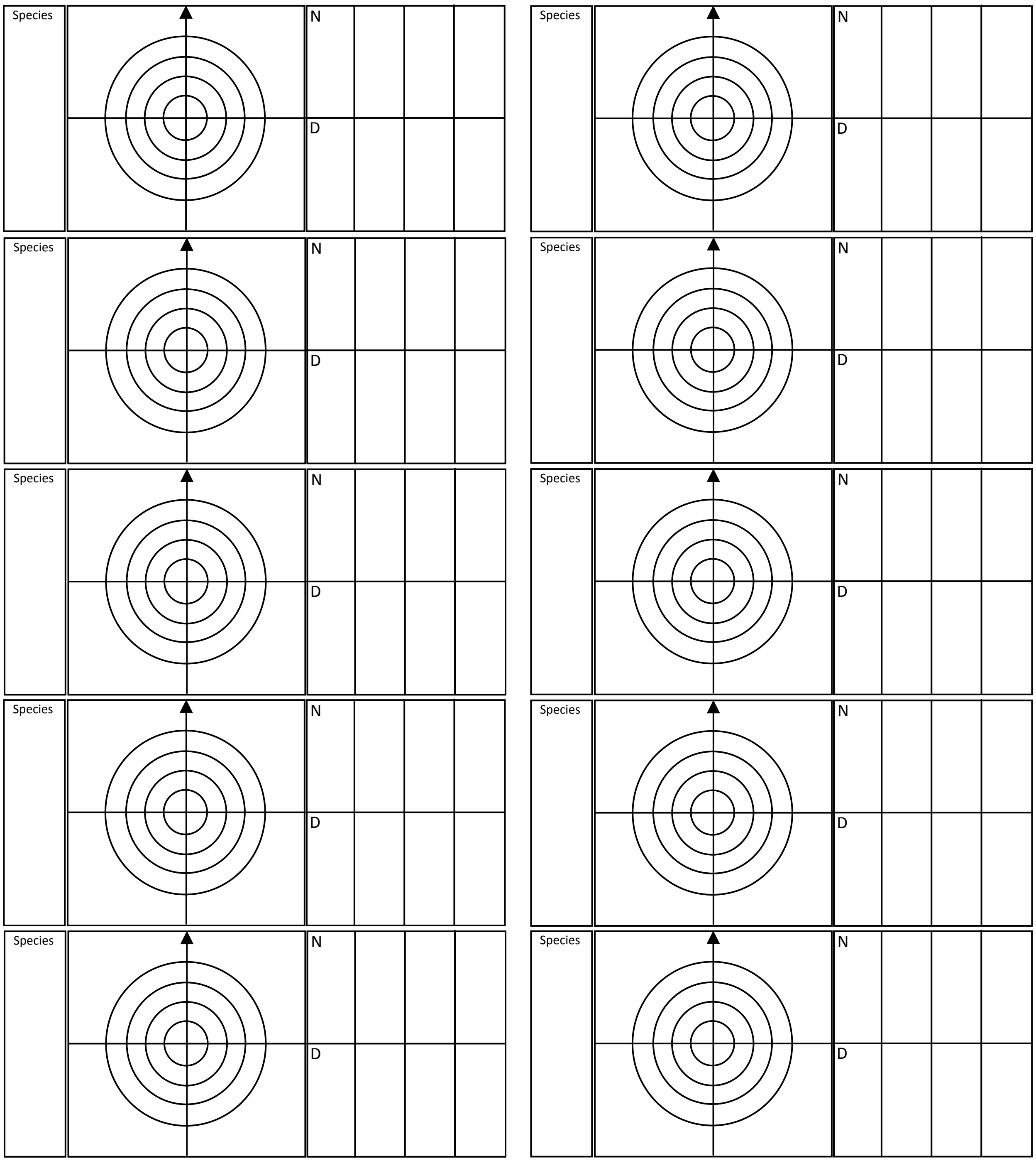
Appendix B

Avian point count field data sheet.

Huntington Urban Bird Survey Point Count Data Sheet Page ___ of ___

Route: _________ Point #: ________ Observer: ___________________________________

Date: _____________________ Time: _______________ Wind Speed/Direction ____ /____ Temp: _____



Appendix C

Taxonomic listing of birds detected with common and scientific names.

Taxonomic Listing of Birds (based on Checklist of Birds of North America, 7th ed., American Ornithologists Union. 1998.)

Phylum: Chordata
Subphylum: Vertebrata
Superclass: Tetrapoda
Class: Aves
Subclass: Neornithes

Order: Falconiformes
  Family: Accipitridae
    Cooper's Hawk (*Accipiter cooperii*)
    Red-shouldered Hawk (*Buteo lineatus*)
  Family: Falconidae
    American Kestrel (*Falco sparverius*)

Order: Charadriiformes
  Family: Charadriidae
    Killdeer (*Charadrius vociferus*)

Order: Columbiformes
  Family: Columbidae
    Rock Pigeon (*Columbia livia*)
    Mourning Dove (*Zenaida macroura*)

Order: Cuculiformes
  Family: Cuculidae
    Yellow-billed Cuckoo (*Coccyzus americana*)

Order: Caprimulgiformes
  Family: Caprimulgidae
    Common Nighthawk (*Chordeiles minor*)

Order: Apodiformes
  Family: Apodidae
    Chimney Swift (*Chaetura pelagica*)
  Family: Trochilidae
    Ruby-throated Hummingbird (*Archilochus colubris*)

Order: Piciformes
  Family: Picidae
    Red-bellied Woodpecker (*Melanerpes carolinus*)
    Downy Woodpecker (*Picoides pubescens*)
    Hairy Woodpecker (*Picoides vilosus*)
    Northern Flicker (*Colaptes auratus*)
    Pileated Woodpecker (*Dryocopus pileatus*)

Order: Passeriformes

Family: Tyrannidae

Eastern Wood-Pewee (*Contopus virens*)
Acadian Flycatcher ( *Empidonax virescens*)
Eastern Phoebe (*Sayornis phoebe*)
Great-crested Flycatcher (*Myiarchus crinitus*)

Family: Vireonidae

White-eyed Vireo (*Vireo griseus*)
Yellow-throated Vireo (*Vireo flavifrons*)
Red-eyed Vireo (*Vireo olivaceus*)

Family: Corvidae

Blue Jay (*Cyanocitta cristata*)
American Crow (*Corvus brachyrhynchos*)

Family: Hirundinidae

Purple Martin (*Progne subis*)
Northern Rough-winged Swallow ( *Stelgidopteryx serripennis*)
Barn Swallow (*Hirundo rustica*)

Family: Paridae

Carolina Chickadee (*Poecile carolinensis*)
Tufted Titmouse (*Baeolophus bicolor*)

Family: Sittidae

White-breasted Nuthatch (*Sitta carolinensis*)

Family: Troglodytidae

Carolina Wren (*Thryothorus ludovicianus*)
House Wren (*Troglodytes aedon*)

Family: Sylviidae

Blue-gray Gnatcatcher (*Polioptila caerulea*)

Family: Turdidae

Eastern Bluebird (*Sialia sialis*)
Wood Thrush (*Hylocichla mustelina*)
American Robin (*Turdus migratorius*)

Family: Mimidae

Gray Catbird (*Dumetella carolinensis*)
Northern Mockingbird (*Mimus polyglottos*)
Brown Thrasher (*Toxostoma rufum*)

Family: Sturnidae

European Starling (*Sturnus vulgaris*)

Family: Bombycillidae
Cedar Waxwing (*Bombycilla cedrorum*)

Family: Parulidae
Northern Parula (*Parula americana*)
Yellow Warbler (*Dendroica petechia*)
Yellow-throated Warbler (*Dendroica dominica*)
American Redstart (*Setophaga ruticilla*)
Common Yellowthroat (*Geothlypis trichas*)
Yellow-breasted Chat (*Icteria virens*)

Family: Thraupidae
Summer Tanager (*Piranga rubra*)
Scarlet Tanager (*Piranga olivacea*)

Family: Emberizidae
Eastern Towhee (*Pipilo erythrophthalmus*)
Chipping Sparrow (*Spizella passerina*)
Field Sparrow (*Spizella pusilla*)
Song Sparrow (*Melosoiza melodia*)

Family: Cardinalidae
Northern Cardinal (*Cardinalis cardinalis*)
Indigo Bunting (*Passerina cyanea*)

Family: Icteridae
Red-winged Blackbird (*Agelaius phoeniceus*)
Common Grackle (*Quiscalus quiscula*)
Brown-headed Cowbird (*Molothrus ater*)
Orchard Oriole (*Icterus spurius*)
Baltimore Oriole (*Icterus galbula*)

Family: Fringillidae
House Finch (*Carpodacus mexicanus*)
American Goldfinch (*Carduelis tristis*)

Family: Passeridae
House Sparrow (*Passer domesticus*)

# Appendix D

Descriptive statistics for individual bird species within the study area ordered by rank of occurrence.

| Rank | Species | Total | Mean | Min | Max | Relative Abundance | Stations Occupied |
|---|---|---|---|---|---|---|---|
| 1 | European Starling | 678 | 3.307 | 0 | 53 | 16.286 | 133 |
| 2 | House Sparrow | 507 | 2.473 | 0 | 12 | 12.178 | 118 |
| 3 | American Robin | 386 | 1.883 | 0 | 6 | 9.272 | 156 |
| 4 | Chimney Swift | 374 | 1.824 | 0 | 11 | 8.983 | 108 |
| 5 | Northern Cardinal | 239 | 1.166 | 0 | 5 | 5.741 | 125 |
| 6 | Song Sparrow | 229 | 1.117 | 0 | 4 | 5.500 | 141 |
| 7 | Rock Pigeon | 216 | 0.883 | 0 | 27 | 5.188 | 36 |
| 8 | Mourning Dove | 180 | 0.878 | 0 | 19 | 4.323 | 85 |
| 9 | Northern Mockingbird | 161 | 0.785 | 0 | 3 | 3.867 | 124 |
| 10 | Common Grackle | 128 | 0.624 | 0 | 12 | 3.074 | 54 |
| 11 | Tufted Titmouse | 102 | 0.498 | 0 | 5 | 2.450 | 62 |
| 12 | Carolina Chickadee | 98 | 0.478 | 0 | 4 | 2.354 | 63 |
| 13 | Blue Jay | 91 | 0.444 | 0 | 4 | 2.185 | 61 |
| 14 | Carolina Wren | 78 | 0.380 | 0 | 2 | 1.873 | 61 |
| 15 | House Finch | 67 | 0.327 | 0 | 5 | 1.609 | 40 |
| 16 | Eastern Towhee | 60 | 0.293 | 0 | 3 | 1.441 | 48 |
| 17 | Red-bellied Woodpecker | 41 | 0.200 | 0 | 2 | 0.984 | 34 |
| 18 | American Crow | 27 | 0.132 | 0 | 5 | 0.648 | 16 |
| 19 | Wood Thrush | 27 | 0.132 | 0 | 2 | 0.648 | 23 |
| 20 | American Goldfinch | 26 | 0.127 | 0 | 5 | 0.624 | 16 |
| 21 | Gray Catbird | 25 | 0.122 | 0 | 2 | 0.600 | 20 |
| 22 | House Wren | 24 | 2.473 | 0 | 12 | 0.576 | 22 |
| 23 | Indigo Bunting | 24 | 0.117 | 0 | 2 | 0.576 | 22 |
| 24 | Brown-headed Cowbird | 23 | 0.098 | 0 | 4 | 0.552 | 15 |
| 25 | Acadian Flycatcher | 23 | 0.112 | 0 | 3 | 0.552 | 18 |
| 26 | Yellow-throated Warbler | 22 | 0.107 | 0 | 3 | 0.528 | 16 |
| 27 | Killdeer | 21 | 0.102 | 0 | 1 | 0.504 | 21 |
| 28 | Red-eyed Vireo | 20 | 0.098 | 0 | 2 | 0.480 | 18 |
| 29 | Cedar Waxwing | 19 | 0.093 | 0 | 6 | 0.456 | 6 |
| 30 | Downy Woodpecker | 18 | 0.088 | 0 | 2 | 0.432 | 17 |
| 31 | White-breasted Nuthatch | 15 | 0.073 | 0 | 3 | 0.360 | 11 |
| 32 | Chipping Sparrow | 15 | 0.073 | 0 | 2 | 0.360 | 12 |
| 33 | Yellow-billed Cuckoo | 14 | 0.068 | 0 | 3 | 0.336 | 11 |
| 34 | Eastern Wood-Pewee | 14 | 0.068 | 0 | 3 | 0.336 | 12 |
| 35 | Northern Rough-winged Swallow | 14 | 0.068 | 0 | 2 | 0.336 | 9 |
| 36 | Eastern Phoebe | 13 | 0.063 | 0 | 1 | 0.312 | 13 |
| 37 | Common Nighthawk | 12 | 0.059 | 0 | 1 | 0.288 | 12 |
| 38 | Great-crested Flycatcher | 12 | 0.059 | 0 | 1 | 0.288 | 12 |
| 39 | Blue-gray Gnatcatcher | 12 | 0.059 | 0 | 2 | 0.288 | 8 |
| 40 | Yellow-throated Vireo | 10 | 0.049 | 0 | 2 | 0.240 | 9 |
| 41 | Eastern Bluebird | 9 | 0.044 | 0 | 2 | 0.216 | 8 |

| Rank | Species | Total | Mean | Min | Max | Relative Abundance | Stations Occupied |
|---|---|---|---|---|---|---|---|
| 42 | Northern Flicker (YS) | 8 | 0.039 | 0 | 1 | 0.192 | 8 |
| 43 | White-eyed Vireo | 8 | 0.039 | 0 | 1 | 0.192 | 8 |
| 44 | Scarlet Tanager | 7 | 0.034 | 0 | 2 | 0.168 | 6 |
| 45 | Red-winged Blackbird | 7 | 0.034 | 0 | 6 | 0.168 | 2 |
| 46 | Pileated Woodpecker | 6 | 0.029 | 0 | 2 | 0.144 | 5 |
| 47 | Yellow Warbler | 6 | 0.029 | 0 | 1 | 0.144 | 6 |
| 48 | Summer Tanager | 6 | 0.029 | 0 | 1 | 0.144 | 6 |
| 49 | Purple Martin | 5 | 0.024 | 0 | 3 | 0.120 | 2 |
| 50 | Brown Thrasher | 5 | 0.024 | 0 | 1 | 0.120 | 5 |
| 51 | Red-shouldered Hawk | 4 | 0.020 | 0 | 2 | 0.096 | 3 |
| 52 | Hairy Woodpecker | 4 | 0.020 | 0 | 1 | 0.096 | 4 |
| 53 | Northern Parula | 4 | 0.020 | 0 | 2 | 0.096 | 3 |
| 54 | American Kestrel | 3 | 0.015 | 0 | 1 | 0.072 | 3 |
| 55 | American Redstart | 3 | 0.015 | 0 | 1 | 0.072 | 3 |
| 56 | Common Yellowthroat | 3 | 0.015 | 0 | 1 | 0.072 | 3 |
| 57 | Cooper's Hawk | 2 | 0.010 | 0 | 1 | 0.048 | 2 |
| 58 | Barn Swallow | 2 | 0.010 | 0 | 1 | 0.048 | 2 |
| 59 | Baltimore Oriole | 2 | 0.010 | 0 | 1 | 0.048 | 2 |
| 60 | Ruby-throated Hummingbird | 1 | 0.005 | 0 | 1 | 0.024 | 1 |
| 61 | Yellow-breasted Chat | 1 | 0.005 | 0 | 1 | 0.024 | 1 |
| 62 | Field Sparrow | 1 | 0.005 | 0 | 1 | 0.024 | 1 |
| 63 | Orchard Oriole | 1 | 0.005 | 0 | 1 | 0.024 | 1 |

Appendix E

Distribution of individual bird species within each development zone.

| Species | Suburban Forest | Low Intensity | Moderate Intensity | High Intensity | Industrial/ Commercial |
|---|---|---|---|---|---|
| Cooper's Hawk | 1 | 0 | 0 | 0 | 1 |
| Red-shouldered Hawk | 1 | 2 | 1 | 0 | 0 |
| American Kestrel | 0 | 0 | 2 | 1 | 0 |
| Killdeer | 1 | 0 | 1 | 7 | 12 |
| Rock Pigeon | 0 | 5 | 50 | 72 | 89 |
| Mourning Dove | 10 | 19 | 45 | 51 | 55 |
| Yellow-billed Cuckoo | 6 | 1 | 5 | 1 | 1 |
| Common Nighthawk | 0 | 1 | 2 | 2 | 7 |
| Chimney Swift | 4 | 33 | 68 | 139 | 130 |
| Ruby-throated Hummingbird | 0 | 1 | 0 | 0 | 0 |
| Red-bellied Woodpecker | 21 | 14 | 5 | 1 | 0 |
| Downy Woodpecker | 9 | 5 | 1 | 3 | 0 |
| Hairy Woodpecker | 1 | 0 | 2 | 0 | 1 |
| Northern Flicker (YS) | 3 | 1 | 2 | 1 | 1 |
| Pileated Woodpecker | 2 | 2 | 2 | 0 | 0 |
| Eastern Wood-Pewee | 9 | 4 | 0 | 1 | 0 |
| Acadian Flycatcher | 17 | 3 | 2 | 0 | 1 |
| Eastern Phoebe | 3 | 5 | 3 | 1 | 1 |
| Great-crested Flycatcher | 5 | 4 | 3 | 0 | 0 |
| White-eyed Vireo | 0 | 3 | 3 | 2 | 0 |
| Yellow-throated Vireo | 7 | 3 | 0 | 0 | 0 |
| Red-eyed Vireo | 12 | 3 | 4 | 1 | 0 |
| Blue Jay | 22 | 22 | 16 | 21 | 10 |
| American Crow | 4 | 1 | 11 | 4 | 7 |
| Purple Martin | 0 | 0 | 3 | 0 | 2 |
| Northern Rough-winged Swallow | 1 | 3 | 2 | 4 | 4 |
| Barn Swallow | 0 | 0 | 0 | 2 | 0 |
| Carolina Chickadee | 46 | 21 | 18 | 11 | 2 |
| Tufted Titmouse | 53 | 32 | 12 | 4 | 1 |
| White-breasted Nuthatch | 9 | 5 | 1 | 0 | 0 |
| Carolina Wren | 32 | 28 | 12 | 5 | 1 |
| House Wren | 7 | 9 | 5 | 2 | 1 |
| Blue-gray Gnatcatcher | 11 | 1 | 0 | 0 | 0 |
| Eastern Bluebird | 5 | 3 | 1 | 0 | 0 |
| Wood Thrush | 19 | 6 | 1 | 1 | 0 |
| American Robin | 50 | 87 | 86 | 97 | 66 |
| Gray Catbird | 6 | 7 | 9 | 3 | 0 |
| Northern Mockingbird | 9 | 33 | 38 | 45 | 36 |
| Brown Thrasher | 4 | 1 | 0 | 0 | 0 |
| European Starling | 20 | 40 | 160 | 228 | 230 |
| Cedar Waxwing | 7 | 6 | 3 | 3 | 0 |

| Species | Suburban Forest | Low Intensity | Moderate Intensity | High Intensity | Industrial/ Commercial |
|---|---|---|---|---|---|
| Northern Parula | 4 | 0 | 0 | 0 | 0 |
| Yellow Warbler | 1 | 2 | 2 | 1 | 0 |
| Yellow-throated Warbler | 15 | 6 | 1 | 0 | 0 |
| American Redstart | 3 | 0 | 0 | 0 | 0 |
| Common Yellowthroat | 0 | 2 | 1 | 0 | 0 |
| Yellow-breasted Chat | 0 | 0 | 1 | 0 | 0 |
| Summer Tanager | 3 | 3 | 0 | 0 | 0 |
| Scarlet Tanager | 5 | 0 | 1 | 1 | 0 |
| Eastern Towhee | 37 | 15 | 7 | 1 | 0 |
| Chipping Sparrow | 12 | 0 | 1 | 1 | 1 |
| Field Sparrow | 0 | 1 | 0 | 0 | 0 |
| Song Sparrow | 36 | 64 | 52 | 45 | 32 |
| Northern Cardinal | 84 | 60 | 56 | 27 | 12 |
| Indigo Bunting | 6 | 5 | 11 | 1 | 1 |
| Red-winged Blackbird | 0 | 0 | 1 | 6 | 0 |
| Common Grackle | 2 | 12 | 35 | 54 | 25 |
| Brown-headed Cowbird | 16 | 3 | 2 | 2 | 0 |
| Orchard Oriole | 1 | 0 | 0 | 0 | 0 |
| Baltimore Oriole | 1 | 1 | 0 | 0 | 0 |
| House Finch | 3 | 16 | 15 | 16 | 17 |
| American Goldfinch | 11 | 2 | 8 | 0 | 5 |
| House Sparrow | 15 | 47 | 98 | 189 | 158 |