THE RELATIONSHIP BETWEEN WILDLIFE BIODIVERSITY AND LANDSCAPE CHARACTERISTICS IN VIRGINIA

Beth R. Stein

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Valerie A. Thomas, Committee Chair
Dean F. Stauffer
Randolph H. Wynne

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(ABSTRACT)

Wildlife biodiversity provides a variety of ecosystem services and is an important indicator of overall ecosystem health. This research investigates the relationship between wildlife biodiversity and landscape characteristics in Virginia. The goal is to produce predictive models of biodiversity within the Commonwealth using environmental characteristics, including fragmentation metrics at the class- and landscape-levels, as well as other environmental variables. The 1248 12-digit watersheds in Virginia are the sampling units for the analyses, with the state stratified into the seven US Environmental Protection Agency's Level III classification. Data on wildlife alpha diversity is based on two sets of species data maintained by the Virginia Dept. of Game & Inland Fisheries (VDGIF).

The first chapter provides an introduction to the issue of biodiversity conservation and the background information for this work. The second chapter describes the study using the 2001 National Land Cover Data to calculate class- and landscape-level fragmentation metrics. Best subset regression is used to determine the best predictors for wildlife biodiversity using these metrics. Final selected models range in predictive power from $R^2 = 0.41$ to 0.73 for each of the 7 ecoregions. The third chapter analyzes the relationship between wildlife biodiversity and various environmental variables in order to determine the strength of these factors as drivers for alpha diversity. These variables are then incorporated with the fragmentation metrics in an attempt to improve the biodiversity models. The environmental variable models had $R^2 = 0.22$ to 0.65 across the ecoregions, while $R^2 = 0.28$ to 0.72 when the environmental and fragmentation variables are combined. The last chapter focuses on the conclusions of the studies, the limitations of the data, and the benefits of this work. Overall, our results underline the importance of using fragmentation metrics in Virginia’s wildlife models.

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CHAPTER 1

Introduction

Biodiversity

Recent decades have brought increased attention to the significance of biodiversity—"the variation of life forms within a given ecosystem, region or the entire earth"—in the environmental arena (Debinski & Brussard 1994; Gillespie 2008). The UN Millenium Project and the World Summit on Sustainable Development specified reducing biodiversity loss as key goals in the millennium; as a result, policies have been implemented across the globe and at all levels of government in an attempt to meet these goals. The year 2010, in particular, escalated the prominence of biodiversity as a conservation goal in the world arena, due to the 2010 Target of the Convention of Biological Diversity and the UN International Year of Biodiversity (Fisher 2009).

To preserve biodiversity, it is necessary to measure the species richness to provide a baseline for monitoring any historical or future trends. While biodiversity can refer to various organismal levels, including genetic, specific, organismal, or functional, one of the easier ways to measure biodiversity is at the level of the individual organisms. Three of the most common ways to measure biodiversity are through the use of alpha diversity, beta diversity, and gamma diversity. Alpha diversity is the total number of unique elements in a specified area, while beta diversity refers to the change in the number of elements across time or space. Gamma diversity refers to the number of species across the landscape, as opposed to the habitat or smaller scales (Magurran 2005).

Ecosystem Services

Ecosystem services are “the benefits provided by ecosystems” to humans (Millennium Ecosystem Assessment 2005). The Millenium Ecosystem Assessment declared biodiversity to be inextricably linked to human welfare across the world. The Assessment attributed biodiversity with providing such critical ecosystem services as the provisioning and regulating of resources, cultural benefits, and life-supporting functions (Millennium Ecosystem Assessment 2005). Every taxonomic group serves at least one function in the ecosystem, so a minimum number of species are needed for proper ecosystem functioning (Collins and Qualset 1999; Loreau et al. 2001). When the number of species drops below this threshold, many environmental services are at risk, including biogeochemical and climatic regulation, soil preservation, vegetation pollination, and watershed maintenance (Myers 1996). These environmental services affect the health, economic, and recreational sectors of human society, among others (Convention on Biological Diversity 2010).

Broader Context of the Work: Biodiversity as an Ecosystem Service

This research is part of a larger initiative to develop a web-based ecosystem service decision support tool for biodiversity being developed by Virginia Tech for the Virginia Department of Game and Inland Fisheries (VDGIF). This tool is designed to be integrated into a larger ecosystem services decision support system called MEASURES (*m*anagement-scale *e*cosystem *as*sessment *u*sing *re*mote *s*ensing), which provides tabular and spatial information on several ecosystem services, including carbon sequestration and water quality at the farm and 6th order hydrologic unit scales. Within MEASURES, land use and land management scenarios are enabled which allow individual landowners, state agencies, and other stakeholders to delineate potential land use changes and assess the effects on each of the ecosystem services components. The goal is to better enable local and state decision-makers to understand the potential effects of their decisions at a specific point in space and time. Wildlife biodiversity was selected for inclusion due to the VDGIF's interest in forecasting changes before they happen, as well as because of the important role wildlife play in helping to support vegetation, encourage tourism and recreation, and produce economic products. Through complex interactions with the abiotic and biotic environment, wildlife has a significant effect on the world in which we live.

The health of wildlife communities can be measured through a variety of approaches, including assessing populations, individuals, species distribution, or abundance. These assessments can focus on indicator or keystone species, threatened and endangered species, particular species of interest or concern, or overall species richness. In this case, the biodiversity component of the MEASURES tool was funded to examine several measures of species richness for all species in the VDGIF database, as well as appropriate species guilds, and relative species richness across landscape gradients. This was largely due to (1) the VDGIF's primary interest in learning how the number of species changes across the state, and (2) the availability of species data records for the state maintained by the VDGIF.

Appropriate Level of Biodiversity: Genetic, Species or Functional

From a research perspective, species biodiversity is the optimal level of analysis for several reasons. First, the study of biodiversity provides an ample opportunity to take advantage of the extensive records of species occurrences in conjunction with increasingly available remote sensing technology. These records have been kept for over 30 years by the VDGIF in the Virginia Fish & Wildlife Information Service (VAFWIS) database and are the culmination of many years of intensive data collection, government expenditures, and aggregation. Second, the trajectory of biodiversity in the world is of concern to many people. To sustain species richness, it is important to determine the current number of species in Virginia. This estimate allows us to predict biodiversity responses to changes in the environment, identify particular areas of concern, and develop strategies for promoting conservation (Gaston 2000). As Gaston (2000) writes: "An understanding of its determinants will impinge on applied issues of major concern to humankind, including the role of biodiversity in ecosystem processes, the spread of alien invasive species, the control of diseases and their vectors, and the likely effects of global environmental chance on the maintenance of biodiversity."

Methods of assessing biodiversity are highly variable. Multiple indices have been derived to describe and quantify species diversity, including Simpson's Index and the Shannon-Wiener Index (Magurran 2005). The different levels of biodiversity can also be assessed based on the spatial scale. According to the traditional nomenclature, alpha diversity describes the number of species within a delineated area; beta diversity, between areas (either spatially or temporally); and gamma diversity, within a landscape (Magurran 2005). Much of the recent literature refers to landscape diversity as "alpha diversity," so I follow this precedent in my research. Additionally, how some researchers choose to measure alpha diversity can also vary between a species richness count and a weighted assessment. For either method, researchers determine their alpha diversity through detectability estimates based on species occurrences or using count statistics as the index (Yoccoz et al. 2001). I chose to measure alpha diversity as a direct count of the number of species sighted within the region.

Although there are multiple levels of assessing biodiversity—including genetic, species, or functional—I focused on species diversity due to the general "recognition of the species as a biological unit, and from the practical issues of the ease and magnitude of data collection," particularly given our relatively large study area (Gaston 2000). This level of analysis also proved the most practical, as the VAFWIS database does not contain nearly enough data to assess genetic diversity and species information is more informative than functional diversity. Furthermore, the VDGIF was interested in learning more about the spatial patterns of wildlife biodiversity across the state, as well as how different land management practices would affect these trends.

Model Development

The goal of this research is to model wildlife biodiversity based on known landscape components. Given the alpha diversity estimates and the landscape properties, I would like to develop a statistical model of the relationship in order to forecast potential future changes in species richness. Models vary in their level of complexity, incorporating variables such as habitat structural properties; forage quality; energy and water availability; physiography; climate; and others (Hawkins 2003; Leyequien et al. 2007). Canada's nation-wide biodiversity monitoring program, BioSpace, measures productivity, topography, land cover, and disturbance. These variables were intended to depict national climatic and structural trends across regional and national landscapes that influence vegetation and fauna (Franklin 2010). Thus, I chose to assess many of these properties in my analysis.

The spatial distribution of the species occurrences data depicts uneven coverage across the state, with some areas sampled much more heavily than others (Figure 1.1). Eastern Virginia seems over-represented in samples, particularly compared to the south-central region. In addition, species records tend to congregate around perennial rivers and streams. Due to this pattern, I chose to use watersheds as the sampling units. The 12-digit hydrologic units (HUs) are naturally delineated at an appropriate scale for biodiversity measurements and land cover analysis. There are a sufficient number of wildlife records within the majority of the HUs to justify the use of such a relatively small unit. Most 12-digit HUs encompass multiple land cover types, yet are still small enough to be effectively managed and provide a sufficient number of sampling units across the state. In addition, the HUs also offer a wide range of alpha diversity values, enabling differentiation between landscape spatial properties and the number of wildlife species recorded (Table 1.1).

Figure 1.1. Initial exploration of the data and selection of an appropriate scale of analysis. The top map depicts all 332,844 wildlife sightings from June 2007 to June 2010 in the geographic point data. Data was collected through wildlife surveys by the Virginia Dept. of Game and Inland Fisheries. The left subset image is representative of the distribution of wildlife sightings with respect to water bodies. Although the wildlife sightings appear to be nearly ubiquitous across Virginia at the state-level, the right subset image shows the wide range in the number of wildlife sightings per hydrologic unit.

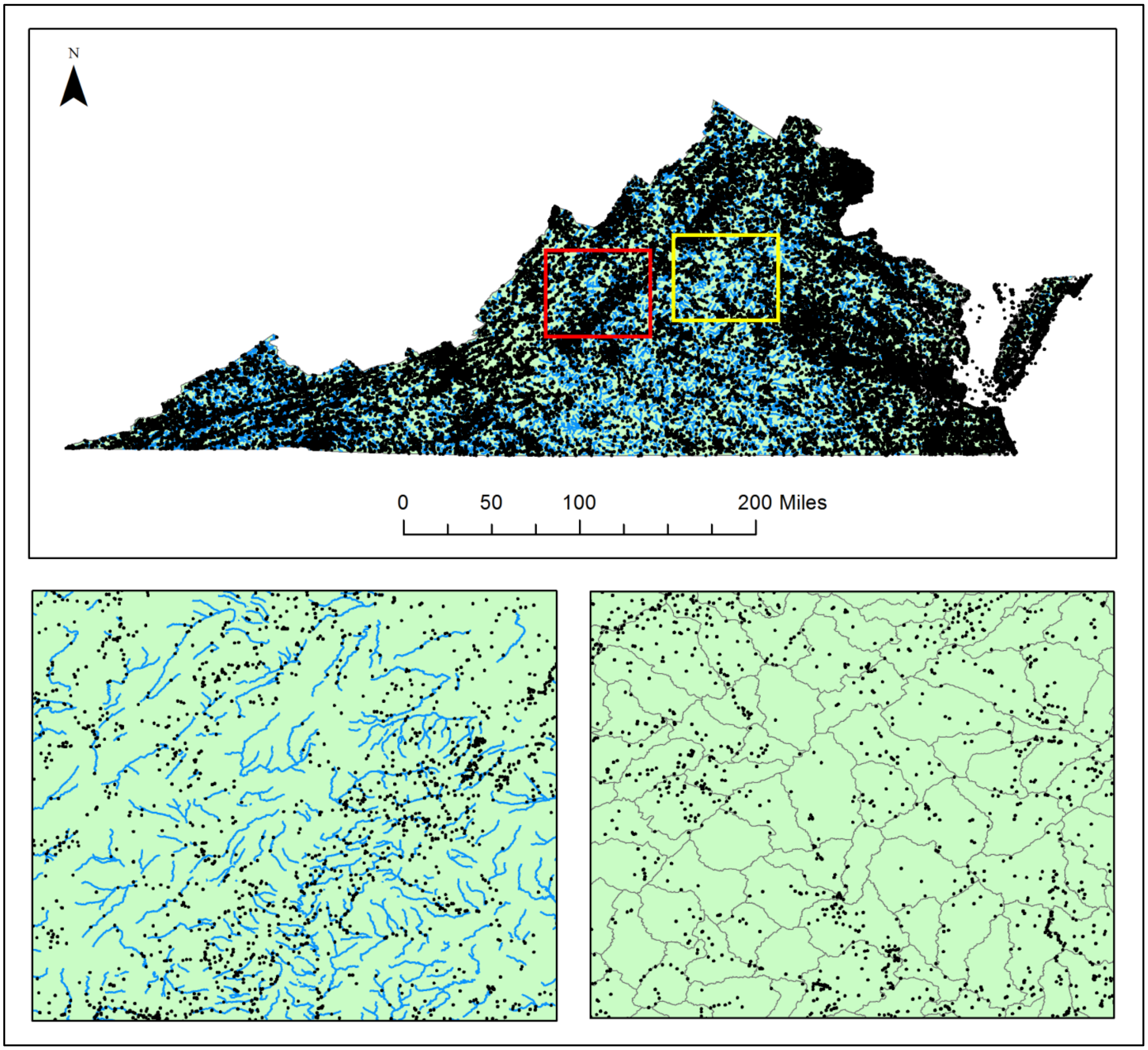

Table 1.1. Alpha diversity statistics in 1248 12-digit hydrologic units in Virginia. Species observation statistics are based on the total number of species from wildlife survey data collected by the Virginia Dept. of Game & Inland Fisheries (VDGIF) from 2007 to 2010.

Summary Characteristics	Value
Mean number of species in hydrologic units	105.20
Number of hydrologic units with no species records	56
Number of hydrologic units with 20 or fewer species recorded	164
Number of hydrologic units with fewer than 50 species recorded	390
Maximum number of species recorded in a hydrologic unit	527

For the analysis in Chapters 2 and 3, I grouped hydrologic units by the Environmental Protection Agency's Level 3 ecoregions. Ecoregions are regional divisions based on macroscale ecosystem patterns that reflect landscape features (Bailey 2005). Due to the varied landscape within Virginia and the evident statistical differences in alpha diversity between ecoregions, these delimitations enabled me to investigate the differences within each ecoregion rather than be confounded by inter-regional factors. Further discussion of the ecoregions follows in the next chapter.

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CHAPTER 2

Modeling Virginia's Wildlife Biodiversity with Land Class Fragmentation Metrics

Abstract

Maintaining wildlife biodiversity is on most conservation agendas today, and is of particular concern given the significant changes that are occurring in land use. We aim to assess the relative importance of land cover properties and fragmentation metrics and to produce a predictive model of biodiversity values for the 12-digit watersheds in Virginia. We stratified the state into seven ecoregions based on the US Environmental Protection Agency's Level III classification and used the 2001 National Land Cover Data as land cover classes. Alpha diversity for the 1248 12-digit hydrologic units was estimated using two wildlife datasets maintained by the Virginia Dept. of Game & Inland Fisheries: species occurrences of wildlife sightings with known geographic locations (332,844 sightings of 1163 unique species), and species occurrences recorded in the Biota of Virginia (BOVA) database from peer-reviewed literature (3319 unique species). We conducted a best subset regression with minimum AICc to determine the best models for each ecoregion. For the geographic point data models, the number of selected predictors ranged from 6 to 19, with an average adjusted $R^2 = 0.50$. For the BOVA models, the number of selected predictors ranged from 4 to 15, with an average adjusted $R^2 = 0.47$. The most prevalent fragmentation metrics are Class Area (CA), Mean Related Circumscribing Circle (CIRCLE), and Interspersion and Juxtaposition Index (IJI) for the geographic point data. CA, IJI, and Perimeter-Area Ratio (PARA) are most prevalent for the BOVA data. Out of all the class fragmentation metrics, Deciduous CA occurs in the most geographic point models and Pasture PARA is in the most BOVA models. Our results indicate the importance of including land class fragmentation metrics in modeling wildlife biodiversity in

Virginia. This provides valuable information on how biodiversity may change in a given ecoregion following a particular land use change.

Introduction

In the past few decades, there has been a great interest in maintaining species biodiversity (Debinski & Brussard 1994, Redford & Richter 1999). Defined as "the variation of life forms within a given ecosystem, region or the entire earth," biodiversity conservation is of the utmost importance in most conservation agendas today (Gillespie et al. 2008). There are three commonly recognized levels of diversity: genetic, population/species, community/ecosystem (Redford & Richter 1999). Each of these can be evaluated at three additional strata: alpha diversity, beta diversity, and gamma diversity. Alpha diversity can be defined as the total number of species within a delineated area. Beta diversity is the amount of species turnover between delineated areas or over time. Gamma diversity refers to the number of species in a landscape composed of multiple communities (Oindo et al. 2003).

Recent conservation efforts have focused on protecting the most sensitive species and preserving biodiversity by setting aside lands specifically for the purpose of wildlife protection. The Gap Analysis program is one such approach designed to find 'gaps' in protection that land managers can then patch (White et al. 1997). These methods minimize the contact wildlife have with human activities; however, the long-term success of conservation requires maintaining "hospitable environments" for wildlife in managed lands as well as protected lands (White et al. 1997, Redford and Richter 1999). This is in part due to the 90% land coverage of areas lacking formal protection across the world, and because not all of the protected lands are managed for biodiversity conservation. Thus, the effects of land use and management decisions in humandisturbed environments are especially important (Polasky 2005). Areas with the highest native biodiversity across taxa should take priority in any ecoregional conservation plan (Redford & Richter 1999).

Species richness counts serve as a well-supported indicator of ecosystem health (Magurran 1988). With field data, calculating biodiversity metrics for a given location is relatively straightforward. However, without complete population figures, there are often gaps in the dataset. Ecological models have been used for decades to extrapolate species population numbers and biodiversity calculations from known species-habitat associations (Oindo et al. 2003). Species-habitat association models tend to look at a variety of variables, but much of the research examining the effects of fragmentation and land class spatial configuration has focused on avian species (Cunningham & Johnson 2011; Hamer et al. 2006). The traditional bias towards birds is a result of the relative ease of identifying avian species, as well as their known taxonomies, ubiquitous nature, and sensitivity to changes in the environment (Gottschalk et al. 2005). In comparison, relatively few studies have examined other taxa or wildlife biodiversity as a whole. This represents a potentially significant oversight that is most likely compounded by the mixed effects of fragmentation on wildlife biodiversity (Cunningham & Johnson 2011).

Humans can have a defining impact on wildlife populations through land use. This has been particularly evident through their effect on the spatial layout, amount, and quality of potential habitat (Laurance & Usche 2009; Price et al. 2005; White et al. 1997). Urbanization tends to decrease the amount of available habitat for species, as well as lead to increased fragmentation and patchiness (Beier & Noss 2008). The underlying foundation of landscape ecology is that landscape configuration can impose significant limits on ecological processes, both biotic and abiotic (Constible et al. 2006). The overarching ecological significance of habitat fragmentation is difficult to determine, particularly given the numerous metrics, their intricacies, and their differing effects on wildlife. Depending on scale, species, and other factors, fragmentation may increase or decrease biodiversity (Fahrig 2003). One possibility is that there are no universally important characteristics of spatial configuration, but instead that they are specific to individual landscapes (Cushman, McGarigal & Neel 2008).

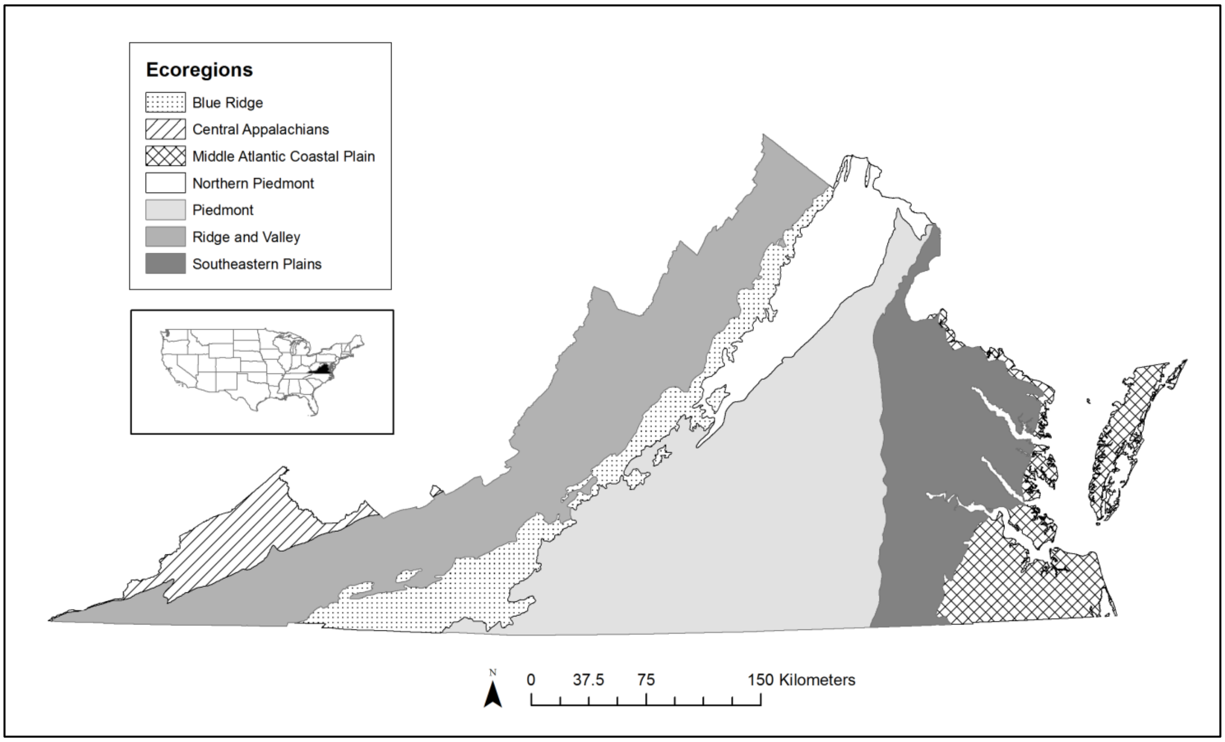
Despite the potentially site-specific nature of the fragmentation metrics, the key drivers in this arena have not been thoroughly investigated in Virginia, nor been intensively correlated with wildlife biodiversity across all taxa. There has also been little uniformity in the selected variables between studies (Cushman, McGarigal & Neel 2008). Thus, our overarching research question in this study is whether land use properties can inform biodiversity estimates and management decisions for all wildlife species, both invertebrates and vertebrates. Specifically, we aim to assess the relative importance of land cover properties and fragmentation metrics and to produce a predictive model of biodiversity values for the 12-digit watersheds in Virginia. With a dearth of information on this topic, we hope our study can provide a basis for management decisions within the study area and its vicinity. Our access to an unusually large database of wildlife observations offers a unique opportunity to examine the relationship between wildlife biodiversity and landscape patterns across taxa and a relatively large scale.

Methods

Study Area

The study area consists of the Commonwealth of Virginia, in the eastern United States. Virginia covers an area of 39,490.09 square miles (US Census Bureau 2010), with the latitude ranging from 36° 31'N to 39° 37'N and longitude from 75° 13'W to 83° 37'W. The mean elevation is 950 feet above sea level, and the monthly average temperatures range from 26.2 to 88.4 degrees (Netstate 1998). We classified the state into seven ecoregions according to the 2010 Environmental Protection Agency's Level III categories: the Blue Ridge, Central Appalachians, Middle Atlantic Coastal Plain, Northern Piedmont, Piedmont, Ridge & Valley, and Southeastern Plains (Figure 2.1) (Environmental Protection Agency 2011). We sampled 1248 12-digit hydrologic units, with an average area of 33.5 square miles.

Figure 2.1. Map of Virginia depicting the seven ecoregions as determined by the US Environmental Protection Agency's Level III categories. Due to the ecological differences across the state reflected in statistically significant mean alpha diversity values among ecoregions, wildlife biodiversity models were developed for each ecoregion.

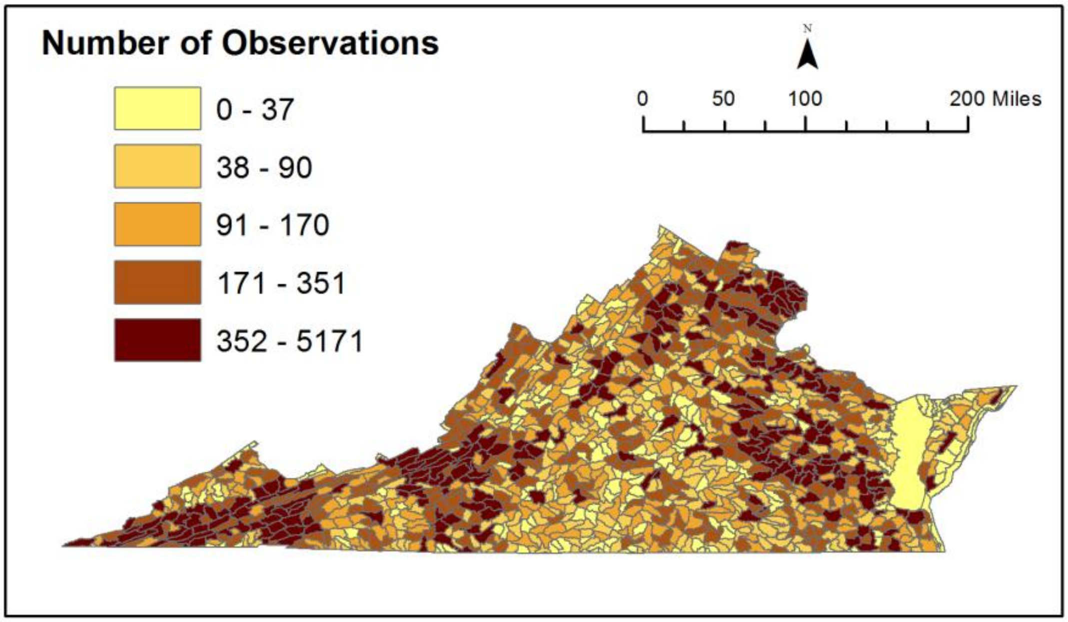


Species Richness – Alpha Diversity

Alpha diversity, or species richness, can be defined as the total number of unique species within a sampling unit (Magurran 2005). We obtained two wildlife datasets from the Virginia Dept. of Game & Inland Fisheries (VDGIF) to calculate alpha diversity. The first dataset consists of 332,844 wildlife sightings of 1163 unique species at documented locations from June 7, 2007 through June 1, 2010. This dataset contains observations of all official fish and wildlife sightings in Virginia from research, management, permitting, or regulatory review processes and will henceforth be referred to as the geographic point data (VDGIF 2007). The second dataset, known as the Biota of Virginia (BOVA) database, encompasses wildlife from the geographic point dataset, but also includes information on other non-spatially referenced sightings. This latter dataset includes wildlife information recorded in peer-reviewed literature and gathered from taxonomic experts (VDGIF 2007). A total of 3319 unique species have been recorded throughout the state from the BOVA database. Although there is no theoretical upper limit for alpha diversity, use of these datasets result in a maximum possible range of alpha diversity from 0-1163 and 0-3319 for the geographic point data and BOVA data, respectively. Both datasets included all taxa.

Compiled from many different sources, the BOVA data combine a variety of collection procedures and sources of error. The data are provided on an “as is” basis, with no guarantee of accuracy or of any agreement between datasets (VDGIF 2007). Neither dataset was designed for species richness calculations, so they are therefore of limited accuracy in their results. The distribution of species observations from the data may not represent true alpha diversity, if some areas are under-sampled. Figure 2.2 depicts the number of observation points per hydrologic unit. Despite these limitations, the BOVA and geographic point data offer an extremely rich source of real species sightings for Virginia. These data provide a unique opportunity for the analysis to move beyond habitat-suitability calculations, or estimates of potential biodiversity. Rather, we are able to assess correlations between habitat characteristics and real measures of biodiversity, with associated error statistics.

Figure 2.2. Number of observation points per hydrologic unit, depicted by quantiles. The number of observation points is based on the number of locations from which the Virginia Dept. of Game & Inland Fisheries (VDGIF) recorded wildlife sightings in Virginia from June 2007 to June 2010.



Stratification into Ecoregions

As mentioned, the minimum sampling unit for these analyses is the 12-digit hydrologic unit (Figure 1), with an overall study boundary as the state of Virginia. However, the landscape within Virginia is highly variable in terms of topography, microclimate, and landcover. The Virginia landscape includes mountainous terrain, coastal plains, and piedmont which we anticipate will have different biodiversity characteristics. Descriptive statistics were generated to determine whether or not there is a statistically significant difference between alpha diversity calculated for the entire state as well as between the various ecoregions. The Kolmogorov-Smirnov (K-S) test was performed to determine data normality. Simple transformations were required to achieve normality, thereby allowing the use of parametric tests for alpha diversity. For geographic point and BOVA data alpha diversity, an Analysis of Variance (ANOVA) was performed to assess whether or not there is a significant difference in alpha diversity ecoregions and the state. An all-pairs Tukey-Kramer HSD report was generated to specify how the alpha diversities of the ecoregions relate to each other, and which ecoregions could be grouped, if any.

Landscape Fragmentation Metrics

The 2001 National Land Cover Data (NLCD) was obtained to determine presence and amount of landcover classes within Virginia and for each ecoregion. The following land classes were present in varying amounts: crops, deciduous forest, evergreen forest, mixed forest, barren, grassland, pasture, shrubs/scrub, woody wetlands, emergent herbaceous wetlands, open water, open development, low density development, medium density development, and high density development (Figure 2.3). The area (Table 2.1) and percentage of each class (Table 2.2) vary by ecoregion.

Figure 2.3. Land classes within the seven Environmental Protection Agency's Level III ecoregions in Virginia based on the 2001 National Land Cover Data (NLCD). The NLCD land cover classes are used to calculate fragmentation metrics to develop wildlife biodiversity models for each ecoregion using state wildlife data.

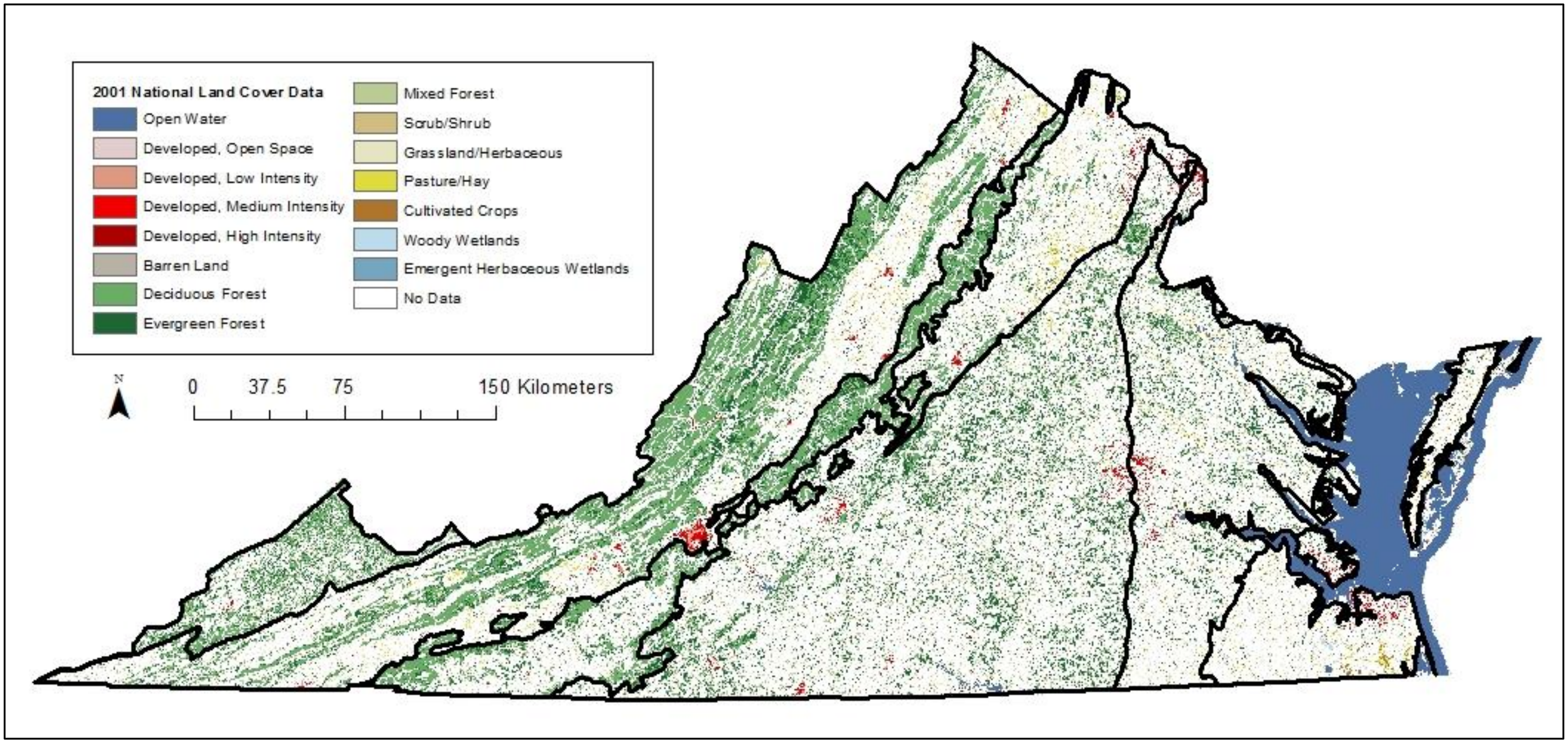


Table 2.1. The area (km^2) of the 2001 National Land Cover Data (NLCD) land cover classes by ecoregion. Virginia ecoregions are as follows: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP). The amount of each land cover class in a hydrologic unit affected which fragmentation metrics were calculated for the wildlife biodiversity models; no metrics were calculated for absent land cover classes.

Land Cover Class	BR	CA	MACP	NP	P	RV	SP
Open Water	19017	13236	180644	44637	516870	141805	291025
Developed, Open Space	392586	196533	327162	505456	1559792	1344642	440169
Developed, Low Intensity	33508	88722	333333	257693	507391	631217	302564
Developed, Medium Intensity	6711	32678	144843	106230	134968	171293	148199
Developed, High Intensity	2093	3276	48737	30590	43064	55449	55088
Barren Land	4641	64447	125764	36354	180531	24556	282898
Deciduous Forest	6645106	3312410	1358177	2536746	14783837	14395631	5094657
Evergreen Forest	423704	73202	995779	473681	5316034	1259601	2872800
Mixed Forest	256417	104770	149432	270071	1345634	759610	283807
Scrub/Shrub	25797	719	0	0	587010	67050	2828
Grassland/Herbaceous	22273	237456	0	0	897094	331186	11930
Pasture/Hay	1300570	247487	1081436	2767962	6366782	6691703	1919667
Cultivated Crops	16621	2054	1382466	399975	701564	351025	1591259
Woody Wetlands	4244	25	799130	28561	616042	8460	902161
Emergent Herbaceous Wetlands	279	5	354833	19373	41938	2686	219590
No Data	87	40	0	0	0	354	0

Table 2.2. The landcover distribution (percent) by ecoregion in Virginia, according to the 2001 National Land Cover Data (NLCD). Ecoregions are classified as follows: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP). The three most prevalent land cover classes across all ecoregions are deciduous forest, pasture/hay, and evergreen forest.

Land Cover Class	BR	CA	MACP	NP	P	RV	SP
Open Water	0.21	0.30	2.48	0.60	1.54	0.54	2.02
Developed, Open Space	4.29	4.49	4.49	6.76	4.64	5.13	3.05
Developed, Low Intensity	0.37	2.03	4.58	3.45	1.51	2.41	2.10
Developed, Medium Intensity	0.07	0.75	1.99	1.42	0.40	0.65	1.03
Developed, High Intensity	0.02	0.07	0.67	0.41	0.13	0.21	0.38
Barren Land	0.05	1.47	1.73	0.49	0.54	0.09	1.96
Deciduous Forest	72.60	75.68	18.65	33.93	44.00	54.87	35.33
Evergreen Forest	4.63	1.67	13.68	6.33	15.82	4.80	19.92
Mixed Forest	2.80	2.39	2.05	3.61	4.01	2.90	1.97
Scrub/Shrub	0.28	0.02	0.00	0.00	1.75	0.26	0.02
Grassland/Herbaceous	0.24	5.43	0.00	0.00	2.67	1.26	0.08
Pasture/Hay	14.21	5.65	14.85	37.02	18.95	25.51	13.31
Cultivated Crops	0.18	0.05	18.99	5.35	2.09	1.34	11.04
Woody Wetlands	0.05	0.00	10.97	0.38	1.83	0.03	6.26
Emergent Herbaceous Wetlands	0.00	0.00	4.87	0.26	0.12	0.01	1.52

We calculated 33 fragmentation metrics for each landcover class in the sampling units, using the program FRAGSTATS (McGarigal et al. 2002). Of the 33 metrics, 15 were repeatedly found to provide some insight to the distribution of alpha diversity, and are defined in Table 2.3. We specified an eight-pixel neighborhood, an edge percent of 5, and an edge distance of 50m. Within 50m from the edge, many studies have shown that microclimatic and other effects begin to disappear (Murcia 1995).

Table 2.3. The 15 class fragmentation metrics calculated from FRAGSTATS that most commonly contributed to the wildlife biodiversity regression models. Information adapted from the FRAGSTATS website (McGarigal et al. 2002) and Schindler et al. 2008.

Metric Name	Abbrev.	Metric Category	Metric Significance
Aggregation Index	AI	Contagion/ Interspersion	Percentage of neighboring pixel, being the same land cover class, based on single-count method
Mean Area	AREA	Area/Density/Edge	Mean size of patches
Total Class Area	CA	Area/Density/Edge	Area of class
Mean Related Circumscribing Circle	CIRCLE	Shape	Mean patch elongation measure; equals 1 minus patch area divided by the area of the smallest circumscribing circle
Clumpiness Index	CLUMPY	Contagion/ Interspersion	Measure of the proportion of like adjacencies involving the corresponding class
Disjunct Core Area Density	DCAD	Core Area	Total number of disjunct core areas, per 100 hectares
Mean Disjunct Core Area	DCORE	Core Area	Mean area of disjunct core areas
Mean Radius of Gyration	GYRATE	Area/Density/Edge	Mean distance for each cell of one patch to the patch centroid
Interspersion & Juxtaposition	IJI	Contagion/ Interspersion	Measure of evenness of patch adjacencies
Largest Patch Index	LPI	Area/Density/Edge	Percentage of total area occupied by the largest patch
Normalized Landscape Shape Index	NLSI	Area/Density/Edge	Ratio of the total edge to the minimum total edge per class, rescaled according the proportion of the classes
Number of Patches	NP	Area/Density/Edge	Number of patches
Mean Perimeter-Area Ratio	PARA	Shape	Mean perimeter per area as a patch shape complexity measure
Patch Density	PD	Area/Density/Edge	Number of patches per area
Mean Shape Index	SHAPE	Shape	Measures the complexity of patch shapes; equals 1 when all patches are circular, but increases with greater shape complexity

Statistical Analysis

The multiple landcover classes and fragmentation metrics resulted in a large number of independent variables for the multivariate analysis (i.e., 15x33 for each ecoregion). Significant data reduction was required before attempting to conduct multivariate regression. After testing the fragmentation metrics for normality and determining the requirement for non-parametric statistics for the fragmentation metrics, Spearman's rank correlation coefficients were calculated comparing the fragmentation metrics within each ecoregion. We removed fragmentation metrics that were highly correlated with each other, based on a Spearman's correlation of 0.75 or above. We also excluded any fragmentation metrics with missing values in greater than 10 percent of the hydrologic units, which typically occurred when a landcover class was not present within the hydrologic unit. These steps reduced the number of metrics from 495 to approximately 80-120, varying slightly by ecoregion.

To further reduce the dataset to 20 independent variables for each ecoregion, backward stepwise regression was conducted on each alpha diversity value and the remaining fragmentation metrics using a p-value threshold stopping rule of 0.25 to enter and 0.10 to leave. We systematically deleted metrics one-by-one based on the highest p-value until only 20 metrics remained. Using the final subset of metrics, we conducted a best subset regression and selected the optimal model based on the minimum Akaike information criterion (AICc) +2 (ΔAICc< 2.0) (Burnham & Anderson 2002). According to this rule, we selected the model with the fewest number of variables that had an AICc of within two of the minimum. We performed leave-one-out cross validation to assess model robustness, and evaluated the PRESS statistic and RMSE. Models were assessed for multi-collinearity by ensuring the variance inflation factors were below 10 (Kutner 2004). Finally, the assumption of normality of the model residuals was tested with the K-S test, where a normal distribution is indicated by a non-significant D statistic.

Due to the relatively large number of variables in many of the models with the minimum AICc, we also selected some models with fewer metrics that might be more practical for management purposes. They were selected based on an asymptotic approach to the adjusted R^2 using the aforementioned p-value thresholds. The residuals of these models were also tested for normality using the K-S test; for those that were not normal, an additional variable was added to the model if this achieved normality of the error term.

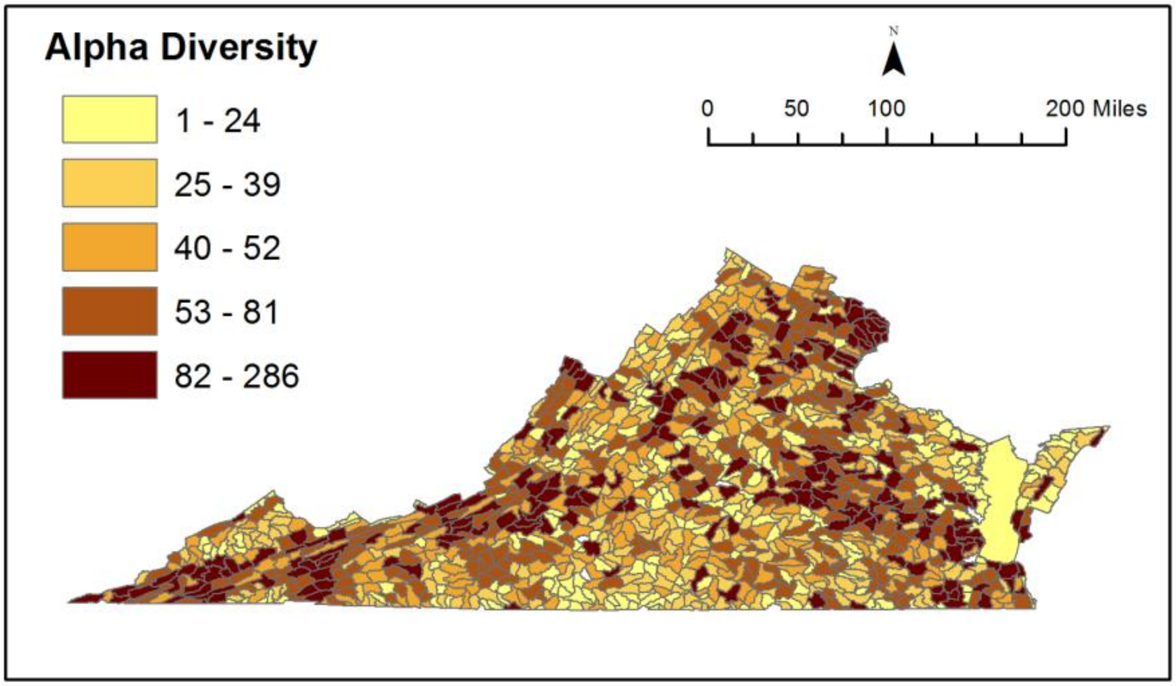
Results

The mean alpha diversity for a hydrologic unit in Virginia is 54.95 according to the geographic point data and 60.06 according to the BOVA data, with variations in the mean number of species by ecoregion (Table 2.4, Figure 2.4). The Spearman correlation coefficient between the number of observation points in each hydrologic unit and the geographic point alpha diversity is 0.86.

Table 2.4. Characteristic alpha diversity statistics for Virginia and its ecoregions for the geographic point and Biota of Virginia (BOVA) data. Alpha diversity is calculated as the total number of species for each of the 1248 hydrologic units; the table below reflects the mean alpha diversity by ecoregion. Geographic point data is based on 332,844 wildlife sightings across Virginia from 2007 to 2010. The BOVA data is collected from peer-reviewed literature, wildlife surveys, and taxonomic experts.

Region	Alpha Diversity	
	Geographic Point	BOVA
Virginia	54.95	60.06
Blue Ridge	54.57	61.56
Central Appalachians	34.00	52.79
Middle Atlantic Coastal Plain	62.68	73.35
Northern Piedmont	66.91	54.98
Piedmont	44.94	51.49
Ridge and Valley	60.00	66.99
Southeastern Plains	61.58	61.67

Figure 2.4. Alpha diversity for each of the hydrologic units in Virginia, classified by quantile from the geographic point data. Alpha diversity is estimated as the total number of unique species in each 12-digit hydrologic unit based on the Virginia Dept. of Game and Inland Fisheries' wildlife surveys taken between June 2007 and June 2010.



ANOVA results (Table 2.5 and 2.6) indicate significant difference among ecoregions (geographic point data: F=9.41, $P<0.01$; BOVA data: F=115.91, $P<0.01$). The Tukey-Kramer HSD means comparison (Table 2.7) suggests that 5 major groupings are possible for the geographic point data alpha diversity and 2 major groupings for the BOVA alpha diversity. Given that these groupings are not the same, we stratified the state by ecoregion and conducted the analysis separately for each.

Table 2.5. ANOVA results testing for significant differences between the ecoregions' geographic point data alpha diversities. Alpha diversity values were estimated based on the number of unique species in each ecoregion according to the Virginia Dept. of Game and Inland Fisheries' records of wildlife sightings.

Source	DF	SS	MS	F	P
Ecoregion	6	91951	15325	9.41	0.00
Error	1240	2020267	1629		
Total	1246	2112218			

Table 2.6. ANOVA results testing for significant differences between the ecoregions' geographic point data alpha diversities. Alpha diversity values were estimated based on the number of unique species in each ecoregion according to the Biota of Virginia (BOVA) database, which contains species occurrence data in Virginia known from peer-reviewed literature, wildlife surveys, and taxonomic experts.

Source	DF	SS	MS	F	P
Ecoregion	6	74069	12345	115.91	0.00
Error	1240	132064	107		
Total	1246	206133			

Table 2.7. Tukey-Kramer HSD means comparison indicating potential ecoregion groupings for the geographic point and Biota of Virginia (BOVA) alpha diversities. Results indicate the potential for two groups for the geographic point data and five groups for the BOVA data.

Ecoregion	N	Geographic Point Mean	Geographic Point Grouping	BOVA Mean	BOVA Grouping
Middle Atlantic Coastal Plain	143	59.61	A	73.35	A
Ridge and Valley	316	57.53	A	66.99	B
Southeastern Plains	128	60.14	A	61.67	C
Blue Ridge	120	52.75	A, B	61.56	C
Northern Piedmont	118	66.91	A	54.98	D
Central Appalachians	43	33.21	B	52.79	D, E
Piedmont	379	43.64	B	51.49	E

Multiple regression models were derived for each of the seven ecoregions. For the geographic point data models, the number of selected predictors ranged from 3 to 19, with adjusted R^2 values ranging from 0.40 to 0.68 (Table 2.8). For the BOVA models, the number of selected predictors ranged from 2 to 15, with adjusted R^2 ranging from 0.41 to 0.67 (Table 2.9). The predicted vs. observed values plots (Figures 2.5 and 2.6) depict a clear relationship between the model alpha diversity predictions and the observed values across the ecoregions. With the exception of the Piedmont and Ridge and Valley geographic point models, all models have normal residuals (Tables 2.10 and 2.11).

Table 2.8. Best subset regression models and their respective selection criteria for the geographic point data across the seven ecoregions in Virginia. Models are composed of the 2001 National Land Cover Data class fragmentation metrics that best approximate wildlife biodiversity in each ecoregion. Biodiversity is estimated as the total number of species in each 12-digit hydrologic unit (HU) from wildlife surveys in the state.

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY	9	108	0.60	0.56	365.57	18.86
Central Appalachians	Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI	3	30	0.53	0.48	120.35	0.35
Middle Atlantic Coastal Plain	Deciduous CA, Deciduous SHAPE Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA	11	118	0.52	0.47	322.70	18.00
Northern Piedmont	Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	11	123	0.46	0.41	294.71	22.14
Piedmont	Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	12	334	0.42	0.40	613.01	23.13
Ridge & Valley	Deciduous CA, Deciduous DCAD, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	12	271	0.46	0.42	112.38	18.25
Southeastern Plains	Deciduous AREA, Crops NP, Crops CIRCLE, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren CA, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open	19	118	0.73	0.68	1.42	448.15

	Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture DCAD, Pasture IJI

Figure 2.5. Graphs of the predicted vs. observed alpha diversity values for the geographic point data in each region using the model with the minimum AICc. Ecoregional graphs are as follows: (a) Blue Ridge, (b) Central Appalachians, (c) Middle Atlantic Coastal Plain, (d) Northern Piedmont, (e) Piedmont, (f) Ridge and Valley, and (g) Southeastern Plains.

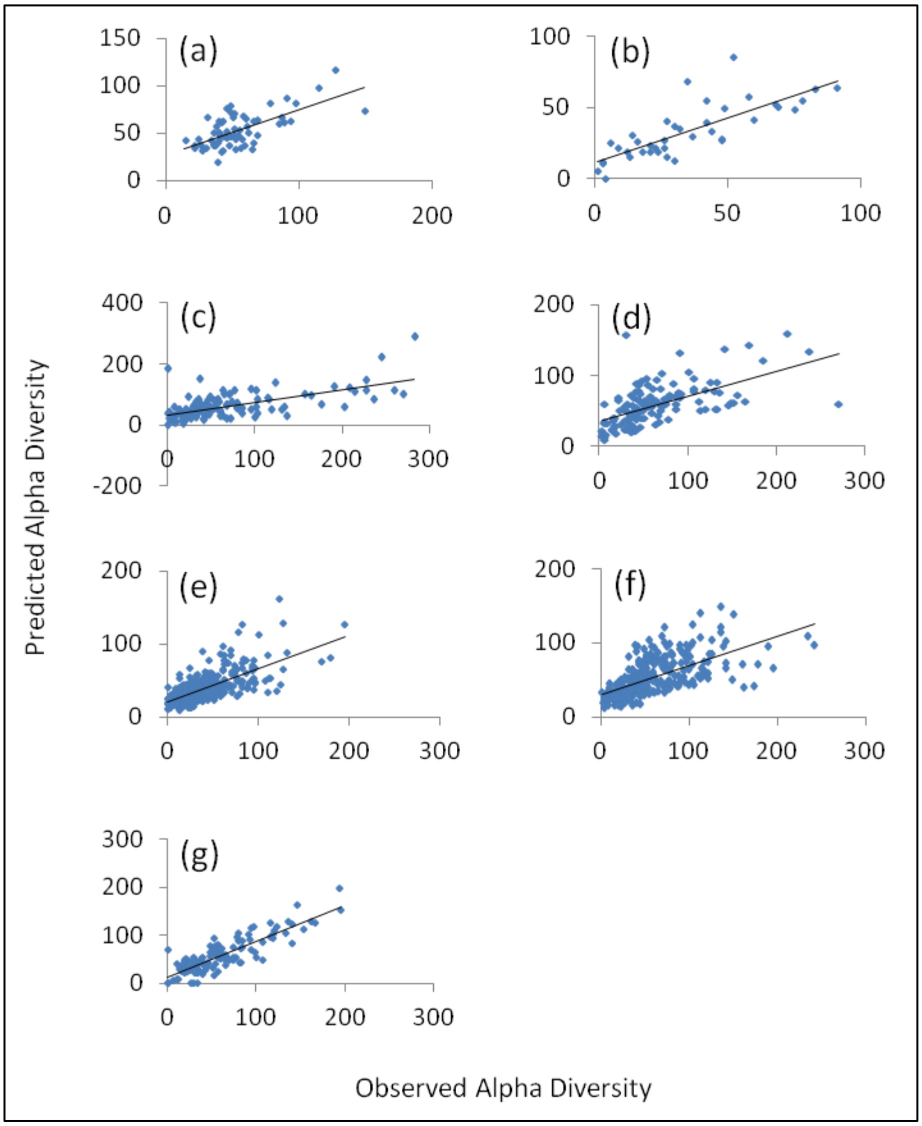


Table 2.9. Best subset regression models and their respective selection criteria for the Biota of Virginia (BOVA) data across the seven ecoregions in Virginia. Models are composed of the 2001 National Land Cover Data class fragmentation metrics that best model wildlife biodiversity in each ecoregion. Biodiversity is estimated as the total number of species in each 12-digit hydrologic unit (HU) from wildlife surveys, taxonomic experts, and peer-reviewed literature.

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	7	109	0.50	0.47	-136.21	15.43
Central Appalachians	Open Water PARA, Open CA	2	24	0.47	0.41	131.81	-5.99
Middle Atlantic Coastal Plain	Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Mixed Forest IJI, Low CA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	15	119	0.71	0.67	4208.41	18.77
Northern Piedmont	Deciduous CIRCLE, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY	9	122	0.56	0.52	-1177.94	15.52
Piedmont	Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	14	339	0.41	0.38	-468.01	18.07
Ridge & Valley	Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA, Open PARA	13	290	0.50	0.47	-2961.87	16.32
Southeastern Plains	Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PARA, Barren CIRCLE, Barren IJI, Medium	14	119	0.53	0.46	762.91	24.90

IJI, Open Water NP, Open Water SHAPE, Open Water
PARA, Low CA, Pasture PD, Pasture AREA

Figure 2.6. Graphs of the predicted vs. observed alpha diversity values for the BOVA data in each region using the model with the minimum AICc. Ecoregional graphs are as follows: (a) Blue Ridge, (b) Central Appalachians, (c) Middle Atlantic Coastal Plain, (d) Northern Piedmont, (e) Piedmont, (f) Ridge and Valley, and (g) Southeastern Plains. Hydrologic units with predicted values of 0 or no known species occurrences were not included.

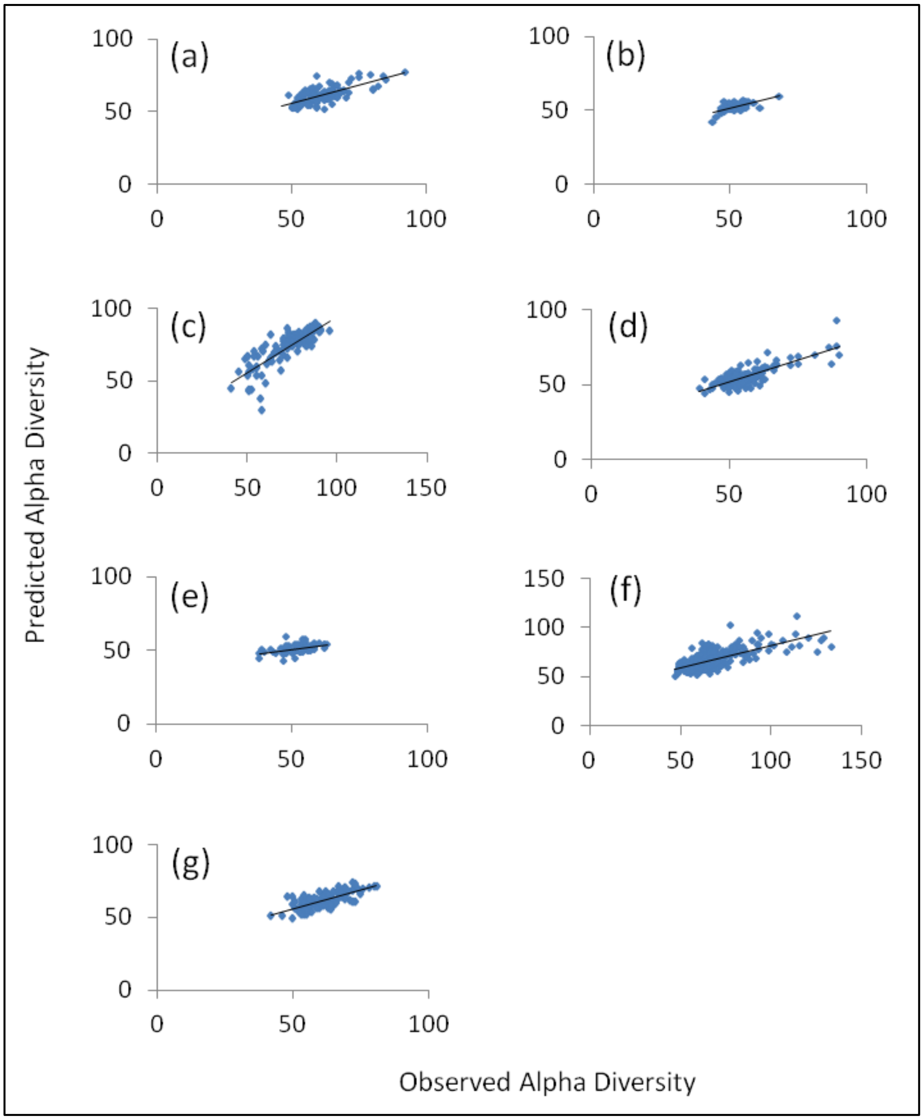


Table 2.10. Cross-validation statistics for the best subset regression models for the geographic point data. Models are designed to predict the wildlife alpha diversity based on the 2001 NLCD fragmentation metrics as calculated from FRAGSTATS. Models were selected based on the minimum AICc for each of Virginia's seven ecoregions.

Model	RMSE	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	1.23	0.04, >0.15	182.05
Central Appalachians	1.57	0.11, >0.15	100.94
Middle Atlantic Coastal Plains	0.88	0.08, 0.07	120.89
Northern Piedmont	0.75	0.05, >0.15	96.50
Piedmont	0.59	0.06, 0.02	121.46
Ridge & Valley	0.29	0.06, 0.03	23.95
Southeastern Plains	1.42	0.04, >0.15	298.50

Table 2.11. Cross-validation statistics for the best subset regression models for the BOVA data. Models are designed to predict the wildlife alpha diversity based on the 2001 NLCD fragmentation metrics as calculated from FRAGSTATS. Models were selected based on the minimum AICc for each of Virginia's seven ecoregions.

Model	RMSE	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.12	0.09, 0.05	16.05
Central Appalachians	3.27	0.09, >0.15	504.30
Middle Atlantic Coastal Plains	10504614	0.07, 0.13	1.60×10^{16}
Northern Piedmont	0.00	0.06, >0.15	4.70×10^{-4}
Piedmont	0.12	0.03, >0.15	4.94
Ridge & Valley	0.00	0.05, 0.07	6.23×10^{-4}
Southeastern Plains	5.46	0.07, >0.15	4184.53

BOVA and geographic point data showed some similarities with respect to the most prevalent land classes and metrics in the regression models. For the geographic point data models, the three most prevalent land classes were pasture, evergreen, and deciduous, in order by rank (Figure 2.7). For the BOVA models, the same three land classes predominated, but with evergreen metrics appearing more often than deciduous. The most prevalent fragmentation metrics are CA, CIRCLE, and IJI for the geographic point data and CA, IJI, and PARA for the BOVA data (Figure 2.8). Out of all the class fragmentation metrics, Deciduous CA occurs in the most geographic point models and Pasture PARA is in the most BOVA models.

Figure 2.7. A comparison of the frequencies the 2001 NLCD land cover classes appeared in the geographic point data and BOVA data best subset regression models across the ecoregions. Frequencies are based on the number of fragmentation metrics for each land cover class that occurred in the regression models. Fragmentation metrics were calculated at the class-level from the NLCD using the FRAGSTATS software (McGarigal et al. 2002).

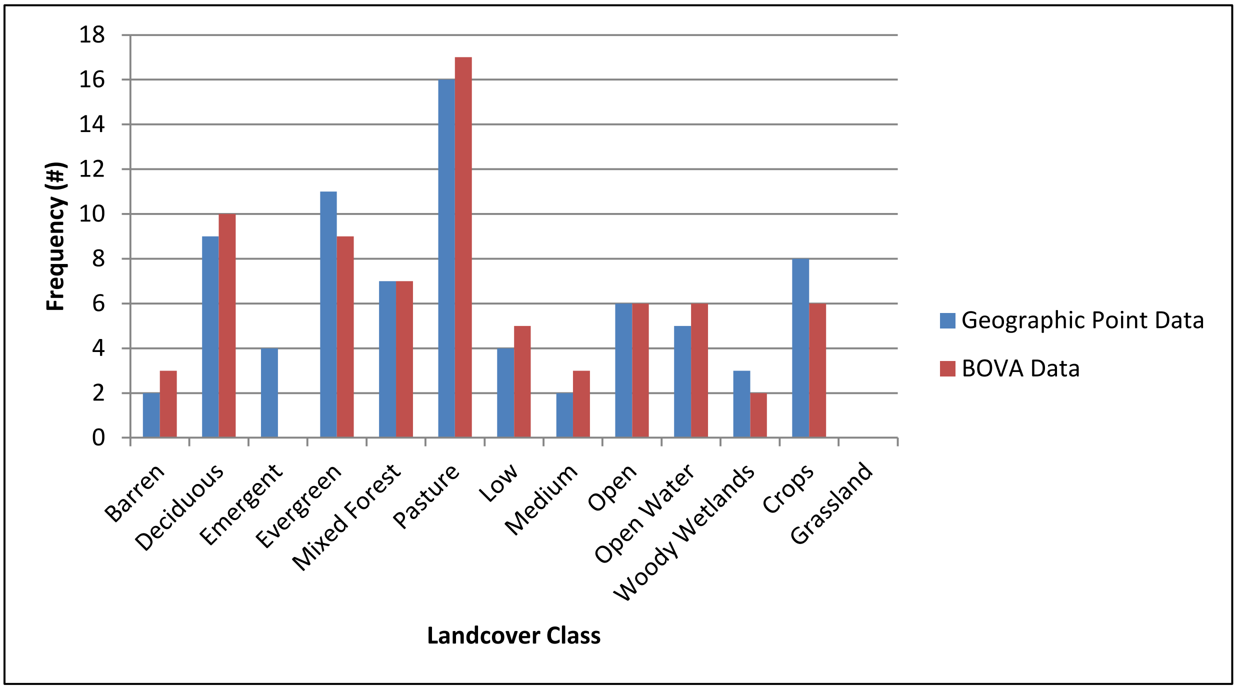
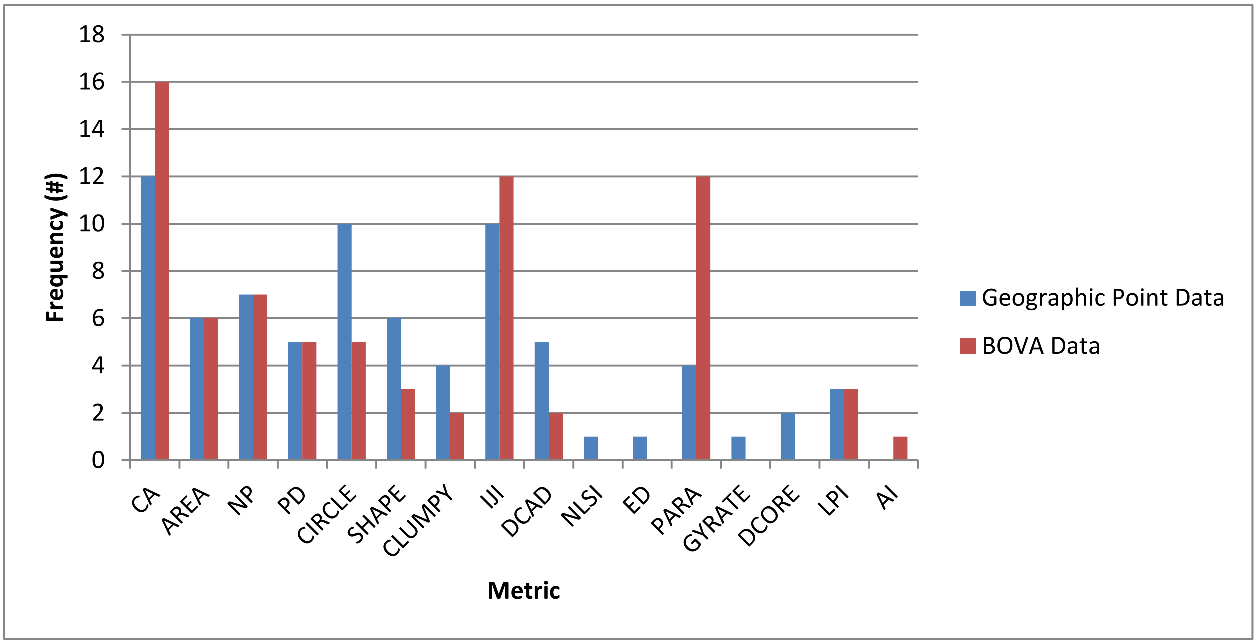


Figure 2.8. A comparison between the frequencies each fragmentation metric appeared in the geographic point data and BOVA data best subset regression models across the ecoregions. Fragmentation metrics were calculated at the class-level from the 2001 NLCD using the FRAGSTATS software (McGarigal et al. 2002).



The models with fewer metrics selected for management purposes are displayed in Tables 2.12 and 2.13. These management models have a lower mean adjusted R^2: 0.34 for the geographic point data and 0.36 for the BOVA data, as compared to 0.49 and 0.48 for the original models. The reduced models range from 2 to 4 predictor variables; the original models have between 2 and 19 variables. In the geographic point data reduced models, CA, NP, and PARA are the most prevalent metrics, with pasture, deciduous forest, and open development as the most occurring land classes for the geographic point data. For the BOVA data, pasture, deciduous forest, and evergreen forest are the most common land classes and PARA, IJI, and CA the most prevalent metrics in the models. Deciduous CA and Pasture PARA occurred in the most geographic point models and BOVA models, respectively.

Table 2.12. Reduced models of the geographic point data for management purposes. These models depict the land cover fragmentation metrics that best estimate alpha diversity for the 12-digit hydrologic units from wildlife survey data in Virginia based on an asymptotic approach to the adjusted R^2.

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Low AREA, Pasture NP, Pasture PD	3	108	0.47	0.46	381.74	41.51
Central Appalachians	Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI	3	30	0.53	0.48	120.35	22.98
Middle Atlantic Coastal Plain	Deciduous CA, Deciduous SHAPE Evergreen IJI	3	118	0.27	0.26	352.53	59.36
Northern Piedmont	Medium DCORE, Open CA, Open IJI	3	123	0.26	0.25	314.25	50.48
Piedmont	Deciduous CA, Pasture PARA, Open NP	3	334	0.32	0.31	647.57	62.88
Ridge & Valley	Deciduous CA, Low CA	2	271	0.29	0.31	164.45	80.35
Southeastern Plains	Deciduous AREA Barren PARA, Open Water NP	3	118	0.36	0.34	508.88	128.68

Table 2.13. Reduced models of the Biota of Virginia (BOVA) data for management purposes. These models depict the land cover fragmentation metrics that best estimate alpha diversity for the 12-digit hydrologic units from wildlife data in Virginia based on an asymptotic approach to the adjusted R2.

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	4	109	0.42	0.40	-126.43	27.47
Central Appalachians	Open Water PARA, Open CA	2	24	0.47	0.41	131.81	-5.99
Middle Atlantic Coastal Plain	Deciduous PD, Crops CA, Evergreen IJI, Pasture PARA	4	119	0.49	0.47	4249.08	78.27
Northern Piedmont	Open Water CA, Low CA, Open AREA	3	122	0.37	0.36	-1149.80	51.84
Piedmont	Pasture PARA, Woody Wetlands NP	2	339	0.26	0.26	-419.68	73.74
Ridge & Valley	Evergreen PARA, Pasture NP	2	290	0.37	0.36	-2918.82	66.25
Southeastern Plains	Evergreen IJI, Medium IJI	2	119	0.29	0.28	781.53	56.92

Discussion

The relatively high frequency of certain classes and metrics as statistically significant in the biodiversity regression models is reasonable given similar findings over the past few decades (Betts 2000). However, it is unclear whether there is sufficient field evidence to support the ecological significance of these variables. The most prevalent land classes are particularly well supported for their species richness (Betts 2000), but the fragmentation metrics are less so.

Deciduous forests, evergreen forests, and pastures are known to play prominent roles in the ecosystem and possess a multitude of species. Percentage of tree cover is a significant predictor for bird occurrences (Cunningham & Johnson 2011), as bird distribution is more closely correlated with forest structure than a particular forest type across a variety of spatial scales (Gil-Tena et al. 2007). In California, coniferous and hardwood forests are the top breeding habitat for terrestrial vertebrates (Verner 1987). They are also species-rich in invertebrates and microbes (Lindenmayer et al. 2002), and insects have shown high susceptibility to forest fragmentation (Didham et al. 1996). Deciduous forests in particular offer a top breeding habitat for birds (Verner 1987), with their large arthropod populations and numerous potential nesting sites (Gil-Tena et al. 2007).

Pastures possess unique characteristics to which their link to biodiversity values may be attributed. Species that require complex habitats tend to thrive in pastures of low intensity grazing, especially those with some trees or shrubs (Lynch 1989). This species diversity may be attributed to the heterogeneous edge vegetation that can be found in Virginia pastures. Pastures also create openings in the landscape that wildlife, such as wild turkeys, may exploit (Glennon & Porter 1999). The area that pastures compose in Virginia probably also enhances its overall significance in the landscape, with pastures making up 8.4% of the total area; they are the second most prevalent land cover class, only less than deciduous (50.9%).

As for the class fragmentation metrics, those we found to be most significant are also well-supported by the literature. Class area (CA) was the most prominent, with significance for seven land classes. One well-accepted theory in landscape ecology purports that above a given threshold of adequate habitat, habitat loss may be the driving factor for species decline, but other landscape factors may come into play below when the amount of habitat drops below the threshold (Andrén 1994). Both mammalian species richness and bird occurrences are highly related to the amount of forest class area (Cerezo et al. 2011, Chiarello 1999, Mörtberg 2001).

The interspersion and juxtaposition index (IJI) has been shown to affect such a wide range of species as wild turkeys, bobcats, and rattlesnakes (Glennon & Porter 1999, Constible et al. 2006, Hoss et al. 2010). A more intermixed habitat gives carnivores reduces the distance they must travel to reach their desired resources. For those predators who revisit particular patches, this spatial configuration reduces energy expenditures involved in finding prey (Constible et al. 2006).

There are several theories as to why the perimeter-to-area ratio is ecologically significant. A lower perimeter-area ratio may imply a more effective distribution of resources, while a higher ratio may increase the probability of organism crossing an edge (Betts 2000). The effect of the perimeter-area ratio may be directly related to the significance of edge effects, including the increased productivity and complexity of vegetation (Constible et al. 2006). Many species, such as white-tailed deer and generalist rodents, tend to increase in abundance near patch edges of dense vegetative land covers. This motivates their predators to scout these locations. Carnivores benefit from patches with a large perimeter-to-area ratio by being able to search more efficiently.

As carnivores often enter and exit patches at corners and rounded edges, complex patch structures also tend to aid their movement (Constible et al. 2006). Generalist avian species are strongly influenced by the perimeter-area ratio of forest patches at certain times of the year (Caprio et al. 2009). The probability of six common bird species occurring has been found to be inversely correlated to the perimeter-area ratio of the patches, because this increases the amount interior areas that are free from edge effects (Helzer & Jelinksi 1999). Wild bee diversity is also negatively related to the perimeter-area ratio of forest patches, perhaps because small forest patches can serve as barriers to desired fields (Carre´ et al. 2009).

Evidence in support of the ecological significance of the related circumscribing circle mean (CIRCLE) metric is sparse, but does exist. The patch shape may be indicative of the level of human disturbance in the landscape, as areas affected by humans tend to have more simple shapes. Systems of transport, such as rivers and roads, are characterized by more linear, elongated shapes. These features have the ability to efficiently transport matter (such as people and sediment), thus potentially spreading disturbances. Patch shape has also been seen to influence the migration patterns of small mammals, and elongated patches contained more millipedes than their compact counterparts (Betts 2000).

Although the models resulting from the BOVA and geographic point data were moderately similar, the optimal BOVA models generally used a greater number of predictors. The BOVA data are a much more exhaustive dataset of the species in the state, so we speculate that the greater model complexity is a result of the higher diversity of species incorporated in the alpha diversity estimates.

Conclusions

More research clearly remains to be done in this area. Even given our unusually large dataset, our wildlife data are most likely not a true representation of Virginia's biodiversity across all taxa and regions. This can be seen by the lack of uniform sampling across regions and hydrologic units, evidenced explicitly in the spatial distribution of the geographic point data but also most likely true of the BOVA data, as well. In addition, our data only represent the species occurrences, but give us no insight into where species are absent. The strong correlation between the number of observation points and the geographic alpha diversity in each hydrologic unit greatly emphasizes the importance of adequate field observations. Given these concerns and the fact that Virginia's wildlife database is much more comprehensive than most that exist within the US or elsewhere, there is a clear need for more comprehensive field sampling initiatives, particularly in light of international concerns regarding global loss of biodiversity.

The fragmentation snapshot may also have not matched up precisely with the temporal range of the geographic point and BOVA data; the point data were collected approximately five years following the land cover data, and the BOVA data spanned a multi-decadal range that encompass the land cover data. Different land classes or higher resolution land classification data could have also made a difference in fragmentation calculations. This is particularly true of the less prevalent land classes, which were often not present in sufficient quantities for FRAGSTATS to calculate their metrics. More specific land classes may also have changed the results, or an examination of fragmentation at other map scales.

One of the greatest issues with the study of biodiversity across taxa is the complexity of taxonomic and inter-species responses to fragmentation. While small mammal and frog species richness responded positively to fragment isolation in one study, birds and ants declined (Gascon et al. 1999). Lindenmayer et al. (2002) found no evidence of the applicability of fragmentation measures to biodiversity estimates across large numbers of species. There is little support for the biological significance of the metrics across multiple species, let alone taxa. In a study on indicator species, regression models used different sets of significant metrics, even for species of the same genus. As in our analysis, there were numerous metrics that were repeatedly statistically significant across ecoregions, but varied in the response direction (positive or negative) (Lindenmayer et al. 2002).

Inarguably the metrics do a better job depicting the landscape configuration than serving as a proxy for wildlife (Lindenmayer et al. 2002). However, the metrics are still useful in the wildlife arena. The site-specific nature of the regression equations would make transferring the equations to other areas difficult, but for those areas sampled, any land use change could be used to predict the change in biodiversity to some degree of accuracy. It is hoped that the prominence of these particular metrics and land classes can be helpful to state agencies and actors in making land management decisions with a concern for overall wildlife biodiversity.

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CHAPTER 3

Use of Landscape Metrics and Environmental Factors as Surrogates for Wildlife Biodiversity

Abstract

Maintaining wildlife biodiversity is on most conservation agendas today, and is of particular concern given the significant changes that are occurring in land use. In this study, we analyzed the relationship between various natural and anthropogenic environmental factors and wildlife biodiversity to determine the strength of these factors as drivers for alpha diversity. We calculated and acquired topographic, vegetative, climatic, and land use variables, as well as landscape and class fragmentation metrics to strengthen the models. We stratified Virginia into seven ecoregions based on the Environmental Protection Agency's Level III classification and used the 2001 National Land Cover Data as land cover classes. Alpha diversity for the 1248 12-digit hydrologic units was calculated using two wildlife datasets maintained by the Virginia Dept. of Game and Inland Fisheries: species occurrences of wildlife sightings with known geographic locations, and species occurrences recorded in the Biota of Virginia (BOVA) database from peer-reviewed literature. We conducted a best subset regression with minimum AICc to determine the best models for each ecoregion with the environmental variables and then all variables. For the environmental models, the adjusted R^2 ranged from 0.18 to 0.60 for the geographic point data and 0.24 to 0.38 for the BOVA data. Acreage is the most prevalent driver for alpha diversity across the models. With the addition of the landscape and class fragmentation metrics, the average adjusted R^2 increased for both the geographic point and BOVA models (adjusted R^2 ranges from 0.26 to 0.67 and 0.40 to 0.66, respectively). The majority of the prominent drivers of alpha diversity in each ecoregion are class fragmentation metrics. Our

results emphasize the value of incorporating class fragmentation metrics into wildlife biodiversity models in Virginia.

Introduction

Biodiversity Models

Species diversity has been used to gauge ecosystem health for decades (Magurran 1998). As each taxonomic group serves one or multiple functions, a minimum number of species is necessary for every ecosystem to function properly (Collins and Qualset 1999; Loreau et al. 2001). When the number of species drops below this threshold a variety of environmental services are affected, including climatic and biogeochemical regulation, watershed functions, soil preservation, vegetation pollination, and pest control (Myers 1996). The resulting impacts are seen in the health, economic, and recreational losses for humans (Convention on Biological Diversity 2010).

Recently, there has been an increased interest in maintaining species diversity. In the past decade, the World Summit on Sustainable Development and UN Millennium Development Goals set as one of their goals the reduction of biodiversity loss. A growing number of policies at all levels of government are addressing biodiversity conservation. In addition, people across the world are supporting measures designed to improve species richness through the numerous non-profit organizations involved in this cause, such as The Nature Conservancy and the World Wide Fund for Nature (WWF) (Rands et al. 2010). The year 2010 in particular highlighted the escalating prominence of biodiversity in the global conservation arena, with the 2010 Target of the Convention of Biological Diversity and the UN International Year of Biodiversity (Fisher

2009). As further proof of its growing importance, conservation biology is now an established academic field (Rands et al. 2010).

However, biodiversity targets are far from met, so “new and improved biodiversity indicators” are necessary to achieve these goals in the future (Fisher 2009, Convention on Biological Diversity 2010). To maintain biodiversity, it is critical to measure species richness and limit any detrimental changes. One common method for measuring biodiversity is to total the number of unique species in a region; this is known as the alpha diversity. The species diversity of all taxa across much of the earth is estimated to be in the thousands per square kilometer, but actual values are difficult to come by (Nagendra and Gadgil 1999). However, with increasing human population, changing land use, and climate change, it is more important than ever to keep track of the potential risks to biodiversity (Foley et al. 2005; Sala et al. 2000). Species-habitat models are developed to link environmental factors with species populations and biodiversity (Zabalga 2008, Oindo et al. 2003). By correlating species presence and abundance with particular environmental factors that compose favorable habitats, models enable researchers to predict other locations of potential habitat using known environmental variables (Franklin 2010). In addition, any changes in the environmental factors can be used to predict the corresponding changes in biodiversity over time.

Biogeographers and ecologists have incorporated numerous environmental variables into their biodiversity models, including topographical features, land use, vegetation, and climate characteristics (Adams 2009; Zabalga 2008; Oindo et al. 2003). Relevant topographical variables include soil properties, elevation, slope, and aspect (Adams 2009; Barnes et al. 1982; Franklin 2010). Land use variables worthy of consideration are the dominant land use, amount of land cover fragmentation, and an estimate of land cover diversity (Boone and Krohn 2000;

Franklin 2010; Leyequien et al. 2007; Rocchini et al. 2010). Fauna biodiversity has also shown a strong association to changes in vegetation, particularly those indicators such as leaf area index, tree cover, aboveground biomass, and Normalized Difference Vegetation Index (NDVI) (Gillespie 2008; Franklin 2010). Lastly, researchers have found value in incorporating climate proxies into their models as well, taking into account the average annual precipitation, mean annual temperature, and minimum temperature of the coldest month (Gillespie 2008; Hawkins et al. 2003; Zabalga 2008).

While environmental variables have been included in species-habitat association models for decades, there may be some value in also incorporating landscape configuration variables. The theoretical basis for this supposition is that anthropogenic effects on wildlife tend to be considerable (Price et al. 2005). Whereas natural disturbances tend to be temporary, human disturbances are often permanent (Bishop 2008). By changing land use, humans reduce potential habitat layout, amount, and quality (Laurance and Usche 2009; White et al. 1997). Different land use changes have varying effects, but urbanization in particular greatly decreases the land available for habitat, as well as increasing fragmentation (Beier and Noss 2008).

Habitat fragmentation is a process by which habitat is broken down into smaller and more numerous patches due to natural and anthropogenic activities (McGarigal and McComb 1999). Fragmentation often occurs concurrently with habitat loss, although there is a clear distinction between the two. The former refers to changes in the spatial layout of habitat and the resulting isolation of patches within a given matrix, while habitat loss involves the reduction in the amount of suitable land available (McComb 1999). Both processes affect the abiotic and biotic elements of the ecosystem. Fragmentation affects the microclimatic conditions, primarily through the creation of additional forest edges. Consequently, vegetation species composition and growth rates change (Rutledge 2003). As habitats become increasingly isolated, wildlife become unable to forage and migrate between habitat patches (Bishop et al. 2008). Reproduction and mortality are consequently affected, influencing animal distributions and abundances through inter-specific interactions. Fragmentation often leads to a community re-structuring in which there is a greater abundance of generalist species and lower species richness (Rutledge 2003).

The increase in the number of patches is insufficient to describe fragmentation. As the theory of island biogeography purports, species persistence is related to patch size and distance from the mainland: habitat connectivity within a landscape is critical (MacArthur and Wilson 1967; Noss 1987). However, since MacArthur and Wilson's salient paper, new metrics have also been developed to describe the spatial configuration of fragmentation. These indices fall into two categories: spatial or non-spatial. The spatial metrics describe patch composition, shape, and configuration; the non-spatial metrics include number of patch classes and area measurements (Rutledge 2003). Over the years, new metrics have been added to help fill the voids in explaining various ecological processes and landscape spatial characteristics (Rutledge 2003). However, even with some studies depicting the best subsets of landscape metrics, there is still controversy (Cushman, McGarigal and Neel 2008).

Objectives

In a previous study, we evaluated the relative importance of land cover characteristics on wildlife biodiversity, as summarized by fragmentation metrics at the land cover class-level. Our results successfully modeled the biodiversity in Virginia's ecoregions with mean adjusted R^2 values of 0.47 and 0.50, depending on the dataset. While this is valuable information, it is subject to ambiguities resulting from the selected land cover classification scheme and data reduction procedures (Stein et al. 2012, in review).

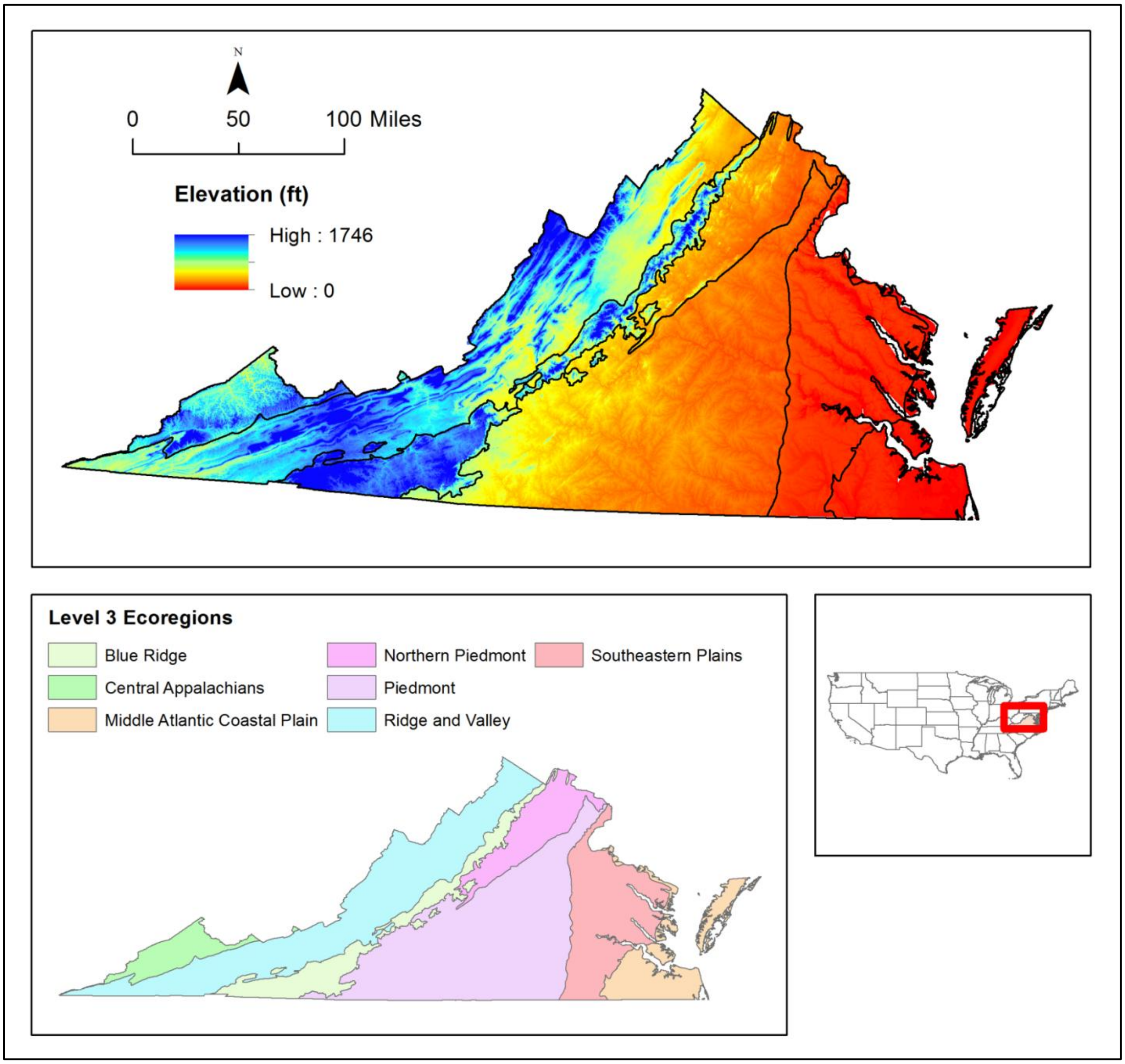
Our overarching research question in this study is whether various environmental properties and landscape fragmentation metrics could inform biodiversity estimates. We start out by evaluating their predictive capabilities on their own, and then incorporate them into the class-level models. We hope to learn whether our predictive models would improve with the addition of other data. As multiple metrics may be most appropriate for an ecosystem-level analysis (Davidson 1998), we examine the confluence of several variables to assess the most influential combination of factors; these include natural as well as anthropogenic drivers. With a dearth of information on this topic in Virginia, we hope our study can provide a basis for management decisions within the study area and its vicinity. Our access to an unusually large database of wildlife observations offers a unique opportunity to examine the relationship between wildlife biodiversity and landscape patterns across a relatively large scale and taxonomic groups.

Methods

Study Area

Our study area is the Commonwealth of Virginia, on the United States East Coast. With latitudes between 36° 31'N to 39° 37'N and longitudes from 75° 13'W to 83° 37'W, Virginia encompasses an area of 39,490 square miles (2010 US Census). The mean elevation is 950 feet above sea level, with distinct spatial patterns across the state. The Appalachian chain runs northeast to southwest across the western side of the state. The eastern side of the state is characterized by flat terrain in the piedmont and coastal plain. Monthly average temperatures range from 26.2 to 88.4 degrees (Netstate). Due to these differences, we divided the state into seven ecoregions based on the 2010 Environmental Protection Agency's Level III categories (Figure 3.1: the Blue Ridge , Central Appalachians, Middle Atlantic Coastal Plain, Northern Piedmont, Piedmont, Ridge and Valley, and Southeastern Plains. We calculated descriptive statistics, tested normality for each ecoregion, and then used an Analysis of Variance (ANOVA) to determine significant statistical differences. The 1248 12-digit hydrologic units (HUs) were our sampling units, with a mean area of 33.47 square miles.

Figure 3.1. Map of Virginia depicting the seven ecoregions as determined by the US Environmental Protection Agency's Level III categories. Due to the significant statistical differences in alpha diversity present among the ecoregions, wildlife biodiversity models were developed separately for each ecoregion.



Species Richness – Alpha Diversity

Alpha diversity was calculated from the Virginia Dept. of Game and Inland Fisheries' (VDGIF) geographic point and Biota of Virginia (BOVA) wildlife datasets. The geographic point data contains 332,844 wildlife sightings of 1163 unique species between June 7, 2007 and June 1, 2010. This dataset consists of all officially documented fish and wildlife sightings in Virginia from management, regulatory review, permitting, or research processes (VDGIF 2007). The BOVA database consists of tabular, non-geographically referenced wildlife data for each hydrologic unit. This includes the geographic point dataset and other sightings, totaling 3319 unique species (VDGIF 2007).

Previous research (Stein et al. 2012, in review) demonstrated a statistically significant difference in alpha diversity across Virginia's seven ecoregions. Due to this finding combined with obvious differences in the environmental variables across the state (e.g. elevation, Figure 3.1), we developed our predictive models separately for each of the seven ecoregions.

Environmental Data

Environmental factors that may have both direct and indirect effects on biodiversity were examined to determine the strength of these factors as predictors of alpha diversity. Studies indicate that biodiversity is clearly linked to topography, vegetation, climate and land use, so these four variable classes composed the primary environmental data layers (Tews et al. 2004; Leyequien et al. 2007; Barnes et al. 1982; Hawkins et al. 2003). In addition, total acreage in the HU was also incorporated as a variable. Data layers were compiled and assessed using a geographic information system (e.g. ArcMap, ESRI, Redlands California).

Topography was assessed by examining the mean elevation, mean slope, and standard deviation of the slope in each hydrologic unit. These variables were chosen based on their use by Canada's biodiversity monitoring program, BioSpace (Franklin 2010), and the confirmatory findings of multiple studies on their significance. Elevation is a major determinant for species diversity across taxa (Debinski and Brussard 1994; López-López et al. 2006), likely due to its connection with climate (Gaston and Blackburn 2000). In addition, different bird species prefer varying slopes, and slope was one of the most important variables in describing mule deer distributions (DeBoer and Diamond 2006; Avey et al. 2003).

We collected digital elevation models (DEMs) at 30m spatial resolution from the Natural Resources Conservation Service (NRCS). Mean and standard deviation slope and mode aspect were calculated from these DEMs. For the geographic point models, we used the mean, standard deviation, and mode for the variables at each of the wildlife occurrences. However, for the BOVA data we calculated the values across the entire hydrologic unit. The purpose of this was to utilize the occurrence data when possible, but take an alternative approach for the wildlife dataset that lacks spatial reference.

Combinations of precipitation and climatic variables have been shown to successfully explain reptile distributions (Guisan and Hofer 2003). Climate data were collected from the National Oceanic and Atmospheric Administration's National Climatic Data Center (NOAA). We downloaded the mean annual precipitation (PPT), mean annual temperature, mean minimum winter temperature, and the mean maximum summer temperature from 106 weather stations in Virginia. Climatic data were based on weather records from 1981 to 2009. After mapping the locations for the weather stations, we determined the closest station with complete climatic data to each hydrologic unit. The climatic data for the closest station were attributed to the HU.

The Normalized Difference Vegetation Index (NDVI) provides a measure of vegetation productivity that has been correlated with the spatial distribution of terrestrial organisms (Verlinden and Masago 1997; Leyequien et al. 2007). This index provides information on the availability of plant resources (Hebblewhite 2009) required by herbivores and insects. We calculated NDVI from Landsat images taken in June and July of 2002. The image analysis was conducted in ENVI Software using the following equation:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

where NIR and RED represent the spectral reflectance measurements in the near-infrared (0.7 to 0.9 µm) and red (approx. 0.65 µm) wavelengths, respectively (Verlinden and Masogo 1997).

The effect of humans on the landscape was assessed using the average population density per hydrologic unit. The average population density was calculated from the 2010 U.S. Census blocks data.

The well-established ‘heterogeneity hypothesis’ in the field of ecology posits that habitats with greater structural complexity will have a greater number of niches and consequently have greater species richness (Tews et al. 2004; Oindo et al. 2003). Thus, there is reason to believe that landscapes with greater habitat heterogeneity will have greater species richness. To take this into account, we calculated the diversity of the land cover using two of the prominent heterogeneity indices, the Shannon-Wiener index (H’) and Simpson’s index (D). These values are calculated as follows:

$$H' = - \Sigma\, p_i \ln p_i$$

$$D = 1 / \Sigma\, p_i^2$$

where p_i represents the percentage of each land cover type in a specific hydrological unit (Magurran 2005). Land use and land cover diversity have been derived from the 2001 National Land Cover Data (NLCD), a Landsat-derived dataset. The NLCD classifies the Virginia landscape into 15 different categories. The following land classes were present in Virginia: crops, deciduous forest, evergreen forest, mixed forest, barren, grassland, pasture, shrubs/scrub, woody wetlands, emergent herbaceous wetlands, open water, open development, low density development, medium density development, and high density development.

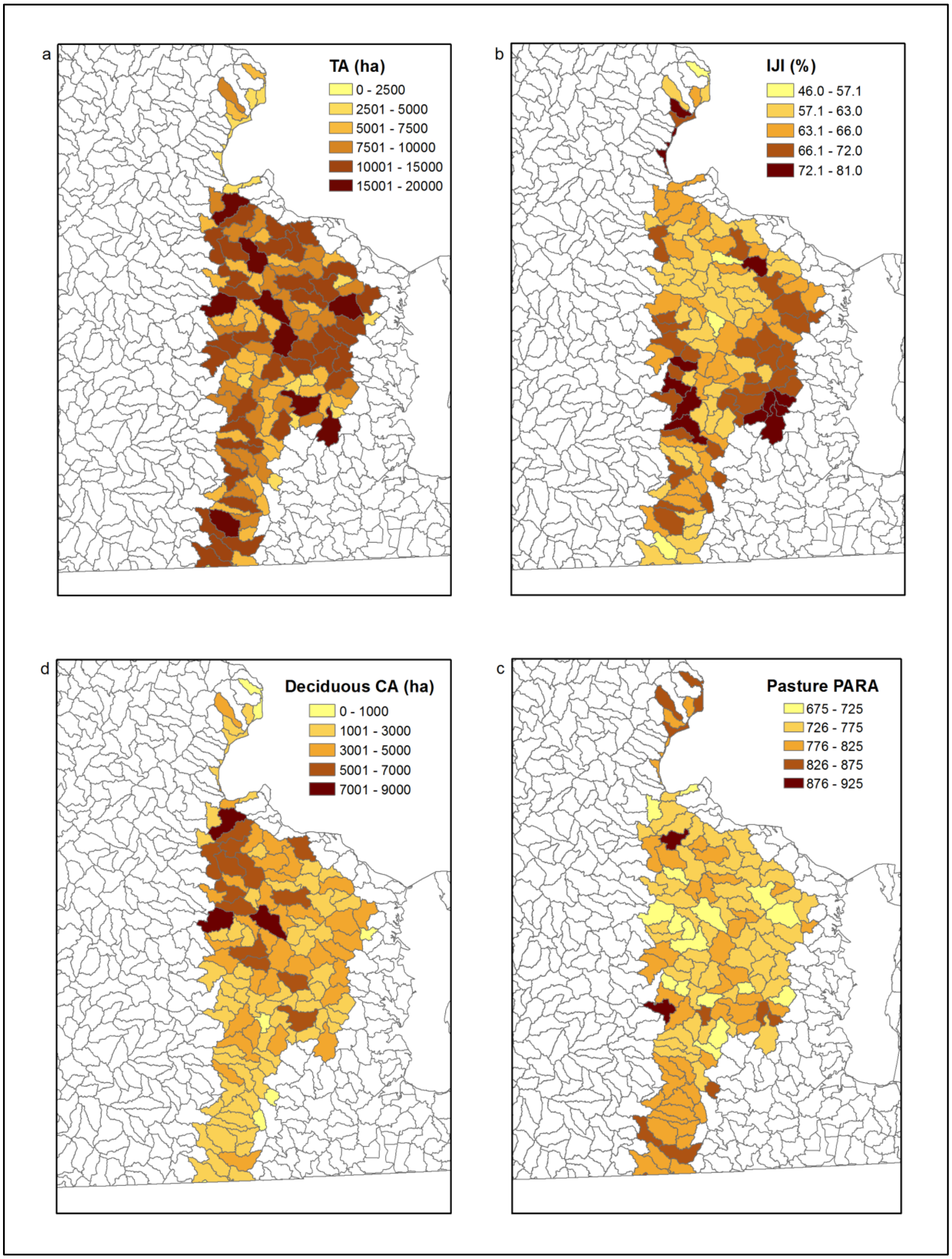
We also calculated 36 landscape fragmentation metrics for each hydrologic unit, using the program FRAGSTATS (McGarigal et al. 2002). Landscape metrics were determined based on their potential ecological significance (Constible et al. 2006). Of these metrics, 20 were repeatedly found to provide some insight to the distribution of alpha diversity, and are defined in Table 3.1. The other metrics are described in McGarigal et al. 2002. We specified an eight-pixel neighborhood and an edge distance of 50m. The eight-pixel neighborhood enabled all adjacent pixels to be considered in calculations, while the 50m-edge represents the distance at which microclimatic and other effects begin to disappear (Murcia 1995).

Table 3.1. The landscape and class fragmentation metrics calculated from FRAGSTATS that most commonly contributed to the alpha diversity regression models. "Category" refers to the type of fragmentation information provided by the metric, as determined by FRAGSTATS. Information adapted from the FRAGSTATS website (McGarigal et al. 2002) and Schindler et al. 2008.

Metric Name	Abbrev.	Category	Definition
Mean Area	AREA	Area/Density/Edge	Mean size of patches
Class Area or Total Area	CA or TA	Area/Density/Edge	Area of class or total area of landscape
Core Area Index	CAI	Core Area	Percentage of area comprised of core area, with 50m buffer
Mean Related Circumscribing Circle	CIRCLE	Shape	Mean elongation measure; equals 1 minus patch area divided by the area of the smallest circumscribing circle
Clumpiness Index	CLUMPY	Contagion/Interspersion	Measure of like adjacencies
Disjunct Core Area Density	DCAD	Core Area	Total number of disjunct core areas, per 100 hectares
Mean Disjunct Core Area	DCORE	Core Area	Mean area of disjunct core areas
Euclidean Nearest Neighbor Distance Distribution	ENN	Isolation/Proximity	Mean nearest neighbor distance
Interspersion and Juxtaposition	IJI	Contagion/Interspersion	Measure of evenness of patch/class adjacencies
Largest Patch Index	LPI	Area/Density/Edge	Percentage of total area occupied by the largest patch
Effective Mesh Size	MESH	Contagion/Interpersion	Measures subdivision in a landscape
Modified Simpson's Diversity Index	MSIDI	Diversity	Measures the number of different patch types and their proportional distribution of area
Normalized Landscape Shape Index	NLSI	Area/Density/Edge	Ratio of the total edge to the minimum total edge per class, rescaled according the proportion of the classes
Number of Patches	NP	Area/Density/Edge	Number of patches
Mean Perimeter-Area Ratio	PARA	Shape	Mean perimeter per area as a shape complexity measure
Patch Density	PD	Area/Density/Edge	Number of patches per area
Path Richness	PR	Diversity	Number of different patch types
Patch Richness Density	PRD	Diversity	Number of different patch types per 100 hectares
Mean Shape Index	SHAPE	Shape	Measure mean shape compaction/irregularity of patches
Splitting Index	SPLIT	Contagion/Interspersion	Measures subdivision in a landscape
Total Core Area	TCA	Core Area	Total amount of core areas in each patch, per hectare

The values for several of the key variables for the Southeastern Plains ecoregion are depicted in Figure 3.2. There appears to be a relatively random arrangement of values across the region's hydrologic units, with little spatial autocorrelation. In addition, no evident pattern is seen between the variables, even for those of the same fragmentation level. For example, although TA and IJI are both landscape-level fragmentation metrics, they each display new information that describes the hydrologic unit. Likewise, Deciduous CA and Pasture PARA are both class metrics, but they are describing the fragmentation within two different landscape classes. Although the area of one land cover class is inherently inversely related to that of the other land classes, the relationship is generally indirect between two specific classes. The different metrics selected all provide new information, as they each describe the fragmentation patterns in a unique manner. No one metric can sufficiently explain the spatial layout of the land cover, as seen by the wide range of values and lack of spatial patterns in the maps.

Figure 3.2. Maps of key variables in the Southeastern Plains ecoregion of Virginia: (a) Total Area (TA); (b) Interspersion and Juxtaposition Index (IJI); (c) Deciduous Core Area (CA); and (d) Pasture Perimeter-Area Ratio (PARA).



Statistical Analysis

To select models for the environmental variables and landscape fragmentation metrics, we removed variables that were highly correlated with each other, based on a Spearman's correlation of 0.75 or above. Then we ran a best subset regression on each dataset separately. The top model was determined based on the minimum Akaike information criterion (AICc) + 2 (ΔAICc< 2.0) (Burnham and Anderson 2002).

For the combined models, we aggregated the top landscape metrics and environmental metrics with VIFs under 10. Then we combined the top 20 FRAGSTATS class metrics as determined from a backward stepwise regression in a previous study (Stein et al. 2012). A backward stepwise regression was conducted on each alpha diversity value and the comprehensive set of independent variables using a p-value threshold stopping rule of 0.25 to enter and 0.10 to leave. We systematically deleted metrics one-by-one based on the highest p-value until only 20 metrics remained. Using the final subset of metrics, we conducted a best subset regression and selected the optimal model based on the minimum AICc +2 (ΔAICc< 2.0) (Burnham and Anderson 2002). According to this rule, we selected the model with the fewest number of variables that had an AICc of within two of the minimum. We performed leave-one-out cross validation to assess model robustness, and evaluated the PRESS statistic and RMSE. Models were assessed for multi-collinearity by ensuring the variance inflation factors were below 10 (Kutner 2004). Those models with VIFs above 10 were de-selected and a new model was chosen with the lowest AICc and VIFs under 10. Finally, the assumption of normality of the model residuals was tested with the K-S test.

The Central Appalachians dataset introduced additional issues with its few observations. For this ecoregion, we selected the best variables that had appeared in the top models in the other ecoregions. We then conducted a Spearman correlation analysis with these variables and the alpha diversity value. The top 20 variables were selected for a best subset regression, which followed the aforementioned model selection process.

Results

Independent Variables

Many of the environmental variables depicted clear geographic patterns across the state, thus confirming our decision to analyze by ecoregion (Table 3.2, Table 3.3, Figure 3.3, Figure 3.4). As expected, the minimum temperature was highest in the mountainous regions, and the maximum temperature and precipitation were highest in the coastal regions. NDVI and population varied throughout the state.

Table 3.2. Summary statistics of the environmental variables by ecoregion for the geographic point (GP) and Biota of Virginia (BOVA) datasets. The following environmental variables were used as predictors to model wildlife biodiversity in Virginia: mean slope, standard deviation slope (Std Slope), mean elevation (Elev), mean maximum summer temperature (Max Temp), mean minimum winter temperature (Min Temp), mean precipitation (Precip), Simpson's Index (SI), Shannon-Weiner Index (SWI), potential evapotranspiration (PET), acreage, and mean Normalized Difference Vegetation Index (NDVI). Variables were calculated for each 12-digit hydrologic unit (HU) in Virginia and modeled in each ecoregion: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP).

Data	Eco-region	# HUs	Mean Slope	Std Slope	Elev	Max Temp	Min Temp	Precip	SI	SWI	Pop	PET	Acreage	NDVI
GP	BR	55	10.86	6.89	682.43	82.42	24.79	43.42	3.05	1.31	86.13	27.22	22730.92	0.79
	CA	35	12.14	7.44	521.33	80.72	24.93	45.79	1.56	0.64	34.58	28.09	17538.14	0.66
	MACP	116	0.88	0.82	5.70	86.45	31.54	46.75	3.21	1.34	515.73	32.22	22162.33	0.71
	NP	8	4.39	3.01	137.51	85.46	26.26	44.70	3.14	1.37	13.18	29.76	22774.02	0.86
	P	259	4.27	2.74	144.09	86.41	26.47	44.64	3.89	1.58	93.29	30.40	22068.44	0.81
	RV	149	8.27	6.17	538.36	82.67	24.02	43.08	2.34	1.07	146.72	27.44	21974.67	0.75
	SP	90	2.45	2.02	18.71	87.91	29.44	45.36	3.17	1.32	144.25	32.23	22452.54	0.76
BOVA	BR	116	11.91	7.05	642.68	82.54	24.66	45.08	2.81	1.25	67.28	27.31	22638.32	0.80
	CA	43	20.56	8.37	614.91	80.72	24.93	45.65	1.53	0.63	34.21	28.19	17828.34	0.67
	MACP	140	0.89	1.01	9.93	86.27	31.28	45.95	3.07	1.27	434.84	32.11	21056.48	0.69
	NP	115	6.37	4.38	188.58	84.61	25.23	44.36	3.71	1.51	287.38	29.21	22851.88	0.85
	P	377	4.65	2.90	148.71	86.37	26.46	44.24	3.91	1.58	96.88	30.33	21703.58	0.81
	RV	306	12.76	7.36	585.37	82.41	23.33	42.36	2.29	1.06	106.38	27.35	20915.61	0.79
	SP	124	2.51	2.30	27.67	87.58	29.32	44.70	3.09	1.29	213.26	32.00	21635.16	0.77

Table 3.3. Summary statistics of the most commonly occurring landscape fragmentation variables in the Virginia wildlife biodiversity models. Fragmentation metrics calculated from FRAGSTATS using the 2001 National Land Cover Data (NLCD) for all hydrologic units in Virginia (McGarigal et al. 2002). Variables include Total Area (TA), Mean Circumscribing Circle (CIRCLE), Number of Patches (NP), Patch Density (PD), Mean Patch Area (AREA), Mean Shape Index (SHAPE), Interspersion and Juxtaposition Index (IJI), Perimeter-Area Ratio (PARA), Largest Patch Index (LPI), Mean Disjunct Core Area (DCORE), and Disjunct Core Area Density (DCAD). The values below are the means for each ecoregion in Virginia: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP).

Ecoregion	TA	CIRCLE	NP	PD	AREA	SHAPE	IJI	PARA	LPI	DCORE	DCAD
BR	8995.76	0.63	1695.92	19.42	5.77	1.61	54.27	845.66	40.50	9.05	6.99
CA	7214.99	0.65	1128	15.83	7.35	1.65	56.12	816.34	55.18	19.55	4.40
MACP	8890.49	0.60	2955.18	34.25	3.83	1.55	67.04	895.88	22.76	6.02	8.76
NP	9159.13	0.59	2629.16	30.05	4.33	1.54	61.06	909.37	26.54	7.39	7.56
P	8760.25	0.62	2579.50	29.98	3.57	1.59	62.82	838.19	23.87	3.96	10.11
RV	8327.76	0.60	1551.74	19.30	6.21	1.55	57.19	896.74	45.18	13.37	5.98
SP	8713.37	0.60	2647.31	31.59	3.61	1.56	64.92	873.17	23.56	4.92	9.06

Figure 3.3. Values for the topographic variables in each hydrologic unit in Virginia: mean slope, standard deviation slope, and mode aspect.

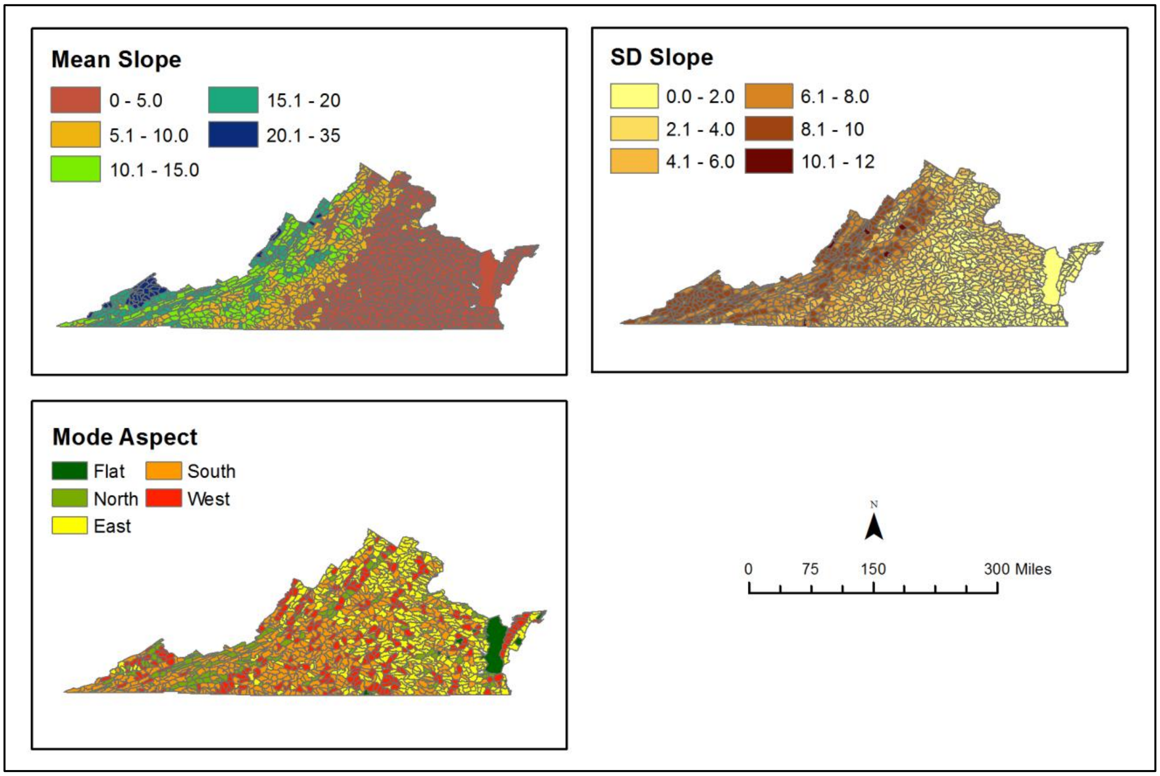
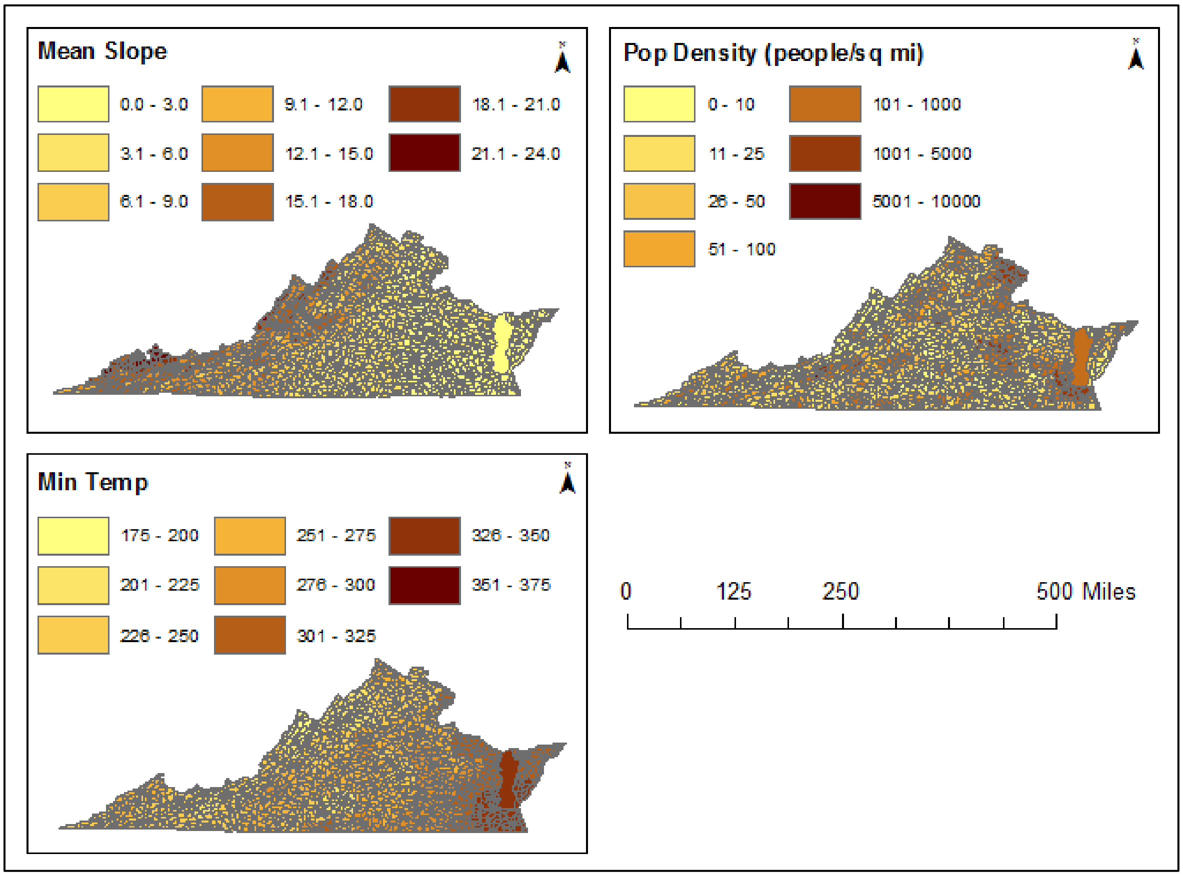


Figure 3.4. Values for three of the BOVA variables in Virginia's 12-digit hydrologic units: mean slope, population density, and minimum winter temperature. While mean slope and minimum temperature show a geographic trend longitudinally across the state, population density varies.



Environmental Models

For the geographic point data models, the number of selected predictors ranged from 3 to 5, with average adjusted R^2 ranging from 0.18 to 0.60; for the BOVA models, the number of selected predictors ranged from 1 to 6, with a range of 0.24 to 0.38 for the average adjusted R^2 (Table 3.4). The Central Appalachians model had the highest adjusted R^2 with the geographic point data (adjusted $R^2 = 0.60$), while the Middle Atlantic Coastal Plain model had the highest with the BOVA data (adjusted $R^2 = 0.38$).

Table 3.4. Selected best subset regression models and their respective selection criteria for the geographic point (GP) and Biota of Virginia (BOVA) data across the seven ecoregions in Virginia. The ecoregions are as follows: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP). Models were developed from the following environmental variables for all 1248 hydrologic units in the state: mean slope, standard deviation slope (Std Dev Slope), mean elevation (Elev), mean maximum summer temperature (Max Temp), mean minimum winter temperature (Min Temp), mean precipitation (Precip), Simpson's Index (SI), Shannon-Weiner Index (SWI), potential evapotranspiration (PET), acreage, and mean Normalized Difference Vegetation Index (NDVI).

Data	Eco-region	Model	# Vars	# HUs	R^2	Adj. R^2	AICc	Cp
GP	BR	SI, Pop Density, Acreage	3	106	0.46	0.45	937.73	6.00
	CA	Elev, Std Dev Slope, PET, Acreage, NDVI	5	40	0.65	0.60	343.66	4.61
	MACP	Min Temp, Pop, Acreage	3	134	0.26	0.24	183.07	4.98
	NP	Min Temp, Pop, Acreage	3	70	0.22	0.18	711.27	4.65
	P	Elev, Std Dev Slope, Pop, Acreage	4	364	0.37	0.36	666.83	2.89
	RV	Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage, NDVI	6	257	0.38	0.36	121.62	6.81
	SP	Max Temp, Acreage, NDVI	3	117	0.27	0.25	253.94	5.01
BOVA	BR	Std Dev Slope, Elev, Precip	3	113	0.32	0.30	-119.49	2.46
	CA	Mean Slope, Min Temp, Acreage	3	41	0.37	0.32	230.99	0.79
	MACP	Mean Slope, Min Temp, Acreage	3	134	0.39	0.38	4792.50	3.29
	NP	Std Dev Slope, Pop, NDVI	3	115	0.39	0.37	-1139.00	5.97
	P	Std Dev Slope, Elev, SI, PET, Acreage, NDVI	6	367	0.25	0.24	-438.90	8.09
	RV	Mean Slope, Precip, Acreage, NDVI	4	295	0.28	0.27	-2936.00	2.59
	SP	Mean Slope, Precip, Pop, PET, NDVI	5	121	0.39	0.36	787.54	2.12

The most frequently occurring variables in the geographic point models were acreage and population density. In the BOVA models, acreage, mean slope, and NDVI were the most commonly occurring variables.

Landscape Models

For the selected landscape models, the average adjusted R^2 ranged from 0.26 to 0.50 for the geographic point data and from 0.16 to 0.51 for the BOVA data (Table 3.5). The most common fragmentation metrics for the geographic point data was TA, followed by CAI, ENN, MSIEI and PRD. For the BOVA data, TA also occurred in the most models, with DCAD, DCORE, MESH and PR as the next most common.

Table 3.5. Selected best subset regression models for each ecoregion in Virginia using landscape fragmentation metrics to predict wildlife alpha diversity estimated from the geographic point (GP) and Biota of Virginia (BOVA) data. Fragmentation metrics were calculated from FRAGSTATS software based on the 2001 National Land Cover Data (McGarigal et al. 2002). Biodiversity is estimated as the total number of species in each 12-digit hydrologic unit (HU) for the following ecoregions: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP). The selected models had the minimum AICc + 2 for the ecoregion and VIFs below 10.

Data	Ecoregion	Model	# Vars	# HUs	R^2	Adj. R^2	AICc	Cp
GP	BR	TA, DCORE, PR, PRD	4	119	0.33	0.31	492.62	5
	CA	TA, ENN, IJI	3	41	0.50	0.50	165.39	6.99
	MACP	TA, CAI, SPLIT	3	131	0.27	0.26	393.52	6.58
	NP	SHAPE, SPLIT, PRD	3	118	0.33	0.31	259.95	4
	P	TA, PARA, CAI, ENN, PRD, MSIEI	6	367	0.34	0.33	715.43	7
	RV	TA, SHAPE, ENN, PR, MSIEI	5	303	0.39	0.38	166.11	8.17
	SP	TA, DCAD, DCORE, CAI, IJI, MSIEI	6	123	0.40	0.37	527.62	8.90
BOVA	BR	DCAD, PR	2	119	0.10	0.16	-90.32	3
	CA	TA, PARA, DCORE, MESH, PR, MSIEI	6	43	0.58	0.51	235.12	7
	MACP	TA, DCAD, COHESION, SPLIT, PR	5	136	0.30	0.28	4890.49	11.92
	NP	ENN, MESH, PRD	3	118	0.29	0.27	731.71	4
	P	TA, SHAPE, DCORE, ENN, IJI	5	378	0.22	0.21	378.93	8.92
	RV	TA, SHAPE, DCAD, DCORE, MSIEI	5	314	0.31	0.29	-3106.99	5.61
	SP	IJI, MESH, PRD	3	126	0.22	0.20	852.69	4

Combined Models: Class, Landscape, and Environmental Variables

The combined models are displayed in Table 3.6, and their cross validation statistics in Table 3.7. The adjusted R^2 values of the combined models range from 0.26 to 0.67 for the geographic point data and from 0.40 to 0.66 for the BOVA data (Table 3.7). With the geographic point data, the Southeastern Plains model had the highest adjusted R^2 with 0.67, but also had the most variables. Out of the BOVA models, the Central Appalachians model had the best fit to the data relative to the number of variables (adjusted $R^2 = 0.66$ with only 5 variables), but also had the fewest sampling units ($n = 34$). All models had normal residuals, with the exception of the Ridge & Valley BOVA model (Table 3.7).

The adjusted R^2 increased when comparing the environmental and landscape models to the combined models for both datasets. In the geographic point models, the average adjusted R^2 increased by 0.10 from the environmental to combined models and from the landscape to combined models. With the BOVA models, the average adjusted R^2 increased by 0.20 from the environmental to combined models, and by 0.24 from the landscape to combined models.

Table 3.6. Selected combined models for the geographic point (GP) and Biota of Virginia (BOVA) data. Combined models were developed by conducting a best subset regression on the class fragmentation metrics, landscape fragmentation metrics, and environmental variables from each of the selected best subset regression models for the respective datasets. Models selected had the minimum AICc + 2 and VIFs below 10 for each ecoregion: Blue Ridge (BR), Central Appalachians (CA), Middle Atlantic Coastal Plain (MACP), Northern Piedmont (NP), Piedmont (P), Ridge and Valley (RV), and Southeastern Plains (SP).

Data	Ecoregion	Model	# Vars	# HUs	R^2	Adj. R^2	AICc	Cp
GP	BR	Crops SHAPE, Mixed Forest AREA, Pasture PD, DCORE, PR	5	108	0.32	0.29	-106.43	7.55
	CA	Evergreen CIRCLE, TA, Elev, Std Dev Slope, PET, NDVI	6	40	0.68	0.62	341.45	5.61
	MACP	Deciduous CA, Crops IJI, Evergreen CA, Pasture IJI, ENN, Min Temp, Pop	7	124	0.47	0.44	126.84	17.36
	NP	SHAPE, PRD, Pop	3	106	0.28	0.26	468.56	11.54
	P	Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA, PRD, Std Dev Slope, Pop	14	332	0.46	0.44	562.35	17.46
	RV	Deciduous CA, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Pop	11	248	0.47	0.45	90.67	17.92
	SP	Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, DCAD, DCORE, IJI, NDVI	18	119	0.72	0.67	194.72	20.99

BOVA	BR	Crops LPI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Elev	6	88	0.61	0.58	-136.53	5.00
	CA	Open Water PARA, Open CA, DCORE, MESH, MSIEI	5	34	0.71	0.66	176.39	4.62
	MACP	Deciduous PD, Deciduous LPI, Crops CA, Evergreen CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, COHESION, Acreage	10	129	0.60	0.57	4580.06	15.15
	NP	Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Pasture CA, Pasture CLUMPY, Std Dev Slope	6	98	0.47	0.43	-978.78	7.56
	P	Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, ENN, IJI, SI	15	334	0.43	0.40	-477.15	18.05
	RV	Deciduous NP, Crops NP, Crops PD, Evergreen PD, Pasture CA, Pasture NP, Pasture PARA, Pasture IJI, Open CA, Open PARA, Precip	11	290	0.51	0.49	-132.09	14.11
	SP	Deciduous AREA, Crops NP, Evergreen NP, Barren PARA, Open Water SHAPE, Pasture PD, Pasture AREA, Precip, NDVI	9	119	0.53	0.50	748.14	14.33

Table 3.7. Cross-validation statistics for the best subset regression models for the geographic point (GP) and BOVA data. Models were designed to predict the wildlife alpha diversity based on a combination of class- and landscape-level fragmentation metrics and environmental variables. Models were selected based on the minimum AICc for each of Virginia's seven ecoregions.

Data	Model	RMSE	Residual K-S, P	Cross-Validation PRESS
GP	BR	0.14	0.07, >0.15	0.29
	CA	14.69	0.16, 0.07	1.24E4
	MACP	0.39	0.05, >0.15	25.58
	NP	2.14	0.08, 0.10	525.19
	P	0.55	0.03, >0.15	104.71
	RV	0.28	0.04, >0.15	20.85
	SP	0.49	0.05, >0.15	35.25
BOVA	BR	0.10	0.07, >0.15	1.61
	CA	2.73	0.08, >0.15	320.14
	MACP	1.17E7	0.08, 0.08	1.99E16
	NP	1.6E-3	0.07, >0.15	3E-4
	P	0.12	0.04, >0.15	4.63
	RV	0.19	0.08, <0.01	10.76
	SP	5.29	0.06, >0.15	3711.48

The mean number of variables in each model type also varies substantially. The landscape models range from 2 to 6 variables while the combined models have from 4 to 19 variables, depending on the ecoregion and dataset. In both datasets, the class-level and combined models have the greatest variability in variable count among the ecoregions; these same model types also use the most variables. The environmental models use the fewest variables, with the landscape-level models using only slightly more. The landscape and environmental BOVA models strongly improve their fit to the data, while nearly all the GP models have only a slight improvement.

The combined model fit the observed alpha diversities in the majority of the hydrologic units. Figure 3.5 shows a close-up of the hydrologic units within the Southeastern Plains ecoregion. The model tended to over-predict alpha diversity, particularly in those HUs with observed alpha diversity values in the middle of the ecoregion's range. The majority of the variables used in the combined models are class metrics (Figure 3.6). In the geographic point combined models, there are 39 class variables compared to 13 landscape and 12 environmental variables in the models. The BOVA models depict an even sharper disparity, with 49 class variables, 6 landscape variables, and 7 environmental variables.

Both the land cover classes and the class- and landscape-level fragmentation metrics used in the combined models show some agreement between the geographic point and BOVA data. In the geographic point models, the most common land cover classes were pasture and mixed forest. Similarly, the most common land cover classes in BOVA combined models were pasture and deciduous forest. CIRCLE, IJI, SHAPE, and CA/TA occurred most frequently in the geographic point combined models, while CA/TA, PARA, and NP occurred most frequently in the BOVA models.

Of the environmental variables, there was little repetition among datasets or ecoregions. The most common environmental variables for the geographic point data were population density and precipitation, which occurred four and three times, respectively, in the combined models. Precipitation occurred in two of the BOVA models, but no other environmental variable was found in more than one BOVA combined model.

Figure 3.5. Observed (a) and predicted (b) alpha diversity values for all hydrologic units located completely within the Southeastern Plains. Predictions were calculated using the combined models with the geographic point dataset. For comparison, the absolute value of the difference between the predicted and observed values is shown in (c).

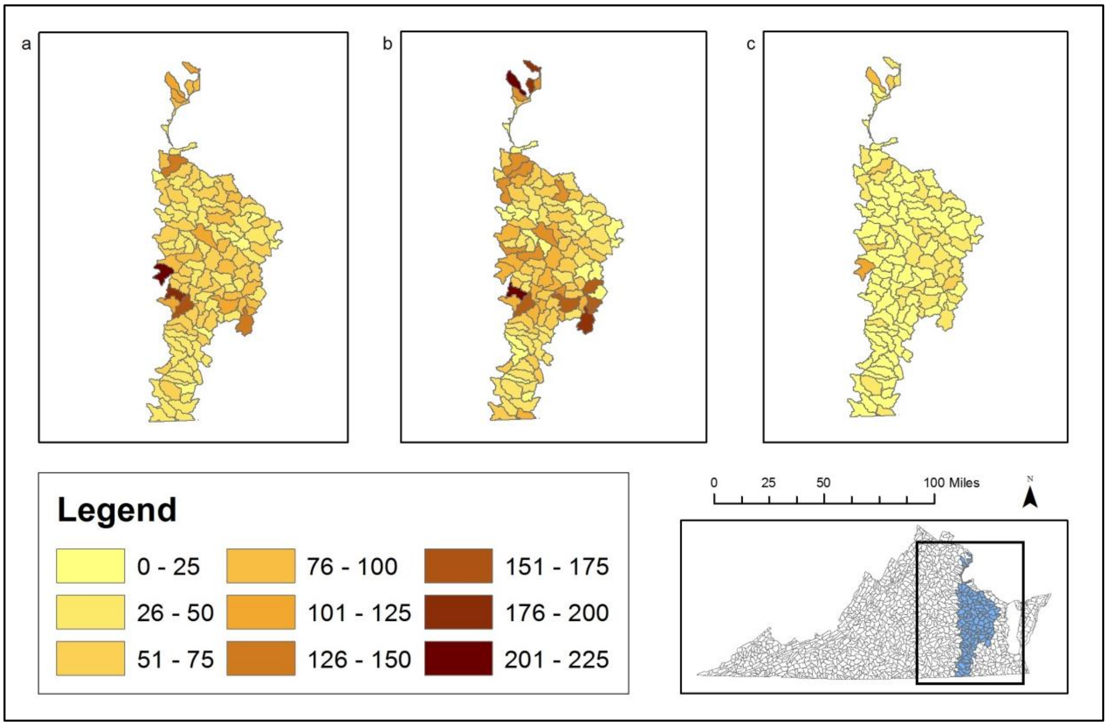
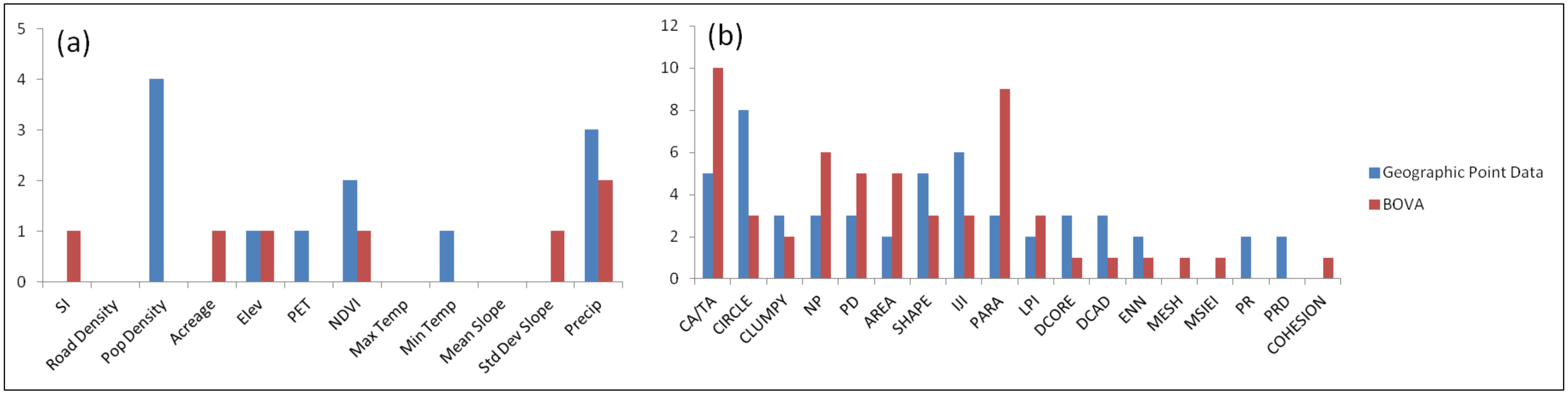


Figure 3.6. Frequency of (a) environmental variables and (b) class and landscape metrics in selected wildlife biodiversity models. Models were developed using best subset regression on all environmental and fragmentation variables for each 12-digit hydrologic unit in Virginia's seven ecoregions. Fragmentation variables were derived using FRAGSTATS (McGarigal et al. 2002) from 2001 National Land Cover Data (NLCD).



Discussion

The class metrics provide much better models for wildlife biodiversity than the landscape metrics or the environmental variables. Given the conceptual similarities between the class- and landscape-level fragmentation metrics, we were surprised to note the much better performance of the class metrics. Other studies reported similar findings for a variety of species (Cunningham and Johnson 2006; Magness et al. 2006; Westphal et al. 2003). The landscape metrics are also preferred to the environmental variables.

The combined models used slightly fewer variables than the class models, with a comparable fit to the alpha diversity values (Stein et al. 2012). However, the combined models are slightly more difficult to put into practice due to their aggregation of various types of variables. From solely a management perspective, the environmental variables are the best because they use the fewest number of variables. Although their model fit leaves room for improvement, the incorporation of additional environmental variables may be beneficial.

It is questionable whether the low effectiveness of the environmental variables at predicting biodiversity estimates is more of a statement on the efficacy of these particular variables or on the ability to match cross-taxonomic species richness. Numerous studies have proven the difficulty of choosing variables that are significant across taxa, and this study seems to reaffirm this notion. The issues of scale, varying inter-specific resource requirements, and habitat preferences add particular levels of complication in this arena (Lindenmayer et al. 2002). The large number of variables and their confluence are also difficult to interpret ecologically.

However, several studies have documented an impressive ability to predict species richness within particular guilds using highly detailed environmental characteristics. For instance, vertical structural complexity as determined from LiDAR data correlates significantly with avian richness in several study areas (Goetz et al. 2007). In addition, Caprio et al. (2009) achieved similar results in their analysis of birds and attributed them to the birds' preferences to individual tree characteristics rather than patch geometry. These results, in tandem with our own, may imply a direct relationship between the spatial resolution of the environmental variables and the efficacy of the wildlife biodiversity models, to a point. Another possibility is that we had not reached the optimal level of resolution with our environmental factors. Since the effectiveness of our models increased with the increasing resolution of our variables, perhaps we would have found a better relationship with biodiversity by using even more detailed variables. It is unclear whether these results are due to the actual species composition in Virginia or the bias of our wildlife data towards birds and other species which prefer higher resolution environmental data.

Even ignoring the ambitious goal of producing biodiversity estimates reflective of all wildlife, the watershed-level study areas make highly detailed habitat requirements difficult to encompass. Even such elements as soil series, slope, aspect, and elevation lose much meaning when averaged across the watershed. The only environmental variable to occur in multiple models was precipitation, and this was most likely due to its consistent values between the hydrologic units, given the relative similarity in climatic conditions across the state. For example, in some ecoregions, most or all of the hydrologic units have the same precipitation amount.

After accounting for these caveats, we find it remarkable that patterns can still be found in predictor variables as related to overarching wildlife biodiversity. In particular, total area or acreage was a commonly occurring variable amongst the environmental variables as well as the landscape fragmentation metrics. There are many studies in support of the species-area relationship (SAR) (Magurran 2005). From a mechanistic perspective, the relationship has been linked to immigration and extinction relations, levels of disturbance, and predation dynamics (MacArthur and Wilson 1967; Brose et al. 2004). In addition, many studies attribute SAR to the increase in habitat heterogeneity. Larger areas are more likely to encompass a greater amount of potential habitat and niches (Gaston and Blackburn 2000). Larger areas also have more energy, which increase species richness through a variety of ecological mechanisms (Honkanen et al. 2010). Thus, our results emphasizing the repeated importance of landscape area in nearly every ecosystem is well supported ecologically.

The relatively high recurrence rate of particular fragmentation metrics in the best subset regression models give credence to their use in biodiversity models. Particularly of note are PARA and CIRCLE, which occurred 12 and 11 times in both datasets, respectively. In addition, pasture was the most frequently occurring land cover class in the top combined models, occurring 8 times in the geographic point models and 15 times in the BOVA models. There are many reasons why pastures promote a diversity of species, and several studies also supporting the findings that species richness increases in lands with a relatively higher percentage of pastures (Stein et al. 2012, in review). The forested classes also performed well, with mixed and deciduous forests being a top contender in the geographic point and BOVA models; although not one of the three most common land cover classes, evergreen also occurred in the majority of ecoregional combined models. These results are consistent with the strong ecological role forests play for bird species in providing breeding habitat and food sources (Lindenmayer et al. 2002, Verner 1987).

Conclusions

There are many issues with our current data that could be improved upon in future research. Although our BOVA dataset was quite large, neither this nor the geographic point dataset likely offer a true representation of the wildlife alpha diversity in Virginia. With the BOVA data, we are unable to observe the precise observation points within the hydrologic units, but the inter-ecoregional trends are clear. Upon examining spatial trends across ecoregions, the absence of uniform sampling becomes apparent. With the geographic point data, the sampling patterns within hydrologic units and ecoregions show a lack of species observations in particular locations. In addition, the predominance of certain species and taxonomic groups (e.g. birds) is also readily apparent. The number of observations recorded within the hydrologic units and their respective geographic point alpha diversities expressed a relatively strong correlation, thus emphasizing the value of sufficient field observations. Similarly, the sampling scheme and documented sightings are by their very nature only evidence for the presence of these species. Species absence data would have provided us with much more information about habitat preferences and distribution, but unfortunately none was available at the state-wide, inter-taxonomic scale.

With a more detailed wildlife dataset, we recommend the addition of finer scale environmental variables. Karl et al. (2000) concluded that greater model complexity improved accuracy in relatively uniform areas, but finer resolution data become increasingly relevant in more heterogeneous landscapes. Although our division of the state into ecoregions was intended to increase homogeneity of study areas, there are still noticeable differences between hydrologic units within the ecoregions. More detailed information, such as canopy/understory structure, vegetation heights, aboveground biomass, isothermality, geology, and soil chemical properties all have potential for future wildlife species-habitat association studies (Goetz et al. 2007, Herkt 2007). A greater number of sampling units would also have been beneficial. Although the 12-digit hydrologic units provided 1248 sampling units, the need to divide the state into ecoregions led to some regions with fewer HUs than desired. For instance, the Central Appalachians region only had 43 HUs located completely within the ecoregional borders. This was especially problematic given our multitude of variables, for which more sampling units may have improved model fit.

Furthermore, the acquired data layers were not all taken from the same time period as the two wildlife datasets. Given the time difference between the datasets, it was difficult to pinpoint the ideal timeframe or year for the environmental data. The National Land Cover Dataset, which was used for the class and landscape fragmentation metrics, was based on 2001 Landsat imagery. The geographic point data were collected in 2007, and the BOVA data were collected during several decades surrounding the land cover data. Lastly, the fragmentation metrics are entirely dependent on the land cover data used. We chose the NLCD due to its relatively detailed categories and high accuracy; however, other classification schemes would have changed our results. The NLCD, with its default classes, had the unfortunate effect of having many HUs where one or more classes were missing. This led to very few sampling units being used for the multiple linear regressions for the class fragmentation models. However, the advantage is that it enabled us to draw the most specific hypotheses possible between wildlife and land cover.

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CHAPTER 4

Conclusion

Synthesis

Our research is a good first step towards learning about the drivers of wildlife biodiversity in Virginia. It offers an easily implementable method for estimating potential biodiversity by land use and hydrologic unit. We consider our ability to model wildlife biodiversity based on land cover class fragmentation a success. The models based on landscape-level fragmentation and the environmental variables were less successful, but still informative even despite the inherent difficulties of wildlife modeling. However, the relationships between the individual variables and the alpha diversity did not show any consistent or expected trends. The biodiversity literature reveals a variety of patterns in species richness observed at the local and global scales. Species richness tends to increase with greater area, precipitation, and evapotranspiration, and to decrease at higher elevations and latitudes. These relationships are a result of complex ecological processes that limit species distributions through physiological constraints, predator-prey dynamics, energy availability, and other mechanisms (Gaston 2000). These expected biodiversity trends were not clearly expressed in Virginia.

Data Issues

Despite these successes, the sampling methods in our datasets prevented us from reaching any strong inductive inferences about Virginia's species. There is no good way of dealing with the lack of species absence data, which is part of the reason we studied biodiversity at the hydrologic-unit level. In addition, the assumption that the count is equal to the actual alpha diversity supposes that all species in the field were detected in the surveys. This is highly unlikely in the case of the Biota of Virginia data, and blatantly untrue for the geographic point data. The geographic point data did not include any systematic sampling for any species, let alone all species. Thus, the alpha diversity estimates are far from complete. Some species which we know exist in great abundance are missing from the geographic point data. This latter omission is particularly interesting given as an unrealistically high proportion of included species are birds. This may be due to the many bird surveys conducted on a state-wise basis, as compared to surveys for the other taxonomic groups. With three times as many species recorded, the Biota of Virginia data helps to fill this gap in our knowledge through its much more comprehensive data. However, at the individual hydrologic unit-level, this dataset is also lacking since it is based on species-habitat associations rather than geographic coordinates.

The probability of detecting wildlife during surveys depends on a variety of factors. These variables can be divided into observer, environmental, and wildlife characteristics (Anderson 2001). Observer-related traits include the observers' experience level, training, education, health (i.e. eyesight and hearing capabilities), interest, and fatigue. The environmental variables include climatic traits (e.g. wind speed, temperature, precipitation, cloud cover), seasonal properties (time of sunrise, season and its phenology), and land cover characteristics (vegetation types, vegetation height and density, and landscape disturbances). The wildlife characteristics affecting detection are highly species-dependent, but include wildlife physical properties, behavior, sex, and calling patterns (Anderson 2001).

Some of these variables may explain why certain species were sighted far more often than others, both within and between hydrologic units. They may also clarify why pasture was such a prominent variable, even more so than several of the forest land cover classes. Pastures tend to have low-lying vegetation, which promote wildlife detection. There are good reasons as to why many species would spend time in pastures, but the ease of wildlife detection and abundance of pastureland in Virginia provide equally good explanations for the unusually high number of sightings.

The dynamic nature of these detection factors complicates our ability to disentangle the competing hypotheses from each other. A related issue is that we have no way to assess the accuracy of our population statistics (Anderson 2001). In addition, due to the lack of surveying across the entire region, we cannot definitively determine species habitat preferences, biodiversity hotspots, or species' distributions; all that can be concluded is that these species occur in habitats with these characteristics.

The Ideal Biodiversity Dataset

It is unrealistic to systematically sample all species in the whole state. One option would be to choose representative HUs per ecoregion for systematic sampling, with sample units selected probabilistically (Anderson 2001). Sampling should be conducted at multiple scales to account for distribution differences and potentially better spread out samples (Thompson 2004). Given the all-encompassing nature of biodiversity measurements, sampling designs should be tailored to specific taxa. Some birds and carnivores repeatedly return to the same breeding grounds, making them easier to census. It is also important to take into account the accessibility of sampling sites, to prevent an uneven distribution across land cover types. For example, although roads tend to be easier to sample than forests, sampling should be conducted in equal numbers or with equal frequency for both.

I recommend a stratified random sampling approach, with the stratification based on land use. This method has several advantages over other sampling procedures. Given homogenous sampling units within strata, the population mean estimate will have a lower standard error than with a similarly sized simple random sample. In addition, this technique helps to ensure the sampling effort will cover important subdivisions within the study area. Stratification may also be less expensive than the alternative sampling approaches and offer increased precision through the use of homogeneous strata (Morrison et al. 2001).

There are many field methods for counting wildlife species. Some of the most popular procedures for count measurements are capture-recapture, point counts, spot mapping, and transects (Morrison et al. 2001). The main criticism for applying these methods across large scales is their high costs in time and labor (Yoccoz et al. 2001). However, there are many types of technology that are used to identify or detect individuals. Some of the more common methods are radio or satellite telemetry, acoustical approaches, photo identification, camera traps, tags, or collars. Types of tags vary, but passive integrated transponders (PIT) and coded wires are used regularly (Thompson 2004). However, mark-recapture is impractical for a state-wide survey, more practical would be point counts, or spot counting, especially for insects. We would choose as many and as large of plots as possible within budget. For non-insect taxa, researchers face the difficulty of wildlife avoidance, which is why video cameras in opportunistic locations would be ideal. From a financial perspective, this method would also be the cheapest in terms of labor, while allowing constant surveillance. For rare and endangered species, we would use an adaptive sampling design, in which sampling intensity is contingent on the early sampling results. Recent studies have concluded that traditional sampling designs are inefficient for detecting rare and endangered species (Thompson 2004).

Given our large number of variables (greater than 500), I would recommend the use of many more sampling units in the future. Our recurring problem of having too many sampling units with missing data given the multitude of variables would have been ameliorated through a more substantial variable reduction procedure or a greater number of sampling units. The best way of reducing the number of variables would have been to use a different land cover classification scheme and/or merge land cover classes, but the National Land Cover Dataset seemed ideal for habitat information, in terms of its spatial resolution and specific classes.

Conclusions

Although the aforementioned sampling and statistical methods will greatly reduce the inaccuracies associated with our figures, error can never be completely eliminated due to the confluence of variables affecting detection. Wildlife monitoring programs can try their best to optimize sampling efforts, labor costs, time allocation, and other resources, but true wildlife population counts can never be validated. The estimates of greatest accuracy tend to incorporate detection probabilities with their count statistics, even when only a subsample of the area was surveyed (Yoccoz et al. 2001). For our research objectives, these measures would need to be done on a species-by-species basis. Such procedures would take a relatively large field crew a span of many months or years to span the entire state.

Despite these issues, this research has provided new insights on wildlife biodiversity in Virginia and their associated landscape characteristics. I have evaluated the effect of various types of fragmentation on wildlife alpha diversity across each of Virginia’s seven ecoregions, as well as other environmental variables. I determined which drivers are the most significant predictors for biodiversity, and I developed predictive models to forecast watershed alpha diversity based on various landscape properties. These models will serve as the mathematical basis for the aforementioned MEASURES biodiversity tool, thus providing valuable information to decision-makers in government, private landowners, and other stakeholders.

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APPENDIX A

Geographic Point Models Using Class Fragmentation Metrics by Ecoregion

Blue Ridge (108 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Low AREA	1	0.28	0.28	1.58	410.01	87.42
Low AREA, Pasture PD	2	0.39	0.38	1.46	394.20	60.08
Low AREA, Pasture NP, Pasture PD	3	0.47	0.46	1.37	381.74	41.51
Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY	4	0.51	0.49	1.34	376.66	34.23
Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY	5	0.53	0.51	1.30	372.85	28.97
Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY	6	0.55	0.52	1.29	371.06	26.28
Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY	7	0.57	0.54	1.26	368.08	22.46
Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY	8	0.59	0.55	1.24	366.58	20.36
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY	9	0.60	0.56	1.23	365.57	18.86
Deciduous PLAND, Deciduous PARA, Deciduous CIRCLE, Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY	10	0.61	0.57	1.22	364.34	17.20
Deciduous PARA, Deciduous CIRCLE, Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY	11	0.62	0.58	1.21	365.43	17.78
Deciduous PARA, Deciduous CIRCLE, Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, Open IJI	12	0.64	0.59	1.19	363.46	15.52
Deciduous PLAND, Deciduous PLADJ, Deciduous NLSI, Crops SHAPE, Evergreen IJI, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD,	13	0.64	0.59	1.19	364.19	15.75

Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, Open IJI						
Deciduous PLAND, Deciduous PARA, Deciduous CIRCLE, Deciduous NLSI, Crops SHAPE, Evergreen IJI, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, Open IJI	14	0.65	0.60	1.18	364.44	15.55
Deciduous PLAND, Deciduous PARA, Deciduous CIRCLE, Deciduous PLADJ, Deciduous NLSI, Crops SHAPE, Evergreen IJI, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, Open IJI	15	0.66	0.60	1.17	364.49	15.19
Deciduous PLAND, Deciduous PARA, Deciduous CIRCLE, Deciduous PLADJ, Deciduous NLSI, Crops SHAPE, Evergreen TCA, Evergreen IJI, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, Open IJI	16	0.66	0.60	1.18	367.16	17.00

Central Appalachians (30 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Deciduous CA	1	0.24	0.21	1.93	129.33	10.30
Deciduous CA, Mixed Forest LPI	2	0.43	0.39	1.69	123.11	2.99
Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI	3	0.53	0.48	1.57	120.35	0.35
Deciduous CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI	4	0.59	0.52	1.50	119.70	-0.31
Deciduous CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Pasture CIRCLE	5	0.63	0.56	1.44	119.51	-0.55
Deciduous CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Pasture CIRCLE, Medium CIRCLE	6	0.67	0.58	1.41	120.44	-0.13
Open Water NP, Low CA, Mixed Forest LPI, Low CIRCLE, Pasture IJI, Open Water IJI, Medium CIRCLE	7	0.69	0.60	1.37	121.87	0.50
Open CA, Open LPI, Mixed Forest LPI, Medium CA, Low CIRCLE, Pasture IJI, Open Water IJI, Medium CIRCLE	8	0.73	0.62	1.33	123.06	0.95
Deciduous CA, Open LPI, Evergreen CIRCLE, Mixed Forest LPI, Medium CA, Low CIRCLE, Pasture IJI, Open Water IJI, Medium CIRCLE	9	0.75	0.63	1.31	126.03	2.07

Open Water NP, Open CA, Open LPI, Evergreen CIRCLE, Mixed Forest LPI, Medium CA, Low CIRCLE, Pasture IJI, Open Water IJI, Medium CIRCLE	10	0.76	0.63	1.32	130.32	3.52
Open Water NP, Low CA, Evergreen CIRCLE, Mixed Forest LPI, Deciduous SHAPE, Low CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Open Water IJI, Medium CIRCLE	11	0.77	0.62	1.33	135.51	5.06
Open Water NP, Low CA, Evergreen IJI, Mixed Forest LPI, Deciduous SHAPE, Low CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	12	0.78	0.62	1.34	141.59	6.64
Open Water NP, Low CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Deciduous SHAPE, Low CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE,	13	0.79	0.61	1.35	148.61	8.20
Open Water NP, Open CA, Open LPI, Low CA, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Pasture CIRCLE, Pasture IJI, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	14	0.79	0.60	1.37	157.29	9.91
Deciduous CA, Open Water NP, Open CA, Open LPI, Low CA, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Pasture CIRCLE, Pasture IJI, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	15	0.80	0.58	1.40	167.46	11.59
Deciduous CA, Open Water NP, Open CA, Open LPI, Low CA, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Low AREA, Pasture CIRCLE, Pasture IJI, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	16	0.80	0.56	1.44	179.99	13.38
Deciduous CA, Open Water NP, Open CA, Open LPI, Low CA, Evergreen IJI, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Low AREA, Pasture CIRCLE, Pasture IJI, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	17	0.80	0.53	1.49	195.50	15.29
Deciduous CA, Open Water NP, Open CA, Low CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Low AREA, Pasture CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	18	0.81	0.49	1.54	214.40	17.15
Deciduous CA, Open Water NP, Open CA, Low CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Open Water CIRCLE, Low AREA, Pasture CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE,	19	0.81	0.45	1.61	238.27	19.06

Deciduous CA, Open Water NP, Open CA, Open LPI, Low CA, Evergreen CIRCLE, Evergreen IJI, Mixed Forest LPI, Medium CA, Deciduous SHAPE, Low CIRCLE, Open Water CIRCLE, Low AREA, Pasture CIRCLE, Pasture IJI, Pasture AREA, Mixed Forest PD, Low IJI, Open Water IJI, Medium CIRCLE	20	0.81	0.39	1.69	269.13	21.00

Middle Atlantic Coastal Plains (118 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open CA	1	0.15	0.14	1.12	366.84	84.33
Crops NP, Evergreen IJI	2	0.21	0.20	1.09	360.13	71.99
Deciduous CA, Deciduous SHAPE Evergreen IJI	3	0.27	0.26	1.05	352.53	59.36
Deciduous CA, Deciduous SHAPE Evergreen IJI, Pasture IJI	4	0.33	0.30	1.01	345.93	49.16
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen IJI, Pasture IJI	5	0.37	0.34	0.98	340.13	40.77
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen IJI, Pasture IJI, Open CA	6	0.40	0.37	0.96	336.19	35.22
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture IJI	7	0.43	0.39	0.95	333.20	31.06
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture IJI	8	0.46	0.42	0.93	329.33	26.19
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI	9	0.47	0.43	0.92	328.68	24.93
Deciduous CA, Deciduous SHAPE Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA	10	0.49	0.44	0.91	328.00	23.68
Deciduous CA, Deciduous SHAPE Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA	11	0.52	0.47	0.88	322.70	18.00
Deciduous CA, Deciduous SHAPE Deciduous CIRCLE Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA	12	0.53	0.48	0.88	322.87	17.74

Deciduous CA, Deciduous SHAPE Deciduous CIRCLE Crops NP, Crops AREA, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA	13	0.55	0.49	0.87	321.26	15.87
Deciduous CA, Deciduous SHAPE Deciduous CIRCLE Crops NP, Crops AREA, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Open Water NP, Pasture AREA, Pasture IJI, Open CA	14	0.56	0.50	0.86	320.70	15.00

Northern Piedmont (123 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Medium DCORE	1	0.13	0.12	0.91	331.01	77.41
Medium DCORE, Open CA	2	0.20	0.19	0.88	322.41	62.98
Medium DCORE, Open CA, Open IJI	3	0.26	0.25	0.85	314.25	50.48
Deciduous CA, Medium DCORE, Open CA, Open IJI	4	0.29	0.27	0.83	311.72	46.22
Deciduous CA, Medium DCORE, Open CA, Open AREA, Open IJI	5	0.33	0.30	0.81	306.82	39.23
Deciduous CA, Evergreen PD, Medium DCORE, Open Water NP, Pasture ED, Open CA	6	0.35	0.32	0.80	305.20	36.53
Deciduous CA, Evergreen PD, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA	7	0.38	0.34	0.79	302.32	32.50
Deciduous CA, Evergreen PD, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA	8	0.40	0.36	0.78	300.92	30.29
Deciduous CA, Evergreen PARA, Evergreen IJI, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	9	0.42	0.38	0.77	298.32	26.88
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	10	0.44	0.39	0.76	296.40	24.34
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	11	0.46	0.41	0.75	294.71	22.14
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Open Water NP, Pasture NP, Pasture ED, Open CA,	12	0.47	0.41	0.75	294.93	21.86

Open AREA, Open IJI						
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	13	0.49	0.42	0.74	294.38	20.86
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Mixed Forest AREA, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	14	0.49	0.43	0.74	295.13	21.09
Deciduous CA, Deciduous SHAPE, Evergreen PD, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	15	0.50	0.43	0.74	296.63	21.98
Deciduous CA, Deciduous GYRATE, Deciduous SHAPE, Deciduous CIRCLE, Evergreen PD, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	16	0.51	0.43	0.73	296.90	21.73
Deciduous CA, Deciduous GYRATE, Deciduous SHAPE, Deciduous CIRCLE, Evergreen PD, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	17	0.52	0.45	0.73	296.06	20.50
Deciduous CA, Deciduous GYRATE, Deciduous SHAPE, Deciduous CIRCLE, Evergreen PD, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Mixed Forest AREA, Open Water CA, Open Water NP, Open Water PARA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI	18	0.54	0.46	0.72	294.84	19

Piedmont (334 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Evergreen NP	1	0.17	0.17	0.70	708.93	143.09
Deciduous CA, Pasture PARA	2	0.26	0.26	0.66	673.45	94.81
Deciduous CA, Pasture PARA, Open NP	3	0.32	0.31	0.63	647.57	62.88

Deciduous CA, Pasture PARA, Open NP, Open LPI	4	0.34	0.33	0.62	639.35	53.08
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Open NP, Open LPI	5	0.36	0.35	0.61	630.45	42.88
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Open NP, Open LPI, Woody Wetlands NP	6	0.37	0.36	0.61	625.82	37.60
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP	7	0.38	0.37	0.61	624.34	35.77
Deciduous CA, Evergreen CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP	8	0.39	0.37	0.60	621.91	32.98
Deciduous CA, Evergreen CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE	9	0.40	0.38	0.60	619.81	30.58
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE	10	0.40	0.39	0.60	617.84	28.35
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	11	0.41	0.39	0.59	614.83	25.12
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	12	0.42	0.40	0.59	613.01	23.13
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	13	0.43	0.40	0.59	611.42	21.40
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Pasture IJI, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	14	0.43	0.41	0.59	611.43	21.25
Deciduous CA, Evergreen CIRCLE, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Pasture IJI, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	15	0.43	0.41	0.59	612.04	21.69

Deciduous CA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	16	0.44	0.41	0.59	611.62	21.13
Deciduous CA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Pasture IJI, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	17	0.44	0.41	0.59	611.83	21.17
Deciduous NP Evergreen CA, Evergreen NP, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	18	0.44	0.41	0.58	612.48	21.64
Deciduous CA, Deciduous NP Evergreen CA, Evergreen NP, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	19	0.45	0.41	0.58	612.31	21.32
Deciduous CA, Deciduous NP Evergreen CA, Evergreen NP, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest IJI, Open Water CIRCLE, Low CIRCLE, Low IJI, Pasture PARA, Pasture CLUMPY, Pasture IJI, Open NP, Open LPI, Open DCORE, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA	20	0.45	0.42	0.58	612.14	21.00

Ridge & Valley (271 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Deciduous CA	1	0.19	0.22	0.35	197.86	126.64
Deciduous CA, Low CA	2	0.29	0.31	0.32	164.45	80.35
Deciduous CA, Evergreen PD, Low CA	3	0.34	0.34	0.31	146.08	57.25

Deciduous CA, Deciduous DCAD, Evergreen PD, Low CA	4	0.38	0.36	0.31	132.77	41.56
Deciduous CA, Deciduous DCAD, Evergreen PD, Low CA, Pasture CIRCLE	5	0.39	0.37	0.30	129.97	38.13
Deciduous CA, Deciduous DCAD, Evergreen PD, Low CA, Pasture CIRCLE, Pasture IJI	6	0.39	0.38	0.30	128.96	36.71
Deciduous CA, Crops IJI, Mixed Forest GYRATE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	7	0.41	0.38	0.30	125.96	33.19
Deciduous CA, Deciduous DCAD, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE	8	0.42	0.39	0.30	122.74	29.53
Deciduous CA, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	9	0.43	0.40	0.29	119.63	26.08
Deciduous CA, Deciduous DCAD, Deciduous CLUMPY, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE	10	0.44	0.41	0.29	116.43	22.62
Deciduous CA, Deciduous DCAD, Deciduous CLUMPY, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	11	0.44	0.41	0.29	115.94	21.93
Deciduous CA, Deciduous DCAD, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	12	0.46	0.42	0.29	112.38	18.25
Deciduous CA, Deciduous DCAD, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD, Pasture IJI	13	0.46	0.42	0.29	112.03	17.75
Deciduous CA, Deciduous DCAD, Deciduous IJI, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD, Pasture IJI	14	0.47	0.42	0.29	112.58	18.10
Deciduous CA, Deciduous SHAPE, Deciduous PARA, Deciduous DCAD, Deciduous CLUMPY, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD	15	0.47	0.42	0.29	113.36	18.68
Deciduous CA, Deciduous SHAPE, Deciduous PARA, Deciduous DCAD, Deciduous CLUMPY, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed	16	0.47	0.42	0.29	113.73	18.85

Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD, Pasture IJI						
Deciduous CA, Deciduous SHAPE, Deciduous PARA, Deciduous DCAD, Deciduous CLUMPY, Deciduous IJI, Crops CA, Crops PD, Crops IJI, Evergreen PD, Mixed Forest GYRATE, Mixed Forest DCORE, Mixed Forest CLUMPY, Low CA, Pasture CIRCLE, Pasture DCAD, Pasture IJI	17	0.48	0.43	0.29	113.00	18.00

Southeastern Plains (118 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open Water NP	1	0.20	0.20	2.25	529.91	181.91
Deciduous AREA Open Water NP	2	0.29	0.27	2.13	519.15	153.25
Deciduous AREA Barren PARA, Open Water NP	3	0.36	0.34	2.03	508.88	128.68
Deciduous AREA Emergent IJI, Barren PARA, Open Water NP	4	0.42	0.40	1.93	498.25	106.06
Deciduous AREA Emergent PD, Emergent IJI, Barren PARA, Open Water NP	5	0.49	0.47	1.82	485.69	82.79
Deciduous AREA Emergent PD, Emergent CIRCLE, Emergent IJI, Barren PARA, Open Water NP	6	0.52	0.49	1.78	481.26	74.32
Deciduous AREA Emergent PD, Emergent CIRCLE, Emergent IJI, Barren PARA, Mixed Forest LPI, Open Water NP	7	0.55	0.52	1.74	476.57	66.00
Deciduous AREA Emergent PD, Emergent IJI, Barren PARA, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD	8	0.58	0.55	1.67	469.04	54.46
Deciduous AREA Emergent PD, Emergent CIRCLE, Emergent IJI, Barren PARA, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD	9	0.61	0.58	1.63	464.26	47.30
Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Barren PARA, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD	10	0.62	0.59	1.61	462.97	44.72
Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD	11	0.64	0.60	1.59	461.00	41.46

Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE	12	0.65	0.61	1.56	458.22	37.45
Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE	13	0.67	0.63	1.53	455.68	33.90
Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture DCAD	14	0.68	0.64	1.51	452.73	30.13
Deciduous AREA Crops CIRCLE, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture DCAD	15	0.69	0.65	1.49	452.07	28.78
Deciduous AREA Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture DCAD, Pasture IJI	16	0.70	0.65	1.48	452.22	28.24
Deciduous AREA Crops NP, Crops CIRCLE, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren CA, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture DCAD	17	0.71	0.66	1.46	451.12	26.55
Deciduous AREA Crops NP, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren CA, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture DCAD, Pasture IJI	18	0.72	0.67	1.45	449.75	24.68
Deciduous AREA Crops NP, Crops CIRCLE, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren CA, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture DCAD, Pasture IJI	19	0.73	0.68	1.42	448.15	22.71

Deciduous AREA Crops NP, Crops CIRCLE, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren CA, Barren LPI, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture DCAD, Pasture IJI	20	0.74	0.69	1.41	446.75	21.00

APPENDIX B

Selected Geographic Point Models Using Class Fragmentation Metrics by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Sq Rt Alpha = 22.08 – 8.38 Deciduous NLSI – 2.94 Crops SHAPE, -0.89 Mixed Forest AREA + 0.36 Low AREA + 0.01 Pasture NP – 1.05 Pasture PD + 3.77 Pasture SHAPE – 0.66 Pasture DCAD – 17.05 Pasture CLUMPY	9	108	0.60	0.56	365.57	18.86
Central Appalachians	Sq Rt Alpha = -15.27 + 0.00 Deciduous CA + 27.00 Evergreen CIRCLE + 3.59 Mixed Forest LPI	3	30	0.53	0.48	120.35	0.35
Middle Atlantic Coastal Plain	Cube Rt Alpha = 12.97 + 0.00 Deciduous CA – 2.82 Deciduous SHAPE – 0.00 Crops NP + 0.08 Crops IJI + 0.00 Evergreen CA – 0.30 Evergreen AREA – 14.38 Evergreen CIRCLE + 0.07 Evergreen IJI + 0.09 Pasture AREA – 0.09 Pasture IJI + 0.00 Open CA	11	118	0.52	0.47	322.70	18.00
Northern Piedmont	Cube Rt Alpha = 7.85 + 0.00 Deciduous CA – 1.40 Evergreen SHAPE – 0.00 Evergreen PARA + 0.03 Evergreen IJI + 1.10 Medium DCORE + 0.00 Open Water CA – 0.00 Pasture NP + 0.02 Pasture ED + 0.00 Open CA – 0.22 Open AREA – 0.03 Open IJI	11	123	0.46	0.41	294.71	22.14
Piedmont	Cube Rt Alpha = -7.99 + 0.00 Deciduous CA + 9.36 Evergreen CIRCLE + 1.73 Open Water CIRCLE + 2.10 Low CIRCLE + 0.01 Low IJI + 0.00 Pasture PARA + 1.90 Pasture CLUMPY + 0.00 Open NP + 0.09 Open LPI + 0.00 Woody Wetlands NP – 0.59 Woody Wetlands SHAPE – 0.00 Woody Wetlands PARA	12	334	0.42	0.40	613.01	23.13
Ridge & Valley	4.5th Rt Alpha = 3.64 + 6.96E-5 Deciduous CA + 0.08 Deciduous DCAD + 0.00 Crops CA – 0.13 Crops PD + 0.01 Crops IJI – 0.04 Evergreen PD + 0.02 Mixed Forest GYRATE + 0.20 Mixed Forest DCORE – 1.82 Mixed	12	271	0.46	0.42	112.38	18.25

	Forest CLUMPY + 0.00 Low CA – 2.86 Pasture CIRCLE + 0.07 Pasture DCAD						
Southeastern Plains	Sq Rt Alpha = -56.39 – 0.06 Deciduous AREA + 0.00 Crops NP + 28.16 Crops CIRCLE – 1.87 Emergent PD – 5.44 Emergent SHAPE + 23.47 Emergent CIRCLE – 0.10 Emergent IJI + 0.44 Evergreen PD – 0.00 Barren CA + 0.01 Barren PARA – 9.82 Medium CIRCLE – 16.14 Mixed Forest LPI + 22.56 Mixed Forest CLUMPY + 0.10 Open Water NP + 6.94 Open Water DCAD – 0.02 Open Water IJI + 46.98 Pasture CIRCLE – 0.95 Pasture DCAD + 0.08 Pasture IJI	19	118	0.73	0.68	1.42	448.15

APPENDIX C

Geographic Point Class Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.035, >0.150	182.05
Central Appalachians	0.106, >0.150	100.94
Middle Atlantic Coastal Plains	0.078, 0.065	120.89
Northern Piedmont	0.051, >0.150	96.50
Piedmont	0.055, 0.019	121.46
Ridge & Valley	0.058, 0.034	23.95
Southeastern Plains	0.037, >0.150	298.50

APPENDIX D

BOVA Models Using Class Fragmentation Metrics by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (109 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pasture PARA	1	0.18	0.17	0.15	-94.42	75.22
Pasture SHAPE, Pasture PARA	2	0.28	0.26	0.15	-106.27	55.49
Pasture SHAPE, Pasture PARA, Open IJI	3	0.33	0.31	0.14	-112.71	45.41
Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	4	0.42	0.40	0.13	-126.43	27.47
Mixed Forest CA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	5	0.44	0.42	0.13	-128.20	24.84
Crops LPI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	6	0.47	0.44	0.13	-132.09	20.09
Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	7	0.50	0.47	0.12	-136.21	15.43
Crops LPI, Evergreen TCA, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	8	0.52	0.48	0.12	-136.85	14.42
Crops LPI, Evergreen TCA, Evergreen IJI, Mixed Forest CA, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open IJI	9	0.53	0.49	0.12	-137.90	13.06
Crops LPI, Evergreen TCA, Evergreen IJI, Mixed Forest CA, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open PD, Open IJI	10	0.54	0.49	0.12	-136.95	13.60
Crops LPI, Evergreen TCA, Evergreen IJI, Mixed Forest CA, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open PD, Open AREA, Open IJI	11	0.55	0.49	0.12	-135.87	14.22
Crops LPI, Evergreen TCA, Evergreen IJI, Mixed Forest CA, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open PLAND, Open PD, Open AREA, Open IJI	12	0.56	0.51	0.12	-136.83	13.00

Central Appalachians (24 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open CA	1	0.32	0.29	3.60	134.76	-4.67
Open Water PARA, Open CA	2	0.47	0.41	3.27	131.81	-5.99
Open Water PARA, Deciduous AREA, Open CA	3	0.53	0.46	3.14	131.99	-5.42
Open Water PARA, Deciduous AREA, Open CA, Open LPI	4	0.58	0.49	3.06	133.06	-4.48
Open Water PARA, Deciduous AREA, Mixed Forest CA, Open CA, Open LPI	5	0.65	0.56	2.84	132.30	-4.21
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Mixed Forest CA, Open CA, Open LPI	6	0.70	0.59	2.73	133.58	-3.22
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Pasture CA, Mixed Forest CA, Open CA, Open LPI	7	0.73	0.61	2.67	136.37	-1.88
Open Water PARA, Deciduous AREA, Mixed Forest CA, Open IJI, Open CA, Open LPI, Crops SHAPE, Deciduous GYRATE	8	0.76	0.63	2.61	139.74	-0.53
Open Water PARA, Deciduous AREA, Mixed Forest CA, Barren IJI, Open CA, Open LPI, Medium CA, Crops SHAPE, Deciduous GYRATE	9	0.78	0.63	2.58	144.71	1.01
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Pasture CA, Mixed Forest CA, Open IJI, Open CA, Open LPI, Crops SHAPE, Deciduous GYRATE	10	0.79	0.63	2.58	151.30	2.65
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Mixed Forest CA, Barren IJI, Deciduous IJI, Open CA, Open LPI, Low CA, Crops SHAPE, Deciduous GYRATE	11	0.81	0.63	2.58	159.45	4.30
Open Water PARA, Deciduous AREA, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Open LPI, Low CA, Medium CA, Crops SHAPE, Crops CA, Deciduous GYRATE	12	0.82	0.62	2.62	170.34	6.06
Open Water PARA, Deciduous AREA, Evergreen IJI, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Low CA, Medium CA, Crops SHAPE, Crops CA	13	0.82	0.59	2.73	185.26	7.99
Open Water PARA, Deciduous AREA, Evergreen IJI, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Open CA, Open LPI, Low CA, Medium CA, Crops SHAPE, Crops CA, Deciduous GYRATE	14	0.83	0.57	2.80	203.71	9.79

Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Low CA, Medium CA, Crops SHAPE, Crops CA	15	0.84	0.53	2.91	229.04	11.64
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture IJI, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Low CA, Medium CA, Crops SHAPE, Crops CA	16	0.85	0.50	3.02	264.37	13.42
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture IJI, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Open Water NP, Low CA, Medium CA, Crops SHAPE, Crops CA	17	0.86	0.45	3.16	318.03	15.21
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture IJI, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Open Water NP, Low CA, Medium CA, Crops SHAPE, Crops CA, Deciduous GYRATE	18	0.87	0.38	3.36	408.57	17.02
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture IJI, Pasture AREA, Pasture CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Open Water NP, Low CA, Medium CA, Crops SHAPE, Crops CA, Deciduous GYRATE	19	0.87	0.23	3.74	592.46	19.01
Open Water PARA, Mixed Forest IJI, Deciduous AREA, Evergreen IJI, Pasture IJI, Pasture AREA, Pasture CA, Mixed Forest CA, Evergreen CA, Barren IJI, Open IJI, Deciduous IJI, Open CA, Open LPI, Open Water NP, Low CA, Medium CA, Crops SHAPE, Crops CA, Deciduous GYRATE	20	0.87	-0.02	4.32	1144.41	21.00

Middle Atlantic Coastal Plain (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pasture PARA	1	0.28	0.28	15489045.00	4282.14	146.22
Deciduous LPI, Pasture PARA	2	0.37	0.36	14554932.00	4268.46	115.69
Deciduous PD, Evergreen IJI, Pasture IJI	3	0.43	0.42	13893383.00	4258.54	95.58
Deciduous PD, Crops CA, Evergreen IJI, Pasture PARA	4	0.49	0.47	13285867.00	4249.08	78.27
Deciduous PD, Crops CA, Evergreen IJI, Pasture PARA,	5	0.52	0.50	12871337.00	4242.74	67.22

Pasture IJI						
Deciduous PD, Crops CA, Evergreen IJI, Pasture CA, Pasture AREA, Pasture PARA	6	0.54	0.52	12644181.00	4239.75	61.64
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Evergreen IJI, Pasture PARA, Pasture IJI	7	0.57	0.54	12335488.00	4235.14	54.19
Deciduous PD, Crops CA, Crops AREA, Evergreen IJI, Low CA, Pasture CA, Pasture AREA, Pasture IJI	8	0.59	0.56	12020571.00	4230.29	46.92
Deciduous CA, Deciduous PD, Deciduous LPI, Crops CA, Evergreen IJI, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA	9	0.62	0.59	11711002.00	4225.43	40.12
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Pasture CA, Pasture IJI	10	0.64	0.60	11465946.00	4221.77	35.14
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen IJI, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	11	0.66	0.63	11096654.00	4215.40	27.62
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen IJI, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	12	0.68	0.64	10846799.00	4211.43	23.06
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	13	0.69	0.65	10738073.00	4210.53	21.67
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Mixed Forest IJI, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	14	0.70	0.66	10610317.00	4209.21	19.96
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Mixed Forest IJI, Low CA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	15	0.71	0.67	10504614.00	4208.41	18.77

Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Mixed Forest IJI, Open Water LSI, Low CA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI	16	0.72	0.68	10365998.00	4206.87	17.00

Northern Piedmont (122 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Low CA	1	0.23	0.23	0.00	-1129.38	85.10
Pasture CLUMPY, Open AREA	2	0.29	0.28	0.00	-1137.15	71.27
Open Water CA, Low CA, Open AREA	3	0.37	0.36	0.00	-1149.80	51.84
Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA	4	0.42	0.40	0.00	-1155.88	42.94
Medium CA, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA	5	0.45	0.43	0.00	-1161.47	35.29
Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA	6	0.48	0.46	0.00	-1166.79	28.50
Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA	7	0.52	0.49	0.00	-1173.03	21.25
Deciduous CIRCLE, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA	8	0.54	0.51	0.00	-1175.80	17.98
Deciduous CIRCLE, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY	9	0.56	0.52	0.00	-1177.94	15.52
Deciduous CIRCLE, Crops CLUMPY, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY	10	0.57	0.53	0.00	-1178.92	14.25
Deciduous CIRCLE, Crops CLUMPY, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, Open AREA	11	0.58	0.53	0.00	-1178.22	14.57
Deciduous CIRCLE, Crops CLUMPY, Evergreen PARA, Medium CA,	12	0.58	0.53	0.00	-1177.04	15.30

Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, Open AREA						
Deciduous CIRCLE, Crops CLUMPY, Evergreen SHAPE, Evergreen PARA, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, Open AREA	13	0.59	0.54	0.00	-1178.11	14.00

Piedmont (339 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Woody Wetlands NP	1	0.22	0.22	0.13	-404.22	93.30
Pasture PARA, Woody Wetlands NP	2	0.26	0.26	0.13	-419.68	73.74
Evergreen PD, Pasture PARA, Woody Wetlands NP	3	0.28	0.28	0.13	-427.62	63.92
Evergreen PD, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI	4	0.30	0.29	0.13	-434.39	55.75
Evergreen PD, Evergreen CIRCLE, Mixed Forest CIRCLE, Woody Wetlands NP, Woody Wetlands IJI	5	0.32	0.31	0.12	-440.73	48.31
Evergreen PD, Evergreen CIRCLE, Mixed Forest CIRCLE, Low IJI, Woody Wetlands NP, Woody Wetlands IJI	6	0.33	0.32	0.12	-443.11	45.39
Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI	7	0.34	0.33	0.12	-448.36	39.43
Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Low IJI, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI	8	0.35	0.34	0.12	-450.60	36.80
Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Low IJI, Pasture PARA, Open CA, Woody Wetlands NP, Woody Wetlands IJI	9	0.36	0.34	0.12	-453.35	33.67
Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Woody Wetlands NP, Woody Wetlands IJI	10	0.37	0.35	0.12	-456.23	30.48
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Low IJI, Pasture PARA, Open CA, Woody Wetlands NP, Woody Wetlands IJI	11	0.38	0.36	0.12	-459.79	26.66

Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Woody Wetlands NP, Woody Wetlands IJI	12	0.39	0.37	0.12	-463.84	22.44
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	13	0.40	0.38	0.12	-465.85	20.31
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	14	0.41	0.38	0.12	-468.01	18.07
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	15	0.41	0.39	0.12	-468.63	17.35
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen PD, Evergreen AREA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	16	0.42	0.39	0.12	-469.03	16.84
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen PD, Evergreen AREA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	17	0.42	0.39	0.12	-468.46	17.25
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen PD, Evergreen AREA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open NP, Open PD, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	18	0.42	0.39	0.12	-466.99	18.51
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen PD, Evergreen AREA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI,	19	0.42	0.39	0.12	-465.54	19.74

Pasture PARA, Open CA, Open NP, Open PD, Open LPI, Woody Wetlands NP, Woody Wetlands IJI						
Deciduous SHAPE, Deciduous PARA, Crops DCORE, Evergreen NP, Evergreen PD, Evergreen AREA, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest PD, Mixed Forest PARA, Mixed Forest CIRCLE, Open Water CLUMPY, Low IJI, Pasture PARA, Open CA, Open NP, Open PD, Open LPI, Woody Wetlands NP, Woody Wetlands IJI	20	0.42	0.39	0.12	-464.04	21.00

Ridge & Valley (290 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Evergreen PARA	1	0.26	0.26	0.00	-2876.16	122.65
Evergreen PARA, Pasture NP	2	0.37	0.36	0.00	-2918.82	66.25
Evergreen PARA, Pasture NP, Open PARA	3	0.39	0.38	0.00	-2926.56	56.60
Deciduous NP, Evergreen PARA, Pasture NP, Open CA	4	0.42	0.41	0.00	-2937.87	43.32
Deciduous CA, Deciduous NP, Evergreen PARA, Pasture NP, Open CA	5	0.43	0.42	0.00	-2940.89	39.66
Deciduous CA, Deciduous NP, Evergreen PARA, Pasture NP, Pasture IJI, Open CA	6	0.44	0.42	0.00	-2942.88	37.20
Deciduous NP, Crops NP, Crops PD, Evergreen PARA, Pasture CA, Pasture NP, Open CA	7	0.45	0.43	0.00	-2945.63	33.97
Deciduous NP, Crops NP, Crops PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Open CA	8	0.46	0.44	0.00	-2949.11	30.06
Deciduous NP, Crops NP, Crops PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Open CA, Open PARA	9	0.47	0.45	0.00	-2951.89	26.95
Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture IJI, Open CA	10	0.48	0.46	0.00	-2957.73	20.86
Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture IJI, Open CA, Open PARA	11	0.49	0.47	0.00	-2960.66	17.79
Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD,	12	0.49	0.47	0.00	-2961.00	17.31

Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Pasture IJI, Open CA, Open PARA						
Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA, Open PARA	13	0.50	0.47	0.00	-2961.87	16.32
Deciduous CA, Deciduous NP, Deciduous IJI, Crops NP, Crops PD, Evergreen PD, Evergreen PARA, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA, Open PARA	14	0.50	0.48	0.00	-2963.12	15.00

Southeastern Plains (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Evergreen IJI	1	0.26	0.26	6.41	784.12	61.82
Evergreen IJI, Medium IJI	2	0.29	0.28	6.31	781.53	56.92
Deciduous PARA, Evergreen IJI, Medium IJI	3	0.32	0.30	6.23	779.56	53.10
Crops NP, Evergreen NP, Evergreen IJI, Pasture PD	4	0.34	0.31	6.17	778.49	50.62
Crops NP, Evergreen NP, Evergreen IJI, Pasture PD, Pasture AREA	5	0.36	0.33	6.08	776.09	46.50
Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Pasture PD, Pasture AREA	6	0.38	0.35	6.02	774.98	44.16
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Open Water NP, Pasture PD, Pasture AREA	7	0.40	0.36	5.95	773.42	41.35
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PARA, Barren CIRCLE, Pasture PD, Pasture AREA	8	0.42	0.37	5.89	772.59	39.50
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PARA, Barren CIRCLE, Medium IJI, Pasture PD, Pasture AREA	9	0.43	0.39	5.83	771.40	37.29
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Low CA, Pasture PD, Pasture LPI, Pasture AREA	10	0.45	0.40	5.76	769.75	34.65
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PARA, Barren CIRCLE, Medium IJI, Open Water SHAPE, Low CA, Pasture PD, Pasture AREA	11	0.47	0.42	5.68	767.81	31.80

Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Open Water SHAPE, Low CA, Pasture PD, Pasture LPI, Pasture AREA	12	0.49	0.43	5.60	766.20	29.42
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Open Water SHAPE, Low CA, Pasture PD, Pasture LPI, Pasture AREA	13	0.51	0.45	5.52	763.93	26.49
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PARA, Barren CIRCLE, Barren IJI, Medium IJI, Open Water NP, Open Water SHAPE, Open Water PARA, Low CA, Pasture PD, Pasture AREA	14	0.53	0.46	5.46	762.91	24.90
Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Mixed Forest GYRATE, Mixed Forest PARA, Open Water SHAPE, Low CA, Pasture PD, Pasture LPI, Pasture AREA	15	0.54	0.48	5.39	761.58	23.09
Deciduous AREA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Mixed Forest GYRATE, Mixed Forest PARA, Open Water NP, Open Water SHAPE, Low CA, Pasture PD, Pasture LPI, Pasture AREA	16	0.55	0.48	5.35	761.55	22.52
Deciduous AREA, Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Mixed Forest GYRATE, Mixed Forest PARA, Open Water NP, Open Water SHAPE, Low CA, Pasture PD, Pasture LPI, Pasture AREA	17	0.56	0.49	5.31	761.37	21.82
Deciduous AREA, Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Mixed Forest GYRATE, Mixed Forest PARA, Open Water NP, Open Water SHAPE, Open Water PARA, Low CA, Pasture PD, Pasture LPI, Pasture AREA	18	0.57	0.50	5.28	761.72	21.60
Deciduous AREA, Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Medium IJI, Mixed Forest GYRATE, Mixed Forest PARA, Open Water NP, Open Water SHAPE, Open Water PARA, Low CA, Pasture PD, Pasture LPI, Pasture AREA	19	0.58	0.50	5.24	761.50	20.90
Deciduous AREA, Deciduous PARA, Crops NP, Evergreen NP, Evergreen IJI, Barren PD, Barren PARA, Barren CIRCLE, Barren IJI, Medium IJI,	20	0.59	0.51	5.22	762.22	21.00

Mixed Forest GYRATE, Mixed Forest PARA, Open Water NP, Open Water SHAPE, Open Water PARA, Low CA, Pasture PD, Pasture LPI, Pasture AREA, Open CA

APPENDIX E

Selected BOVA Models Using Class Fragmentation Metrics by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Sq Rt Alpha = 2.24 – 1.37 Crops LPI – 0.01 Evergreen IJI + 0.09 Low AREA + 2.26 Pasture SHAPE + 0.00 Pasture PARA – 0.16 Pasture DCAD – 0.02 Open IJI	7	109	0.50	0.47	-136.21	15.43
Central Appalachians	Alpha = 58.09 – 0.01 Open Water PARA + 0.01 Open CA	2	24	0.47	0.41	131.81	-5.99
Middle Atlantic Coastal Plain	Alpha^4 = -3.03E8 + 8312.43 Deciduous CA – 6.02E6 Deciduous PD – 927746 Deciduous LPI + 3.51 Deciduous CIRCLE + 16377.70 Crops CA – 3.60 Crops AREA – 3956.88 Evergreen CA + 1.43E6 Evergreen IJI + 62908 Mixed Forest PARA – 347513 Mixed Forest IJI + 4420.11 Low CA – 19795.4 Pasture CA + 2.85E6 Pasture AREA + 57381.20 Pasture PARA – 686240 Pasture IJI	15	119	0.71	0.67	4208.41	18.77
Northern Piedmont	1/Alpha = 0.03 – 0.03 Deciduous CIRCLE + 7.86E-6 Medium CA – 4.27E-5 Medium AI – 4.22E-6 Mixed Forest CA + 0.00 Mixed Forest AREA – 5.92E-7 Open Water CA – 4.93E-6 Low CA + 3.84E-7 Pasture CA + 0.01 Pasture CLUMPY	9	122	0.56	0.52	-1177.94	15.52
Piedmont	Cube Rt Alpha = 3.45 – 0.29 Deciduous SHAPE – 0.00 Deciduous PARA + 0.02 Evergreen PD + 2.30 Evergreen CIRCLE + 0.00 Mixed Forest CA – 0.00 Mixed Forest PARA – 1.08 Mixed Forest CIRCLE – 0.16 Open Water CLUMPY – 0.00 Low IJI + 0.00 Pasture PARA – 6.81E-5 Open CA + 0.01 Open LPI + 0.00 Woody Wetlands NP + 0.00 Woody Wetlands IJI	14	339	0.41	0.38	-468.01	18.07
Ridge & Valley	100th Rt Alpha = 1.04 + 7.89E-6 Deciduous NP – 3.30E-5 Deciduous IJI + 1.77E-5 Crops NP – 0.00 Crops PD – 0.00 Evergreen PD – 4.25E-6 Evergreen PARA – 5.97E-7 Pasture	13	290	0.50	0.47	-2961.87	16.32

	CA + 5.88E-6 Pasture NP + 3.09E-6 Pasture PARA + 0.00 Pasture DCAD + 4.19E-5 Pasture IJI – 2.07E-6 Open CA + 3.94E-6 Open PARA						
Southeastern Plains	Alpha = -24.13 – 0.13 Deciduous AREA + 0.03 Crops NP – 0.02 Evergreen NP + 0.31 Evergreen IJI + 0.06 Barren PARA + 102.767 Barren CIRCLE – 0.25 Barren IJI – 0.13 Medium IJI + 0.16 Open Water NP – 4.42 Open Water SHAPE – 0.01 Open Water PARA – 0.00 Low CA – 1.58 Pasture PD – 1.19 Pasture AREA	14	119	0.53	0.46	762.91	24.90

APPENDIX F

BOVA Class Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.086, 0.049	16.0514
Central Appalachians	0.088, >0.150	504.305
Middle Atlantic Coastal Plains	0.071, 0.127	1.4965E16
Northern Piedmont	0.061, >0.150	0.00047
Piedmont	0.033, >0.150	4.94183
Ridge & Valley	0.050, 0.072	0.0006231
Southeastern Plains	0.065, >0.150	4184.53

APPENDIX G

Selected Geographic Point Management Models by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Sq Rt Alpha = 7.48 + 0.51 Low AREA + 0.01 Pasture NP – 0.87 Pasture PD	3	109	0.47	0.46	381.74	41.51
Central Appalachians	Sq Rt Alpha = -2.91 + 0.00 Deciduous CA + 29.64 Evergreen CIRCLE + 12.44 Medium CLUMPY – 0.02 Mixed Forest PARA	4	24	0.58	0.53	151.87	22.98
Middle Atlantic Coastal Plain	Cube Rt Alpha = 5.44 + 0.00 Deciduous CA – 3.09 Deciduous SHAPE + 0.05 Evergreen IJI	3	119	0.27	0.26	352.53	59.36
Northern Piedmont	Cube Rt Alpha = 4.23 + 1.24 Medium DCORE + 0.00 Open CA – 0.02 Open IJI + 7.47E-5 Deciduous CA	4	122	0.29	0.27	311.72	46.22
Piedmont	Cube Rt Alpha = 0.20 + 0.00 Deciduous CA + 0.00 Pasture PARA + 0.00 Open NP	3	339	0.32	0.31	647.57	62.88
Ridge & Valley	4.5th Rt = 1.96 + 6.47E-5 Deciduous CA + 0.00 Low CA		290	0.29	0.31	164.45	80.35
Southeastern Plains	Sq Rt Alpha = -5.42 – 0.05 Deciduous AREA + 0.01 Barren PARA + 0.11 Open Water NP	3	119	0.36	0.34	508.88	128.68

APPENDIX H

Geographic Point Management Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.053, >0.150	230.86
Central Appalachians	0.077, >0.150	98.38
Middle Atlantic Coastal Plains	0.053, >0.150	162.79
Northern Piedmont	0.076, 0.062	99.28
Piedmont	0.049, 0.037	152.95
Ridge & Valley	0.062, <0.01	29.58
Southeastern Plains	0.068, >0.150	511.05

APPENDIX I

Selected BOVA Management Models by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Cube Rt Alpha = 2.09 + 0.65 Pasture SHAPE + 0.00 Pasture PARA – 0.04 Pasture DCAD – 0.00 Open IJI	4	109	0.42	0.40	-126.43	27.47
Central Appalachians	Alpha = -47.36 – 0.04 Deciduous GYRATE + 11.93 Deciduous SHAPE -2.41 Grassland AREA + 138.85 Mixed Forest CIRCLE	4	24	0.39	0.31	223.15	20.33
Middle Atlantic Coastal Plain	Alpha^4 = -1.01E8 – 2.69E6 Deciduous PD + 6674.54 Crops CA + 508570 Evergreen IJI + 127537 Pasture PARA	4	119	0.49	0.47	4249.08	78.27
Northern Piedmont	1/Alpha = 0.02 – 8.88E-7 Open Water CA – 1.97E-6 Low CA – 0.00 Open AREA	3	122	0.37	0.36	-1149.80	51.84
Piedmont	Cube Rt Alpha = 3.27 + 0.00 Pasture PARA + 0.00 Woody Wetlands NP	2	339	0.26	0.26	-419.68	73.74
Ridge & Valley	Alpha = 104.02 – 0.05 Evergreen PARA + 0.05 Pasture NP	2	290	0.37	0.36	-2918.82	66.25
Southeastern Plains	Alpha = 41.85 + 0.44 Evergreen IJI – 0.10 Medium IJI	2	119	0.29	0.28	781.53	56.92

APPENDIX J

BOVA Management Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.081, 0.065	2.44
Central Appalachians	0.117, >0.150	570.26
Middle Atlantic Coastal Plains	0.048, >0.150	28155000000000000.00
Northern Piedmont	0.042, >0.150	0.00
Piedmont	0.025, >0.150	5.80
Ridge & Valley	0.080, <0.010	38739.20
Southeastern Plains	0.053, >0.150	5062.16

APPENDIX K

Frequency of Land Classes in Models Using Class Fragmentation Metrics

Land Class	Geographic Point Frequency	BOVA Frequency
Barren	1	0
Deciduous	6	3
Emergent	0	0
Evergreen	2	3
Mixed Forest	1	1
Pasture	3	5
Low	2	1
Medium	2	1
Open	3	2
Open Water	1	1
Woody Wetlands	0	1
Crops	0	1
Grassland	0	1

APPENDIX L

Frequency of Fragmentation Metrics in Models Using Class Fragmentation Metrics

Metric	Geographic Point Frequency	BOVA Frequency
CA	6	3
AREA	2	2
NP	3	2
PD	1	1
CIRCLE	1	1
SHAPE	1	2
CLUMPY	1	0
IJI	2	4
DCAD	0	1
NLSI	0	0
ED	0	0
PARA	3	4
GYRATE	0	1
DCORE	1	0
LPI	0	0
AI	0	0

APPENDIX M

Geographic Point Models Using Landscape Fragmentation Metrics by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
PRD	1	0.10	0.09	2.13	521.48	38.50
TA, PRD	2	0.18	0.16	2.04	512.43	26.72
DCORE, PR, PRD	3	0.27	0.25	1.93	501.15	13.77
TA, DCORE, PR, PRD	4	0.33	0.31	1.86	492.62	5.00

Central Appalachians (41 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
TA	1	0.38	0.36	1.80	169.01	12.43
TA, ENN	2	0.43	0.40	1.75	168.01	10.43
TA, ENN, IJI	3	0.50	0.46	1.66	165.39	6.99
TA, ENN, IJI, PR	4	0.55	0.50	1.60	163.83	5.00

Middle Atlantic Coastal Plain (131 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
ENN	1	0.17	0.16	1.13	407.54	22.02
TA, ENN	2	0.25	0.23	1.08	396.31	9.58
TA, CAI, SPLIT	3	0.27	0.26	1.06	393.52	6.58
TA, CAI, ENN, SPLIT	4	0.29	0.27	1.05	392.04	5.00

Northern Piedmont (118 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
PRD	1	0.19	0.18	0.77	277.88	23.67
SHAPE, PRD	2	0.29	0.28	0.72	263.90	8.08
SHAPE, SPLIT, PRD	3	0.33	0.31	0.71	259.95	4.00

Piedmont (367 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
TA	1	0.21	0.21	0.69	771.04	67.87
TA, PARA	2	0.30	0.29	0.65	731.32	23.52
TA, PARA, PRD	3	0.30	0.30	0.65	729.95	21.95
TA, PARA, ENN, MSIEI	4	0.32	0.31	0.64	721.18	12.87
TA, PARA, ENN, PRD, MSIEI	5	0.33	0.32	0.64	718.88	10.48
TA, PARA, CAI, ENN, PRD, MSIEI	6	0.34	0.33	0.63	715.43	7.00

Ridge & Valley (303 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
TA	1	0.27	0.27	0.34	212.32	59.14
TA, PR	2	0.34	0.33	0.33	186.62	29.80
TA, SHAPE, PR	3	0.35	0.34	0.32	184.64	27.46
TA, SHAPE, ENN, MSIEI	4	0.37	0.36	0.32	176.32	18.57
TA, SHAPE, ENN, PR, MSIEI	5	0.39	0.38	0.31	166.11	8.17
TA, SHAPE, ENN, COHESION, PR, MSIEI	6	0.40	0.39	0.31	164.99	7.00

Southeastern Plains (123 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
CAI	1	0.16	0.15	2.31	559.69	48.40
CAI, MSIEI	2	0.26	0.25	2.18	545.89	30.06
DCAD, DCORE, CAI	3	0.29	0.28	2.13	541.74	24.69
DCAD, DCORE, CAI, MSIEI	4	0.35	0.32	2.06	534.72	16.59
DCAD, DCORE, CAI, IJI, MSIEI	5	0.38	0.35	2.02	531.11	12.56
TA, DCAD, DCORE, CAI, IJI, MSIEI	6	0.40	0.37	1.98	527.62	8.90
TA, DCAD, DCORE, CAI, ENN, IJI, MSIEI	7	0.42	0.38	1.97	526.90	8.00

APPENDIX N

Selected Geographic Point Models Using Landscape Fragmentation Metrics by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Sq Rt Alpha = -1.81+ 0.00 TA + 0.09 DCORE + 0.45 PR + 3.18 PRD	4	119	0.33	0.31	492.62	5.00
Central Appalachians	Sq Rt Alpha = 15.52 + 0.00 TA – 0.04 ENN – 0.13 IJI	3	41	0.50	0.50	165.39	6.99
Middle Atlantic Coastal Plain	Sq Rt Alpha = 3.50 – 9.77E-5 TA – 0.42 CAI + 0.00 SPLIT	3	131	0.27	0.26	393.52	6.58
Northern Piedmont	Cube Rt Alpha = 7.94 – 2.21 SHAPE + 0.01 SPLIT – 5.05 PRD	3	118	0.33	0.31	259.95	4.00
Piedmont	Cube Rt Alpha = -4.15 + 8.27 TA + 0.01 PARA – 0.21 CAI + 0.01 ENN -1.04 PRD + 2.14 MSIEI	6	367	0.34	0.33	715.43	7.00
Ridge & Valley	4.5th Rt = 0.30 + 4.77E-5 TA + 1.17 SHAPE – 0.00 ENN + 0.05 PR – 0.69 MSIEI	5	303	0.39	0.38	166.11	8.17
Southeastern Plains	Sq Rt Alpha = 21.04 + 0.00 TA -0.82 DCAD – 0.36 DCORE – 1.30 CAI – 0.12 IJI + 9.63 MSIEI	6	123	0.40	0.37	527.62	8.90

APPENDIX O

Geographic Point Landscape Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.046, >0.150	524.601
Central Appalachians	0.137, 0.052	123.181
Middle Atlantic Coastal Plains	0.045, >0.150	142.833
Northern Piedmont	0.075, 0.097	536.745
Piedmont	0.057, <0.010	150.423
Ridge & Valley	0.084, <0.010	1384.88
Southeastern Plains	0.052, >0.150	521.417

APPENDIX P

BOVA Models Using Landscape Fragmentation Metrics by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
DCAD	1	0.04	0.03	0.17	-85.15	8.35
DCAD, PR	2	0.10	0.08	0.16	-90.32	3.00

Central Appalachians (43 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
DCORE	1	0.22	0.21	4.11	248.14	27.90
DCORE, MSIEI	2	0.29	0.26	3.97	246.64	24.04
TA, PARA, DCORE	3	0.38	0.33	3.78	243.84	18.88
TA, PARA, DCORE, PR	4	0.46	0.40	3.58	240.62	13.94
TA, PARA, DCORE, MESH, MSIEI	5	0.51	0.44	3.44	239.12	11.40
TA, PARA, DCORE, MESH, PR, MSIEI	6	0.58	0.51	3.22	235.12	7.00

Middle Atlantic Coastal Plain (136 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
TA	1	0.10	0.09	16866721.00	4916.43	43.34
DCAD, SPLIT	2	0.23	0.22	15695422.00	4897.96	20.70

DCAD, SPLIT, MSIEI	3	0.26	0.24	15397507.00	4893.88	15.94
DCAD, SPLIT, PR, MSIEI	4	0.27	0.25	15326434.00	4893.77	15.54
TA, DCAD, COHESION, SPLIT, PR	5	0.30	0.28	15077026.00	4890.49	11.92
TA, DCAD, COHESION, SPLIT, PR, MSIEI	6	0.32	0.28	14996494.00	4890.24	11.44
TA, DCAD, IJI, COHESION, SPLIT, PR, MSIEI	7	0.33	0.29	14891156.00	4889.56	10.55
TA, SHAPE, DCAD, CAI, ENN, SPLIT, PR, MSIEI	8	0.33	0.29	14912737.00	4891.22	11.91

Northern Piedmont (118 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
PRD	1	0.16	0.16	5.62	746.68	20.25
ENN, PRD	2	0.26	0.25	5.31	734.03	6.43
ENN, MESH, PRD	3	0.29	0.27	5.23	731.71	4.00

Piedmont (378 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
ENN	1	0.10	0.10	0.42	424.89	58.72
DCORE, ENN	2	0.15	0.14	0.41	407.16	38.67
TA, SHAPE, ENN	3	0.18	0.18	0.40	392.53	22.94
TA, DCORE, ENN, IJI	4	0.20	0.19	0.40	385.79	15.89
TA, SHAPE, DCORE, ENN, IJI	5	0.22	0.21	0.40	378.93	8.92
TA, SHAPE, DCORE, ENN, IJI, SPLIT	6	0.23	0.22	0.39	377.04	7.00

Ridge & Valley (314 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
SHAPE	1	0.21	0.21	0.00	-3076.41	38.14
TA, SHAPE	2	0.26	0.25	0.00	-3091.82	21.31
TA, SHAPE, MSIEI	3	0.27	0.26	0.00	-3094.03	18.85
TA, SHAPE, DCORE, MSIEI	4	0.30	0.29	0.00	-3107.96	4.71
TA, SHAPE, DCAD, DCORE, MSIEI	5	0.31	0.29	0.00	-3106.99	5.61
TA, SHAPE, DCAD, DCORE, COHESION, MSIEI	6	0.31	0.29	0.00	-3105.51	7.00

Southeastern Plains (126 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
IJI	1	0.10	0.09	7.43	867.05	19.48
IJI, PRD	2	0.15	0.14	7.22	861.08	12.67
IJI, MESH, PRD	3	0.22	0.20	6.95	852.69	4.00

APPENDIX Q

Selected BOVA Models Using Landscape Fragmentation Metrics by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Cube Rt Alpha = 3.78 – 0.02 DCAD + 0.02 PR	2	119	0.10	0.16	-90.32	3.00
Central Appalachians	Alpha = 24.87 + 0.00 TA + 0.06 PARA – 0.29 DCORE – 0.00 MESH -1.35 PR – 23.25 MSIEI	6	43	0.58	0.51	235.12	7.00
Middle Atlantic Coastal Plain	Alpha^4 = 382642204 + 1514.21 TA – 3872852 DCAD – 3066178 COHESION + 147704.59 SPLIT - 3362649 PR	5	136	0.30	0.28	4890.49	11.92
Northern Piedmont	Alpha = 72.50 – 0.11 ENN + 0.00 MESH – 26.26 PRD	3	118	0.29	0.27	731.71	4.00
Piedmont	Sq Rt Alpha = 8.23 + 3.03 TA – 1.01 SHAPE + 0.04 DCORE – 0.01 ENN + 0.02 IJI	5	378	0.22	0.21	378.93	8.92
Ridge & Valley	100th Rt Alpha = 1.03 + 1.24E-7 TA + 0.01 SHAPE + 2.38E-5 DCAD – 3.77E-5 DCORE – 0.00 MSIEI	5	314	0.31	0.29	-3106.99	5.61
Southeastern Plains	Alpha = 36.13 + 0.44 IJI – 0.00 MESH – 2.83 PRD	3	126	0.22	0.20	852.69	4.00

APPENDIX R

BOVA Landscape Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.075, 0.098	3.24395
Central Appalachians	0.068, >0.150	534.768
Middle Atlantic Coastal Plains	0.056, >0.150	3.06239E16
Northern Piedmont	0.070, >0.150	0.000408254
Piedmont	0.035, >0.150	7.17904
Ridge & Valley	0.095, <0.010	18.1006
Southeastern Plains	0.038, >0.150	6837.28

APPENDIX S

Geographic Point Models Using Environmental Variables by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (106 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pop Density	1	0.29	0.28	22.27	962.96	35.50
Pop Density, Acreage	2	0.42	0.41	20.25	943.95	12.60
SI, Pop Density, Acreage	3	0.46	0.45	19.56	937.73	6.00
Elevation, SI, Pop Density, Acreage	4	0.48	0.46	19.35	936.64	4.78
Elevation, SI, Pop Density, Acreage, NDVI	5	0.48	0.46	19.32	937.55	5.47
Elevation, Mean Slope, Std Dev Slope, SI, Pop Density, Acreage	6	0.49	0.46	19.26	938.10	5.81
Elevation, Mean Slope, Std Dev Slope, Max Temp, SI, Pop Density, Acreage	7	0.50	0.46	19.24	939.21	6.63
Elevation, Mean Slope, Std Dev Slope, Min Temp, Precip, SI, Pop Density, Acreage	8	0.51	0.47	19.20	940.22	7.34
Elevation, Mean Slope, Std Dev Slope, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	9	0.51	0.46	19.24	941.96	8.66
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	10	0.51	0.46	19.27	943.76	10.00
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.51	0.46	19.37	946.36	12.00

Central Appalachians (40 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Acreage	1	0.27	0.25	21.04	361.83	31.34

Std Dev Slope, Acreage	2	0.37	0.33	19.88	358.72	24.57
PET, Acreage, NDVI	3	0.48	0.44	18.32	353.69	16.37
Elevation, PET, Acreage, NDVI	4	0.55	0.50	17.26	350.57	11.73
Elevation, Std Dev Slope, PET, Acreage, NDVI	5	0.65	0.60	15.48	343.66	4.61
Elevation, Mean Slope, Std Dev Slope, PET, Acreage, NDVI	6	0.66	0.60	15.42	345.33	5.43
Elevation, Std Dev Slope, Min Temp, Precip, PET, Acreage, NDVI	7	0.67	0.60	15.38	347.26	6.33
Elevation, Std Dev Slope, Min Temp, Precip, Pop Density, PET, Acreage, NDVI	8	0.68	0.60	15.40	349.66	7.45
Elevation, Mean Slope, Std Dev Slope, Max Temp, Precip, Pop Density, PET, Acreage, NDVI	9	0.69	0.60	15.42	352.29	8.57
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, Pop Density, PET, Acreage, NDVI	10	0.70	0.59	15.53	355.63	10.01
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.70	0.58	15.80	360.06	12.00

Middle Atlantic Coastal Plain (134 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Min Temp	1	0.12	0.11	0.51	202.49	26.32
Min Temp, Acreage	2	0.21	0.20	0.48	189.86	12.02
Min Temp, Pop Density, Acreage	3	0.26	0.24	0.47	183.07	4.98
Max Temp, Min Temp, Pop Density, Acreage	4	0.28	0.26	0.46	181.58	3.42
Max Temp, Min Temp, SI, Pop Density, Acreage	5	0.29	0.27	0.46	181.27	3.03
Mean Slope, Max Temp, Min Temp, SI, Pop Density, Acreage	6	0.30	0.27	0.46	182.04	3.65
Mean Slope, Max Temp, Min Temp, SI, Pop Density, Acreage, NDVI	7	0.31	0.27	0.46	183.43	4.82
Elevation, Mean Slope, Max Temp, Min Temp, SI, Pop Density, Acreage, NDVI	8	0.31	0.26	0.46	185.32	6.40
Elevation, Mean Slope, Max Temp, Min Temp, SI, Pop Density, PET, Acreage, NDVI	9	0.31	0.26	0.46	187.27	8.02
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, SI, Pop Density,	10	0.31	0.25	0.46	189.67	10.00

PET, Acreage, NDVI						
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.31	0.25	0.47	192.12	12.00

Northern Piedmont (70 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Acreage	1	0.08	0.07	39.58	717.96	12.29
Pop Density, Acreage	2	0.15	0.13	38.35	714.76	8.42
Min Temp, Pop Density, Acreage	3	0.22	0.18	37.07	711.27	4.65
Min Temp, Pop Density, Acreage, NDVI	4	0.25	0.20	36.59	710.75	3.93
Elevation, Min Temp, Pop Density, Acreage, NDVI	5	0.27	0.21	36.50	711.81	4.65
Mean Slope, Std Dev Slope, Min Temp, Pop Density, Acreage, NDVI	6	0.30	0.23	35.92	711.02	3.73
Mean Slope, Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage, NDVI	7	0.31	0.23	36.02	712.92	5.10
Mean Slope, Std Dev Slope, Max Temp, Min Temp, Pop Density, PET, Acreage, NDVI	8	0.31	0.22	36.16	715.06	6.60
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Pop Density, PET, Acreage, NDVI	9	0.32	0.21	36.37	717.55	8.33
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, Pop Density, PET, Acreage, NDVI	10	0.32	0.20	36.58	720.09	10.01
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.32	0.19	36.89	723.10	12.00

Piedmont (364 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Acreage	1	0.22	0.22	0.66	736.04	79.00
Pop Density, Acreage	2	0.32	0.31	0.62	690.08	26.77

Std Dev Slope, Pop Density, Acreage	3	0.35	0.35	0.61	673.72	9.78
Elevation, Std Dev Slope, Pop Density, Acreage	4	0.37	0.36	0.60	666.83	2.89
Elevation, Mean Slope, Std Dev Slope, Pop Density, Acreage	5	0.37	0.36	0.60	665.87	1.92
Elevation, Mean Slope, Std Dev Slope, Pop Density, PET, Acreage	6	0.37	0.36	0.60	666.53	2.53
Elevation, Mean Slope, Std Dev Slope, Max Temp, Pop Density, PET, Acreage	7	0.37	0.36	0.60	668.26	4.17
Elevation, Mean Slope, Std Dev Slope, Max Temp, Pop Density, PET, Acreage, NDVI	8	0.38	0.36	0.60	670.22	6.03
Elevation, Mean Slope, Std Dev Slope, Max Temp, SI, Pop Density, PET, Acreage, NDVI	9	0.38	0.36	0.60	672.32	8.00
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, SI, Pop Density, PET, Acreage, NDVI	10	0.38	0.36	0.60	674.46	10.00
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.38	0.36	0.60	676.61	12.00

Ridge & Valley (257 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Acreage	1	0.26	0.25	0.33	156.66	45.23
Std Dev Slope, Acreage	2	0.29	0.28	0.32	147.85	34.87
Std Dev Slope, Acreage, NDVI	3	0.32	0.31	0.31	136.68	22.51
Std Dev Slope, Precip, Acreage, NDVI	4	0.34	0.33	0.31	131.91	17.35
Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage	5	0.36	0.35	0.30	125.50	10.72
Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage, NDVI	6	0.38	0.36	0.30	121.62	6.81
Mean Slope, Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage, NDVI	7	0.38	0.36	0.30	121.53	6.65
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Pop Density, Acreage, NDVI	8	0.38	0.36	0.30	122.51	7.51
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, Pop Density, Acreage, NDVI	9	0.39	0.37	0.30	123.13	8.02
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, Pop	10	0.39	0.36	0.30	125.32	10.01

Density, PET, Acreage, NDVI						
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.39	0.36	0.30	127.54	12.00

Southeastern Plains (117 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
NDVI	1	0.21	0.20	0.72	259.73	11.31
Acreage, NDVI	2	0.24	0.23	0.71	256.32	7.55
Max Temp, Acreage, NDVI	3	0.27	0.25	0.70	253.94	5.01
Max Temp, Pop Density, Acreage, NDVI	4	0.29	0.27	0.69	252.98	3.95
Mean Slope, Max Temp, Pop Density, Acreage, NDVI	5	0.30	0.27	0.69	253.46	4.27
Mean Slope, Std Dev Slope, Max Temp, Pop Density, Acreage, NDVI	6	0.32	0.28	0.69	253.62	4.29
Mean Slope, Std Dev Slope, Max Temp, Precip, Pop Density, Acreage, NDVI	7	0.32	0.28	0.69	254.99	5.39
Mean Slope, Std Dev Slope, Max Temp, Precip, SI, Pop Density, Acreage, NDVI	8	0.33	0.28	0.69	256.76	6.82
Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	9	0.33	0.27	0.69	258.73	8.40
Elevation, Mean Slope, Std Dev Slope, Max Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	10	0.33	0.27	0.69	260.99	10.20
Elevation, Mean Slope, Std Dev Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.33	0.26	0.69	263.30	12.00

APPENDIX T

Selected Geographic Point Models Using Environmental Variables by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Alpha = 50.26 – 9.96 SI + 0.08 Pop Density + 0.00 Acreage	3	106	0.46	0.45	937.73	6.00
Central Appalachians	Alpha = -374.96 + 0.08 Elev + 3.09 Std Dev Slope + 9.76 PET + 0.00 Acreage + 67.34 NDVI	5	40	0.65	0.60	343.66	4.61
Middle Atlantic Coastal Plain	4.5th Rt Alpha = -1.10 + 0.01 Min Temp + 6.09E-5 Pop Density + 1.84E-5 Acreage	3	134	0.26	0.24	183.07	4.98
Northern Piedmont	Alpha = 178.01 – 0.60 Min Temp + 0.05 Pop Density + 0.00 Acreage	3	70	0.22	0.18	711.27	4.65
Piedmont	Cube Rt Alpha = 2.38 – 0.00 Elev + 0.11 Std Dev Slope + 0.00 Pop Density + 3.80E-5 Acreage	4	364	0.37	0.36	666.83	2.89
Ridge & Valley	4.5th Rt Alpha = 3.04 + 0.03 Std Dev Slope – 0.00 Max Temp + 0.00 Min Temp + 9.74 Pop Density + 2.19E-5 Acreage – 0.45 NDVI	6	257	0.38	0.36	121.62	6.81
Southeastern Plains	Cube Rt Alpha = 14.92 – 0.01 Max Temp + 1.91E-5 Acreage – 3.25 NDVI	3	117	0.27	0.25	253.94	5.01

APPENDIX U

Geographic Point Environmental Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.084, 0.050	65567
Central Appalachians	0.115, >0.15	11642.2
Middle Atlantic Coastal Plains	0.076, 0.052	43.3351
Northern Piedmont	0.092, 0.145	2108.52
Piedmont	0.033, >0.15	133.320
Ridge & Valley	0.053, 0.044	30.7549
Southeastern Plains	0.052, >0.15	74.2215

APPENDIX V

BOVA Models Using Environmental Variables by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (113 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Elevation	1	0.23	0.23	0.15	-110.84	11.55
Std Dev Slope, Elevation	2	0.28	0.27	0.14	-116.45	5.55
Std Dev Slope, Elevation, Precip	3	0.32	0.30	0.14	-119.49	2.46
Std Dev Slope, Elevation, Precip, Pop Density	4	0.34	0.31	0.14	-120.47	1.45
Std Dev Slope, Elevation, Precip, SI, Pop Density	5	0.34	0.31	0.14	-119.35	2.39
Mean Slope, Std Dev Slope, Elevation, Precip, SI, Pop Density	6	0.35	0.32	0.14	-119.00	2.60
Mean Slope, Std Dev Slope, Elevation, Precip, SI, Pop Density, Acreage	7	0.36	0.31	0.14	-117.01	4.27
Mean Slope, Std Dev Slope, Elevation, Precip, SI, Pop Density, Acreage, NDVI	8	0.36	0.31	0.14	-114.82	6.07
Mean Slope, Std Dev Slope, Elevation, Max Temp, Precip, SI, Pop Density, Acreage, NDVI	9	0.36	0.30	0.14	-112.42	8.02
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	10	0.36	0.29	0.14	-109.93	10.00
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.36	0.29	0.14	-107.38	12.00

Central Appalachians (41 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Mean Slope	1	0.19	0.17	4.08	236.21	6.43

Mean Slope, Min Temp	2	0.29	0.25	3.87	233.37	3.16
Mean Slope, Min Temp, Acreage	3	0.37	0.32	3.69	230.99	0.79
Mean Slope, Max Temp, Min Temp, Acreage	4	0.43	0.36	3.58	230.01	-0.16
Mean Slope, Max Temp, Min Temp, SI, Acreage	5	0.43	0.35	3.61	232.43	1.47
Mean Slope, Max Temp, Min Temp, SI, PET, Acreage	6	0.44	0.34	3.64	235.17	3.20
Mean Slope, Max Temp, Min Temp, SI, PET, Acreage, NDVI	7	0.44	0.32	3.69	238.24	5.03
Mean Slope, Max Temp, Min Temp, Precip, SI, PET, Acreage, NDVI	8	0.44	0.30	3.74	241.74	7.01
Mean Slope, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	9	0.44	0.28	3.80	245.50	9.00
Mean Slope, Elev, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	10	0.44	0.26	3.86	249.54	11.00

Middle Atlantic Coastal Plain (134 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Mean Slope	1	0.22	0.21	20000000.00	4821.70	36.00
Mean Slope, Acreage	2	0.34	0.33	10000000.00	4800.70	11.64
Mean Slope, Min Temp, Acreage	3	0.39	0.38	10000000.00	4792.50	3.29
Mean Slope, Min Temp, Acreage, NDVI	4	0.40	0.38	10000000.00	4792.60	3.29
Mean Slope, Max Temp, Min Temp, Acreage, NDVI	5	0.42	0.39	10000000.00	4791.90	2.53
Mean Slope, Max Temp, Min Temp, Precip, Acreage, NDVI	6	0.42	0.39	10000000.00	4792.70	3.20
Mean Slope, Elevation, Max Temp, Min Temp, Precip, Acreage, NDVI	7	0.42	0.39	10000000.00	4794.30	4.52
Mean Slope, Elevation, Max Temp, Min Temp, Precip, Pop Density, Acreage, NDVI	8	0.43	0.39	10000000.00	4796.40	6.32
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, Pop Density, Acreage, NDVI	9	0.43	0.38	10000000.00	4798.60	8.19
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, Pop Density, PET, Acreage, NDVI	10	0.43	0.38	10000000.00	4800.80	10.01

Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.43	0.38	10000000.00	4803.30	12.00

Northern Piedmont (115 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Std Dev Slope	1	0.21	0.20	0.00	-1113.00	36.02
Std Dev Slope, Pop Density	2	0.35	0.34	0.00	-1133.00	12.01
Std Dev Slope, Pop Density, NDVI	3	0.39	0.37	0.00	-1139.00	5.97
Std Dev Slope, Pop Density, Acreage, NDVI	4	0.41	0.39	0.00	-1141.00	4.06
Std Dev Slope, Precip, Pop Density, Acreage, NDVI	5	0.42	0.39	0.00	-1141.00	4.27
Std Dev Slope, Min Temp, Precip, Pop Density, Acreage, NDVI	6	0.43	0.40	0.00	-1140.00	5.12
Std Dev Slope, Elevation, Min Temp, Precip, Pop Density, Acreage, NDVI	7	0.43	0.40	0.00	-1138.00	5.94
Std Dev Slope, Elevation, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	8	0.44	0.40	0.00	-1137.00	6.95
Mean Slope, Std Dev Slope, Elevation, Min Temp, Precip, SI, Pop Density, Acreage, NDVI	9	0.44	0.40	0.00	-1136.00	8.13
Mean Slope, Std Dev Slope, Elevation, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	10	0.44	0.39	0.00	-1133.00	10.01
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.44	0.38	0.00	-1131.00	12.00

Piedmont (367 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
SI	1	0.11	0.11	0.14	-388.50	63.00
SI, PET	2	0.16	0.15	0.14	-406.30	42.57

SI, PET, NDVI	3	0.19	0.18	0.14	-417.70	30.04
SI, PET, Acreage, NDVI	4	0.22	0.21	0.13	-428.20	19.02
Std Dev Slope, Elevation, SI, Acreage, NDVI	5	0.23	0.22	0.13	-432.30	14.74
Std Dev Slope, Elevation, SI, PET, Acreage, NDVI	6	0.25	0.24	0.13	-438.90	8.09
Std Dev Slope, Elevation, Max Temp, SI, PET, Acreage, NDVI	7	0.25	0.24	0.13	-438.50	8.35
Std Dev Slope, Elevation, Max Temp, Min Temp, SI, PET, Acreage, NDVI	8	0.26	0.24	0.13	-439.40	7.41
Std Dev Slope, Elevation, Max Temp, Min Temp, SI, Pop Density, PET, Acreage, NDVI	9	0.26	0.24	0.13	-438.00	8.78
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, SI, Pop Density, PET, Acreage, NDVI	10	0.26	0.24	0.13	-436.40	10.28
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.26	0.24	0.13	-434.50	12.00

Ridge & Valley (295 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Precip	1	0.18	0.17	0.00	-2901.19	39.71
Precip, Acreage	2	0.22	0.21	0.00	-2913.88	25.58
Precip, Acreage, NDVI	3	0.26	0.25	0.00	-2928.53	10.25
Mean Slope, Precip, Acreage, NDVI	4	0.28	0.27	0.00	-2936.19	2.59
Std Dev Slope, Elevation, Precip, Acreage, NDVI	5	0.29	0.27	0.00	-2935.36	3.35
Std Dev Slope, Elevation, Precip, PET, Acreage, NDVI	6	0.29	0.28	0.00	-2935.27	3.40
Std Dev Slope, Elevation, Precip, Pop Density, PET, Acreage, NDVI	7	0.29	0.28	0.00	-2933.92	4.65
Std Dev Slope, Elevation, Min Temp, Precip, Pop Density, PET, Acreage, NDVI	8	0.29	0.27	0.00	-2931.99	6.44
Mean Slope, Std Dev Slope, Elevation, Precip, SI, Pop Density, PET, Acreage, NDVI	9	0.29	0.27	0.00	-2930.02	8.26
Mean Slope, Std Dev Slope, Elevation, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	10	0.29	0.27	0.00	-2928.05	10.07

Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.30	0.27	0.00	-2925.93	12.00

Southeastern Plains (121 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Mean Slope	1	0.19	0.18	6.87	814.04	31.75
Precip, Pop Density	2	0.28	0.27	6.49	801.39	16.64
Mean Slope, Precip, Pop Density	3	0.35	0.33	6.20	791.36	6.00
Mean Slope, Precip, Pop Density, PET	4	0.36	0.34	6.15	790.52	5.04
Mean Slope, Precip, Pop Density, PET, NDVI	5	0.39	0.36	6.04	787.54	2.12
Mean Slope, Max Temp, Precip, Pop Density, PET, NDVI	6	0.40	0.37	6.03	788.20	2.62
Mean Slope, Max Temp, Precip, Pop Density, PET, Acreage, NDVI	7	0.40	0.36	6.04	790.04	4.18
Mean Slope, Elevation, Max Temp, Precip, Pop Density, PET, Acreage, NDVI	8	0.40	0.36	6.06	792.24	6.02
Mean Slope, Std Dev Slope, Elevation, Max Temp, Precip, Pop Density, PET, Acreage, NDVI	9	0.40	0.35	6.09	794.65	8.00
Mean Slope, Std Dev Slope, Elevation, Max Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	10	0.40	0.35	6.12	797.11	10.00
Mean Slope, Std Dev Slope, Elevation, Max Temp, Min Temp, Precip, SI, Pop Density, PET, Acreage, NDVI	11	0.40	0.34	6.15	799.62	12.00

APPENDIX W

Selected BOVA Models Using Environmental Variables by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Cube Rt Alpha = 3.86 + 0.03 Std Dev Slope + 0.00 Elevation – 7.82 Precip	3	113	0.32	0.30	-119.49	2.46
Central Appalachians	Alpha = 99.73 – 0.66 Mean Slope – 0.15 Min Temp + 0.00 Acreage	3	41	0.37	0.32	230.99	0.79
Middle Atlantic Coastal Plain	$Alpha^4$ = -63410787 – 7810499 Mean Slope + 287412.06 Min Temp + 615.56 Acreage	3	134	0.39	0.38	4792.50	3.29
Northern Piedmont	1/Alpha = 0.03 – 0.00 Std Dev Slope – 1.40E-6 Pop Density – 0.01 NDVI	3	115	0.39	0.37	-1139.00	5.97
Piedmont	Cube Rt Alpha = 3.29 + 0.03 Std Dev Slope – 0.00 Elev – 0.05 SI + 0.02 PET + 3.34E-6 Acreage – 0.25 NDVI	6	367	0.25	0.24	-438.90	8.09
Ridge & Valley	100th Rt Alpha = 1.04 + 7.12E-5 Mean Slope + 1.43E-6 Precip + 4.81E-8 Acreage – 0.00 NDVI	4	295	0.28	0.27	-2936.00	2.59
Southeastern Plains	Alpha = 46.97 – 2.01 Mean Slope + 0.02 Precip + 0.00 Pop Density – 1.69 PET – 10.27 NDVI	5	121	0.39	0.36	787.54	2.12

APPENDIX X

BOVA Environmental Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.116, <0.010	2.53462
Central Appalachians	0.069, >0.15	715.554
Middle Atlantic Coastal Plains	0.061, >0.15	2.66122E16
Northern Piedmont	0.054, >0.15	0.000327729
Piedmont	0.022, >0.15	6.45399
Ridge & Valley	0.077, <0.010	0.000826087
Southeastern Plains	0.045, >0.15	4851.07

APPENDIX Y

Geographic Point Models Using a Combination of Class, Landscape, and Environmental Variables by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (108 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pasture PD	1	0.15	0.14	0.16	-90.79	25.94
Crops SHAPE, Pasture PD	2	0.20	0.18	0.15	-94.84	20.68
Mixed Forest AREA, Pasture PD, PR	3	0.24	0.22	0.15	-98.83	15.85
Crops SHAPE, Mixed Forest AREA, Pasture PD, PR	4	0.29	0.26	0.14	-103.73	10.44
Crops SHAPE, Mixed Forest AREA, Pasture PD, DCORE, PR	5	0.32	0.29	0.14	-106.43	7.55
Crops SHAPE, Mixed Forest AREA, Pasture PD, DCORE, PR, PRD	6	0.35	0.31	0.14	-108.24	5.64
Crops SHAPE, Mixed Forest AREA, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD	7	0.36	0.31	0.14	-107.29	6.33
Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture PD, DCORE, PR, PRD, Pop Density	8	0.37	0.32	0.14	-107.23	6.20
Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD, SI	9	0.38	0.32	0.14	-106.07	7.03
Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD, SI, Pop Density	10	0.39	0.32	0.14	-104.98	7.76
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD, SI, Pop Density	11	0.39	0.32	0.14	-103.64	8.68
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD, SI, Pop Density	12	0.40	0.32	0.14	-101.81	9.99
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY, DCORE, PR, PRD, SI, Pop Density, Acreage	13	0.40	0.32	0.14	-99.57	11.60

Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture CLUMPY, TA, DCORE, PR, PRD, SI, Pop Density, Acreage	14	0.40	0.31	0.14	-97.23	13.24
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture DCAD, Pasture CLUMPY, TA, DCORE, PR, PRD, SI, Pop Density, Acreage	15	0.40	0.31	0.14	-94.64	15.04
Deciduous NLSI, Crops SHAPE, Mixed Forest AREA, Low AREA, Pasture NP, Pasture PD, Pasture SHAPE, Pasture DCAD, Pasture CLUMPY, TA, DCORE, PR, PRD, SI, Pop Density, Acreage	16	0.40	0.30	0.14	-91.81	17.00

Central Appalachians (40 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Acreage	1	0.25	0.23	21.09	362.04	39.01
Mixed Forest LPI, Acreage	2	0.39	0.35	19.28	356.27	27.04
Mixed Forest LPI, Std Dev Slope, Acreage	3	0.47	0.42	18.18	353.11	20.83
Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI, Std Dev Slope	4	0.55	0.50	16.90	348.90	14.36
Elev, Std Dev Slope, PET, Acreage, NDVI	5	0.64	0.59	15.44	343.49	7.99
Evergreen CIRCLE, TA, Elev, Std Dev Slope, PET, NDVI	6	0.68	0.62	14.69	341.45	5.61
Evergreen CIRCLE, TA, IJI, Elev, Std Dev Slope, PET, NDVI	7	0.71	0.65	14.19	340.79	4.59
Evergreen CIRCLE, Mixed Forest LPI, TA, IJI, Elev, Std Dev Slope, PET, NDVI	8	0.72	0.64	14.31	343.76	6.15
Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI, TA, IJI, Elev, Std Dev Slope, PET, NDVI	9	0.72	0.63	14.50	347.39	8.01
Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI, TA, IJI, Elev, Std Dev Slope, PET, Acreage, NDVI	10	0.72	0.62	14.75	351.51	10.00
Deciduous CA, Evergreen CIRCLE, Mixed Forest LPI, TA, ENN, IJI, Elev, Std Dev Slope, PET, Acreage, NDVI	11	0.72	0.61	15.01	355.95	12.00

Middle Atlantic Coastal Plain (124 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
ENN	1	0.16	0.15	0.47	169.92	77.64
ENN, Acreage	2	0.24	0.23	0.45	159.75	60.96
Evergreen CA, ENN, Min Temp	3	0.32	0.31	0.43	147.70	43.57
Deciduous CA, Crops IJI, Evergreen CIRCLE, Min Temp	4	0.36	0.34	0.42	142.47	36.29
Deciduous CA, Evergreen CA, ENN, Min Temp, Pop Density	5	0.39	0.37	0.41	138.13	30.51
Deciduous CA, Crops IJI, Evergreen CA, Pasture IJI, ENN, Min Temp	6	0.44	0.41	0.39	131.35	22.46
Deciduous CA, Crops IJI, Evergreen CA, Pasture IJI, ENN, Min Temp, Pop Density	7	0.47	0.44	0.39	126.84	17.36
Deciduous CA, Crops IJI, Evergreen CA, Evergreen IJI, Pasture IJI, ENN, Min Temp, Pop Density	8	0.48	0.44	0.38	126.55	16.69
Deciduous CA, Deciduous SHAPE, Crops IJI, Evergreen CA, Evergreen IJI, Pasture IJI, ENN, Min Temp, Pop Density	9	0.49	0.45	0.38	126.04	15.84
Deciduous CA, Deciduous SHAPE, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture IJI, ENN, Min Temp, Pop Density	10	0.50	0.46	0.38	126.02	15.47
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture IJI, ENN, Min Temp, Pop Density	11	0.51	0.46	0.38	126.46	15.54
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture IJI, Open CA, ENN, Min Temp, Pop Density	12	0.52	0.47	0.37	126.70	15.41
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA, ENN, Min Temp, Pop Density	13	0.53	0.47	0.37	127.19	15.51
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA, ENN, IJI, Min Temp, Pop Density	14	0.53	0.47	0.37	128.41	16.24
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA, TA, ENN, Min Temp, Pop Density, Acreage	15	0.54	0.48	0.37	128.78	16.19

Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA, TA, ENN, IJI, Min Temp, Pop Density, Acreage	16	0.55	0.48	0.37	130.18	17.03
Deciduous CA, Deciduous SHAPE, Crops NP, Crops IJI, Evergreen CA, Evergreen AREA, Evergreen CIRCLE, Evergreen IJI, Pasture AREA, Pasture IJI, Open CA, TA, ENN, IJI, Min Temp, Pop Density, Acreage	17	0.55	0.48	0.37	131.77	18.00

Northern Piedmont (106 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open CA	1	0.15	0.15	2.29	480.80	26.12
Pop Density, Acreage	2	0.24	0.23	2.18	471.13	14.59
SHAPE, PRD, Pop Density	3	0.28	0.26	2.14	468.56	11.54
Open Water CA, SHAPE, PRD, Pop Density	4	0.30	0.27	2.12	467.70	10.37
Pasture NP, Open CA, Open AREA, SHAPE, PRD	5	0.31	0.28	2.11	467.58	9.99
Evergreen SHAPE, Evergreen PARA, Pasture NP, Open CA, Open AREA, PRD	6	0.33	0.28	2.10	468.06	10.17
Evergreen SHAPE, Evergreen PARA, Medium DCORE, Pasture NP, Open CA, Open AREA, PRD	7	0.34	0.30	2.08	467.54	9.40
Deciduous CA, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA, SHAPE, PRD	8	0.36	0.30	2.07	467.90	9.47
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Pasture NP, Pasture ED, Open CA, Open AREA, PRD	9	0.37	0.32	2.05	467.44	8.79
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA, PRD	10	0.39	0.32	2.04	467.94	8.98
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, PRD	11	0.40	0.33	2.03	468.58	9.28
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, PRD, Pop Density	12	0.40	0.33	2.03	470.00	10.21
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium	13	0.41	0.33	2.03	470.91	10.69

DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, PRD, Pop Density						
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, PRD, Pop Density, Acreage	14	0.42	0.33	2.03	473.03	12.14
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, SPLIT, PRD, Pop Density, Acreage	15	0.42	0.32	2.04	475.74	14.03
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, SPLIT, PRD, Min Temp, Pop Density, Acreage	16	0.42	0.31	2.05	478.62	16.01
Deciduous CA, Evergreen SHAPE, Evergreen PARA, Evergreen IJI, Medium DCORE, Open Water CA, Pasture NP, Pasture ED, Open CA, Open AREA, Open IJI, SHAPE, SPLIT, PRD, Min Temp, Pop Density, Acreage	17	0.42	0.31	2.06	481.59	18.00

Piedmont (332 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
PRD	1	0.17	0.17	0.67	679.73	166.47
Deciduous CA, Pop Density	2	0.27	0.27	0.63	636.66	105.63
Deciduous CA, Woody Wetlands NP, Pop Density	3	0.33	0.32	0.60	613.54	76.11
Deciduous CA, Woody Wetlands NP, Std Dev Slope, Pop Density	4	0.36	0.35	0.59	600.89	60.75
Deciduous CA, Open NP, Open LPI, Woody Wetlands NP, Std Dev Slope	5	0.37	0.36	0.58	593.70	52.20
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Open NP, Open LPI, PRD	6	0.39	0.38	0.58	587.33	44.82
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Woody Wetlands NP, PRD, Std Dev Slope, Pop Density	7	0.41	0.39	0.57	580.76	37.46
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Open NP, Open LPI, Woody Wetlands NP, PRD, Std Dev Slope	8	0.42	0.40	0.57	575.90	32.10
Deciduous CA, Evergreen CIRCLE, Pasture PARA, Open NP, Open LPI, Woody Wetlands NP, ENN, PRD, Std Dev Slope	9	0.43	0.41	0.56	573.26	29.15

Deciduous CA, Evergreen CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, PRD, Std Dev Slope, Pop Density	10	0.43	0.41	0.56	571.57	27.22
Deciduous CA, Evergreen CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, PRD, Std Dev Slope, Pop Density	11	0.44	0.42	0.56	568.47	23.92
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, PRD, Std Dev Slope, Pop Density	12	0.45	0.43	0.56	567.28	22.57
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA, PRD, Std Dev Slope	13	0.45	0.43	0.55	565.61	20.76
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA, PRD, Std Dev Slope, Pop Density	14	0.46	0.44	0.55	562.35	17.46
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA, ENN, PRD, Std Dev Slope, Pop Density	15	0.46	0.44	0.55	563.04	17.99
Deciduous CA, Evergreen CIRCLE, Open Water CIRCLE, Low CIRCLE, Pasture PARA, Pasture CLUMPY, Open NP, Open LPI, Woody Wetlands NP, Woody Wetlands SHAPE, Woody Wetlands PARA, ENN, PRD, MSIEI, Std Dev Slope, Pop Density	16	0.47	0.44	0.55	562.14	17.00

Ridge & Valley (248 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Deciduous CA	1	0.19	0.19	0.34	174.46	125.81
Deciduous CA, SHAPE	2	0.31	0.30	0.32	138.74	75.55
Deciduous CA, SHAPE, ENN	3	0.35	0.34	0.31	126.03	59.17

Deciduous CA, SHAPE, ENN, Pop Density	4	0.37	0.36	0.30	118.29	49.52
Deciduous CA, Crops IJI, SHAPE, ENN, PR	5	0.39	0.38	0.30	111.97	41.90
Deciduous CA, Crops IJI, SHAPE, ENN, PR, Pop Density	6	0.41	0.40	0.29	106.65	35.68
Deciduous CA, Crops IJI, Pasture CIRCLE, SHAPE, ENN, PR, Pop Density	7	0.43	0.41	0.29	102.70	31.12
Deciduous CA, Crops IJI, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope	8	0.44	0.42	0.29	98.84	26.79
Deciduous CA, Crops IJI, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Pop Density	9	0.46	0.44	0.29	94.10	21.72
Deciduous CA, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, SHAPE, ENN, PR, Std Dev Slope, Pop Density	10	0.46	0.44	0.28	93.96	21.36
Deciduous CA, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Pop Density	11	0.47	0.45	0.28	90.67	17.92
Deciduous CA, Crops PD, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Pop Density	12	0.48	0.45	0.28	91.10	18.16
Deciduous CA, Crops CA, Crops PD, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Pop Density	13	0.48	0.46	0.28	89.93	16.85
Deciduous CA, Crops CA, Crops PD, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Min Temp, Pop Density	14	0.49	0.46	0.28	91.01	17.70
Deciduous CA, Crops CA, Crops PD, Crops IJI, Mixed Forest DCORE, Mixed Forest CLUMPY, Pasture CIRCLE, Pasture DCAD, SHAPE, ENN, PR, Std Dev Slope, Max Temp, Min Temp, Pop Density	15	0.49	0.46	0.28	89.39	16.00

Southeastern Plains (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open Water NP	1	0.19	0.18	0.77	280.15	183.48

Open Water NP, NDVI	2	0.28	0.27	0.73	267.83	151.32
Open Water NP, DCORE, NDVI	3	0.35	0.33	0.70	258.83	129.64
Barren PARA, Open Water NP, DCORE, NDVI	4	0.41	0.39	0.67	248.44	107.44
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Open Water NP	5	0.48	0.46	0.63	236.25	84.70
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Open Water NP, NDVI	6	0.53	0.50	0.60	226.25	67.87
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Open Water NP, Open Water DCAD, NDVI	7	0.56	0.53	0.59	221.71	60.15
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Mixed Forest LPI, Open Water NP, Open Water DCAD, NDVI	8	0.58	0.55	0.57	217.39	53.21
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, NDVI	9	0.61	0.58	0.55	210.60	43.72
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, NDVI	10	0.62	0.59	0.55	209.06	40.98
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture IJI, NDVI	11	0.63	0.60	0.54	208.51	39.46
Deciduous AREA, Emergent PD, Emergent IJI, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture IJI, IJI, NDVI	12	0.65	0.61	0.53	205.99	35.83
Deciduous AREA, Emergent PD, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture IJI, IJI, NDVI	13	0.66	0.62	0.53	204.91	33.88
Deciduous AREA, Emergent PD, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, IJI, NDVI	14	0.68	0.63	0.52	202.10	30.26
Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, NDVI	15	0.69	0.64	0.51	200.51	28.01

Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, IJI, NDVI	16	0.70	0.65	0.50	197.67	24.70
Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, DCAD, IJI, NDVI	17	0.71	0.66	0.50	197.78	24.22
Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Pasture CIRCLE, Pasture IJI, DCAD, DCORE, IJI, NDVI	18	0.72	0.67	0.49	194.72	20.99
Deciduous AREA, Emergent PD, Emergent SHAPE, Emergent CIRCLE, Emergent IJI, Evergreen PD, Barren PARA, Medium CIRCLE, Mixed Forest LPI, Mixed Forest CLUMPY, Open Water NP, Open Water DCAD, Open Water IJI, Pasture CIRCLE, Pasture IJI, DCAD, DCORE, IJI, NDVI	19	0.73	0.68	0.48	194.14	20.00

APPENDIX Z

Selected Geographic Point Models Using a Combination of Class, Landscape, and Environmental Variables by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Cube Rt Alpha = 4.27 – 0.39 Crops SHAPE – 0.14 Mixed Forest AREA – 0.06 Pasture PD + 0.01 DCORE + 0.04 PR	5	108	0.32	0.29	-106.43	7.55
Central Appalachians	Alpha = -453.67 + 163.73 Evergreen CIRCLE + 0.00 TA + 0.07 Elev + 3.38 Std Dev Slope + 9.10 PET + 64.68 NDVI	6	40	0.68	0.62	341.45	5.61
Middle Atlantic Coastal Plain	4.5th Rt Alpha = -1.05 + 0.00 Deciduous CA + 0.02 Crops IJI + 0.00 Evergreen CA – 0.02 Pasture IJI – 0.01 ENN + 0.01 Min Temp + 4.48E-5 Pop Density	7	124	0.47	0.44	126.84	17.36
Northern Piedmont	Sq Rt Alpha = 18.55 – 5.81 SHAPE – 13.54 PRD + 0.00 Pop Density	3	106	0.28	0.26	468.56	11.54
Piedmont	Cube Rt Alpha = -7.25 + 9.38E-5 Deciduous CA + 9.76 Evergreen CIRCLE + 1.54 Open Water CIRCLE + 1.58 Low CIRCLE + 0.00 Pasture PARA + 2.02 Pasture CLUMPY + 0.00 Open NP + 0.06 Open LPI + 0.00 Woody Wetlands NP – 0.48 Woody Wetlands SHAPE – 0.00 Woody Wetlands PARA – 1.19 PRD + 0.06 Std Dev Slope + 0.00 Pop Density	14	332	0.46	0.44	562.35	17.46
Ridge & Valley	4.5th Rt Alpha = 0.59 + 7.25E-5 Deciduous CA + 0.01 Crops IJI + 0.19 Mixed Forest DCORE – 0.80 Mixed Forest CLUMPY – 2.41 Pasture CIRCLE + 0.06 Pasture DCAD + 1.56 SHAPE – 0.00 ENN + 0.05 PR + 0.03 Std Dev Slope + 0.00 Pop Density	11	248	0.47	0.45	90.67	17.92
Southeastern Plains	Cube Rt Alpha = -7.01 – 0.02 Deciduous AREA – 0.67 Emergent PD – 1.70 Emergent SHAPE + 6.03 Emergent CIRCLE – 0.03 Emergent IJI + 0.17 Evergreen PD + 0.01 Barren PARA – 2.88 Medium CIRCLE – 6.27 Mixed Forest LPI + 10.50 Mixed Forest CLUMPY + 0.04 Open Water NP	18	119	0.72	0.67	194.72	20.99

	+ 1.98 Open Water DCAD + 12.01 Pasture CIRCLE + 0.04 Pasture IJI – 0.16 DCAD – 0.09 DCORE – 0.04 IJI – 1.23 NDVI

APPENDIX AA

Geographic Point Combined Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.069, >0.150	0.288030
Central Appalachians	0.155, 0.066	12399.9
Middle Atlantic Coastal Plains	0.046, >0.150	25.5840
Northern Piedmont	0.076, 0.099	525.185
Piedmont	0.033, >0.150	104.708
Ridge & Valley	0.040, >0.150	20.8467
Southeastern Plains	0.045, >0.150	35.2501

APPENDIX AB

Selected BOVA Models Using a Combination of Class, Landscape, and Environmental Variables by Ecoregion

Note: The model with the minimum AICc + 2 and VIFs below 10 is highlighted; this model was selected as the best in the ecoregion.

Blue Ridge (88 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Elev	1	0.31	0.30	0.13	-99.03	53.91
Pasture DCAD, Elev	2	0.44	0.42	0.12	-114.59	30.71
Pasture PARA, Pasture DCAD, Elev	3	0.49	0.47	0.12	-121.28	21.83
Pasture SHAPE, Pasture PARA, Pasture DCAD, Elev	4	0.55	0.53	0.11	-129.13	12.73
Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Elev	5	0.58	0.55	0.11	-132.88	8.64
Crops LPI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Elev	6	0.61	0.58	0.10	-136.53	5.00
Crops LPI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, Elev	7	0.62	0.58	0.10	-136.10	5.17
Crops LPI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, DCAD, Elev	8	0.62	0.58	0.10	-134.88	6.01
Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, DCAD, Elev	9	0.62	0.58	0.10	-133.01	7.37
Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, DCAD, Elev, Precip	10	0.63	0.58	0.11	-130.59	9.15
Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, DCAD, PR, Elev, Precip	11	0.63	0.57	0.11	-128.00	11.00
Crops LPI, Evergreen IJI, Low AREA, Pasture SHAPE, Pasture PARA, Pasture DCAD, Open Water IJI, DCAD, PR, Std Slope, Elev, Precip	12	0.63	0.57	0.11	-125.17	13.00

Central Appalachians (34 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Open Water PARA	1	0.22	0.19	4.20	198.85	42.28
Open Water PARA, Open CA	2	0.43	0.39	3.64	190.52	24.44
Open Water PARA, Open CA, DCORE	3	0.50	0.45	3.47	189.01	20.25
Open Water PARA, Open CA, DCORE, MSIEI	4	0.63	0.57	3.05	182.03	10.52
Open Water PARA, Open CA, DCORE, MESH, MSIEI	5	0.71	0.66	2.73	176.39	4.62
Open Water PARA, Open CA, PARA, DCORE, MESH, MSIEI	6	0.74	0.68	2.64	176.31	3.99
Open Water PARA, Open CA, PARA, DCORE, MESH, MSIEI, Mean Slope	7	0.75	0.69	2.62	178.38	4.84
Open Water PARA, Open CA, PARA, DCORE, MESH, MSIEI, Mean Slope, Acreage	8	0.76	0.68	2.66	182.03	6.57
Open Water PARA, Open CA, PARA, DCORE, MESH, MSIEI, Mean Slope, Min Temp, Acreage	9	0.76	0.67	2.68	185.66	8.04
Open Water PARA, Open CA, TA, PARA, DCORE, MESH, MSIEI, Mean Slope, Min Temp, Acreage	10	0.76	0.66	2.74	190.47	10.01
Open Water PARA, Open CA, TA, PARA, DCORE, MESH, PR, MSIEI, Mean Slope, Min Temp, Acreage	11	0.76	0.64	2.80	195.80	12.00

Middle Atlantic Coastal Plain (129 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pasture PARA	1	0.19	0.19	16008353.00	4650.13	121.49
Pasture PARA, Acreage	2	0.32	0.31	14703167.00	4629.30	83.30
Deciduous CA, Pasture PARA, Acreage	3	0.42	0.41	13636815.00	4611.01	55.05
Deciduous CA, Pasture PARA, Pasture IJI, Acreage	4	0.47	0.45	13172985.00	4603.24	43.96
Deciduous CA, Pasture PARA, Pasture IJI, COHESION, Acreage	5	0.50	0.47	12865311.00	4598.34	37.19
Deciduous LPI, Crops CA, Evergreen CA, Pasture CA, Pasture PARA, Acreage	6	0.52	0.50	12540062.00	4592.95	30.30

Deciduous LPI, Crops CA, Evergreen CA, Pasture CA, Pasture AREA, Pasture PARA, Acreage	7	0.55	0.53	12221228.00	4587.56	23.87
Deciduous PD, Crops CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, COHESION, Acreage	8	0.57	0.54	12051933.00	4585.24	21.01
Deciduous PD, Deciduous LPI, Crops CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, COHESION, Acreage	9	0.59	0.55	11845636.00	4582.10	17.46
Deciduous PD, Deciduous LPI, Crops CA, Evergreen CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, COHESION, Acreage	10	0.60	0.57	11691074.00	4580.06	15.15
Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Evergreen CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, COHESION, Acreage	11	0.61	0.57	11622447.00	4579.92	14.70
Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Evergreen CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI, COHESION, Acreage	12	0.61	0.57	11578619.00	4580.35	14.78
Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI, COHESION, Acreage	13	0.62	0.58	11501413.00	4580.07	14.21
Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI, COHESION, Acreage	14	0.63	0.58	11480830.00	4581.09	14.80
Deciduous CA, Deciduous PD, Deciduous LPI, Deciduous CIRCLE, Crops CA, Crops AREA, Evergreen CA, Evergreen IJI, Mixed Forest PARA, Pasture CA, Pasture AREA, Pasture PARA, Pasture IJI, COHESION, Acreage	15	0.63	0.58	11490771.00	4582.84	16.00

Northern Piedmont (98 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Std Slope	1	0.19	0.18	0.00	-948.56	45.95

Low CA, Std Slope	2	0.37	0.35	0.00	-970.40	17.54
Deciduous CIRCLE, Pasture CLUMPY, Std Slope	3	0.39	0.38	0.00	-972.88	14.40
Mixed Forest CA, Mixed Forest AREA, Low CA, Std Slope	4	0.42	0.40	0.00	-975.47	11.35
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Pasture CLUMPY, Std Slope	5	0.44	0.41	0.00	-976.54	9.98
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Pasture CA, Pasture CLUMPY, Std Slope	6	0.47	0.43	0.00	-978.78	7.56
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Pasture CA, Pasture CLUMPY, Std Slope, NDVI	7	0.49	0.45	0.00	-979.80	6.40
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Pasture CA, Pasture CLUMPY, PRD, Std Slope, NDVI	8	0.50	0.46	0.00	-980.24	5.80
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Low CA, Pasture CA, Pasture CLUMPY, Std Slope, Pop Density, NDVI	9	0.51	0.46	0.00	-978.48	7.12
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Low CA, Pasture CA, Pasture CLUMPY, PRD, Std Slope, Pop Density, NDVI	10	0.51	0.46	0.00	-977.06	8.10
Deciduous CIRCLE, Mixed Forest CA, Mixed Forest AREA, Low CA, Pasture CA, Pasture CLUMPY, ENN, PRD, Std Slope, Pop Density, NDVI	11	0.52	0.45	0.00	-975.04	9.55
Deciduous CIRCLE, Medium CA, Mixed Forest CA, Mixed Forest AREA, Low CA, Pasture CA, Pasture CLUMPY, ENN, PRD, Std Slope, Pop Density, NDVI	12	0.52	0.45	0.00	-972.96	11.00
Deciduous CIRCLE, Medium CA, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, ENN, PRD, Std Slope, Pop Density, NDVI	13	0.52	0.45	0.00	-970.60	12.63
Deciduous CIRCLE, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, ENN, PRD, Std Slope, Pop Density, NDVI	14	0.52	0.44	0.00	-968.22	14.22
Deciduous CIRCLE, Medium CA, Medium AI, Mixed Forest CA, Mixed Forest AREA, Open Water CA, Low CA, Pasture CA, Pasture CLUMPY, ENN, MESH, PRD, Std Slope, Pop Density, NDVI	15	0.52	0.44	0.00	-965.56	16.00

Piedmont (334 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Woody Wetlands NP	1	0.22	0.21	0.13	-403.39	106.47
Woody Wetlands NP, SI	2	0.26	0.25	0.13	-419.87	84.92
Pasture PARA, Woody Wetlands NP, SI	3	0.30	0.29	0.12	-436.51	64.43
Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI, SI	4	0.32	0.31	0.12	-442.38	57.25
Evergreen PD, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI, SI	5	0.33	0.32	0.12	-448.93	49.52
Evergreen PD, Mixed Forest CA, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI, SI	6	0.34	0.33	0.12	-452.47	45.30
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI, SI	7	0.35	0.34	0.12	-454.15	43.18
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Mixed Forest CA, Pasture PARA, Woody Wetlands NP, Woody Wetlands IJI, SI	8	0.36	0.35	0.12	-458.02	38.75
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Mixed Forest CA, Pasture PARA, Open CA, Woody Wetlands NP, Woody Wetlands IJI, SI	9	0.37	0.36	0.12	-461.50	34.84
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Mixed Forest CA, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, SI	10	0.38	0.37	0.12	-465.12	30.86
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, SI	11	0.39	0.37	0.12	-467.48	28.25
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, SI	12	0.40	0.38	0.12	-470.94	24.58
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, SI	13	0.41	0.39	0.12	-474.24	21.15
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, SI, Avg NDVI	14	0.42	0.39	0.12	-475.38	19.90

Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, ENN, IJI, SI	15	0.43	0.40	0.12	-477.15	18.05
Deciduous SHAPE, Deciduous PARA, Evergreen PD, Evergreen CIRCLE, Mixed Forest CA, Mixed Forest CIRCLE, Open Water CLUMPY, Pasture PARA, Open CA, Open LPI, Woody Wetlands NP, Woody Wetlands IJI, ENN, IJI, SI, NDVI	16	0.43	0.40	0.11	-478.11	17.00

Ridge & Valley (290 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Pasture NP	1	0.26	0.26	0.23	-30.93	141.20
Pasture NP, Precip	2	0.35	0.35	0.21	-67.18	90.34
Pasture NP, Open PARA, Precip	3	0.40	0.40	0.21	-89.54	62.09
Pasture NP, Pasture PARA, Open PARA, Precip	4	0.44	0.43	0.20	-106.66	42.05
Deciduous NP, Pasture NP, Pasture PARA, Open CA, Precip	5	0.46	0.45	0.20	-112.65	35.18
Deciduous NP, Pasture NP, Pasture PARA, Open CA, Open PARA, Precip	6	0.47	0.46	0.19	-120.49	26.61
Deciduous NP, Pasture NP, Pasture PARA, Pasture IJI, Open CA, Open PARA, Precip	7	0.48	0.47	0.19	-120.25	26.65
Deciduous NP, Pasture NP, Pasture PARA, Pasture IJI, Open CA, Open PARA, MSIEI, Precip	8	0.49	0.47	0.19	-122.12	24.52
Deciduous NP, Crops NP, Crops PD, Pasture CA, Pasture NP, Pasture PARA, Open CA, Open PARA, Precip	9	0.50	0.48	0.19	-125.60	20.80
Deciduous NP, Crops NP, Crops PD, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Open CA, Open PARA, Precip	10	0.50	0.49	0.19	-127.89	18.35
Deciduous NP, Crops NP, Crops PD, Evergreen PD, Pasture CA, Pasture NP, Pasture PARA, Pasture IJI, Open CA, Open PARA, Precip	11	0.51	0.49	0.19	-132.09	14.11
Deciduous NP, Crops NP, Crops PD, Evergreen PD, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA,	12	0.52	0.50	0.19	-132.29	13.80

Open PARA, Precip						
Deciduous NP, Crops NP, Crops PD, Evergreen PD, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA, Open PARA, MSIEI, Precip	13	0.52	0.50	0.19	-131.35	14.56
Deciduous NP, Crops NP, Crops PD, Evergreen PD, Pasture CA, Pasture NP, Pasture PARA, Pasture DCAD, Pasture IJI, Open CA, Open PARA, DCORE, MSIEI, Precip	14	0.52	0.50	0.19	-130.76	15.00

Southeastern Plains (119 HUs)

Model	# Vars	R^2	Adj R^2	RMSE	AICc	Cp
Precip	1	0.17	0.17	6.80	798.02	85.91
Deciduous AREA, Precip	2	0.26	0.25	6.46	787.10	67.03
Deciduous AREA, Medium IJI, Precip	3	0.32	0.30	6.23	779.68	55.07
Deciduous AREA, Crops NP, Evergreen NP, Precip	4	0.39	0.37	5.90	767.86	38.59
Deciduous AREA, Open Water SHAPE, Pasture AREA, Precip, NDVI	5	0.43	0.40	5.76	763.10	32.14
Deciduous AREA, Crops NP, Evergreen NP, Open Water SHAPE, Precip, NDVI	6	0.46	0.43	5.63	758.99	26.85
Deciduous AREA, Crops NP, Evergreen NP, Open Water SHAPE, Pasture AREA, Precip, NDVI	7	0.49	0.46	5.48	753.94	20.90
Deciduous AREA, Crops NP, Evergreen NP, Barren PARA, Open Water SHAPE, Pasture AREA, Precip, NDVI	8	0.52	0.49	5.34	748.89	15.39
Deciduous AREA, Crops NP, Evergreen NP, Barren PARA, Open Water SHAPE, Pasture PD, Pasture AREA, Precip, NDVI	9	0.53	0.50	5.29	748.14	14.33
Deciduous AREA, Crops NP, Evergreen NP, Barren PARA, Barren CIRCLE, Open Water SHAPE, Pasture PD, Pasture AREA, Precip, NDVI	10	0.55	0.50	5.24	747.52	13.42
Deciduous AREA, Crops NP, Evergreen NP, Barren PARA, Barren CIRCLE, Medium IJI, Open Water SHAPE, Pasture PD, Pasture AREA, Precip, NDVI	11	0.56	0.51	5.19	746.30	12.00

APPENDIX AC

Selected BOVA Models Using a Combination of Class, Landscape, and Environmental Variables by Ecoregion

Ecoregion	Model	# Vars	# HUs	R^2	Adj R^2	AICc	Cp
Blue Ridge	Cube Rt Alpha = 1.92 – 0.35 Crops LPI + 0.03 Low AREA + 0.50 Pasture SHAPE + 0.00 Pasture PARA – 0.06 Pasture DCAD + 0.00 Elev	6	88	0.61	0.58	-136.53	5.00
Central Appalachians	Alpha = 73.97 – 0.02 Open Water PARA + 0.02 Open CA - 0.28 DCORE – 0.00 MESH – 33.24 MSIEI	5	34	0.71	0.66	176.39	4.62
Middle Atlantic Coastal Plain	Alpha^4 = 83536992.2 – 2098822.1 Deciduous PD – 333784.5 Deciduous LPI + 7954.24 Crops CA – 3292.71 Evergreen CA 85054.37 Mixed Forest PARA – 16153.47 Pasture CA + 2351811.9 Pasture AREA + 79222.91 Pasture PARA – 2131884.5 COHESION + 1134.71 Acreage	10	129	0.60	0.57	4580.06	15.15
Northern Piedmont	1/Alpha = 0.03 – 0.04 Deciduous CIRCLE – 3.18 Mixed Forest CA + 0.00 Mixed Forest AREA + 2.60E-7 Pasture CA + 0.01 Pasture CLUMPY – 0.00 Std Slope	6	98	0.47	0.43	-978.78	7.56
Piedmont	Cube Rt Alpha = 3.00 – 0.32 Deciduous SHAPE – 0.00 Deciduous PARA + 0.02 Evergreen PD + 1.79 Evergreen CIRCLE + 0.00 Mixed Forest CA – 0.76 Mixed Forest CIRCLE – 0.16 Open Water CLUMPY + 0.00 Pasture PARA – 0.00 Open CA + 0.02 Open LPI + 0.00 Woody Wetlands NP + 0.00 Woody Wetlands IJI + 0.00 ENN + 0.00 IJI – 0.03 SI	15	334	0.43	0.40	-477.15	18.05
Ridge & Valley	Cube Rt Alpha = 2.08 + 0.00 Deciduous NP + 0.00 Crops NP – 0.10 Crops PD – 0.02 Evergreen PD -4.40E-5 Pasture CA + 0.00 Pasture NP + 0.00 Pasture PARA + 0.00 Pasture IJI – 0.00 Open CA + 0.00 Open PARA + 0.00 Precip	11	290	0.51	0.49	-132.09	14.11
Southeastern Plains	Alpha = 1.93 – 0.15 Deciduous AREA + 0.03 Crops NP – 0.03 Evergreen NP + 0.03 Barren PARA – 3.92 Open Water	9	119	0.53	0.50	748.14	14.33

	SHAPE – 1.12 Pasture PD – 0.97 Pasture AREA + 0.01 Precip – 13.06 NDVI

APPENDIX AD

BOVA Combined Models Cross-Validation Statistics

Model	Residual K-S, P	Cross-Validation PRESS
Blue Ridge	0.067, >0.150	1.60639
Central Appalachians	0.082, >0.150	320.135
Middle Atlantic Coastal Plains	0.075, 0.076	1.99103E16
Northern Piedmont	0.069, >0.150	0.000304764
Piedmont	0.037, >0.150	4.63107
Ridge & Valley	0.075, <0.010	10.7599
Southeastern Plains	0.060, >0.150	3711.48

APPENDIX AE

Figures

Figure 1. Graph of the frequency of each variable type in the combined best subset models for the geographic point data and BOVA data across the ecoregions. Three types of variables were used: environmental factors, landscape fragmentation metrics, and class fragmentation metrics. Landscape and class fragmentation metrics were calculated using FRAGSTATS software (McGarigal et al. 2002).

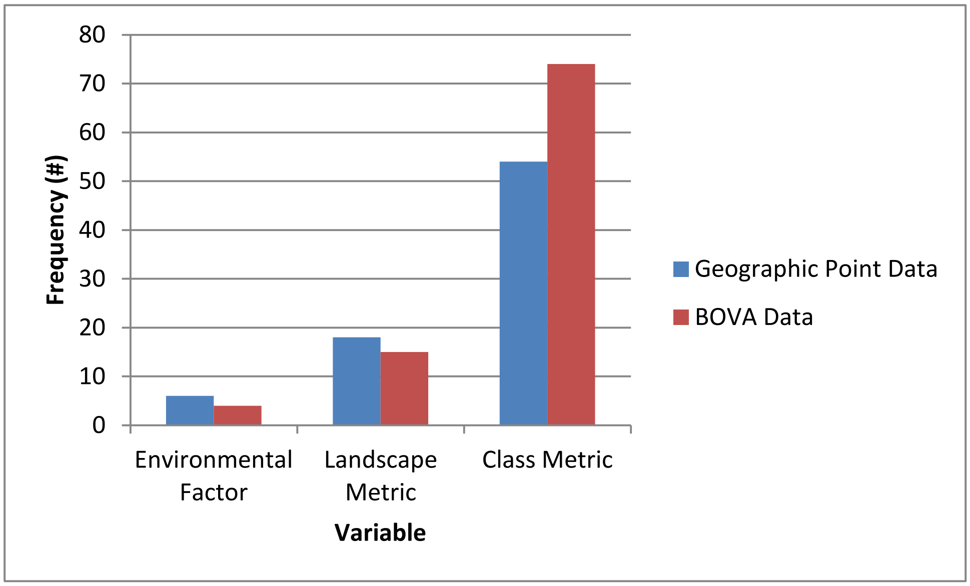

Figure 2. Graph of adjusted R^2 by ecoregion and number of variables for each type of model with the geographic point data.

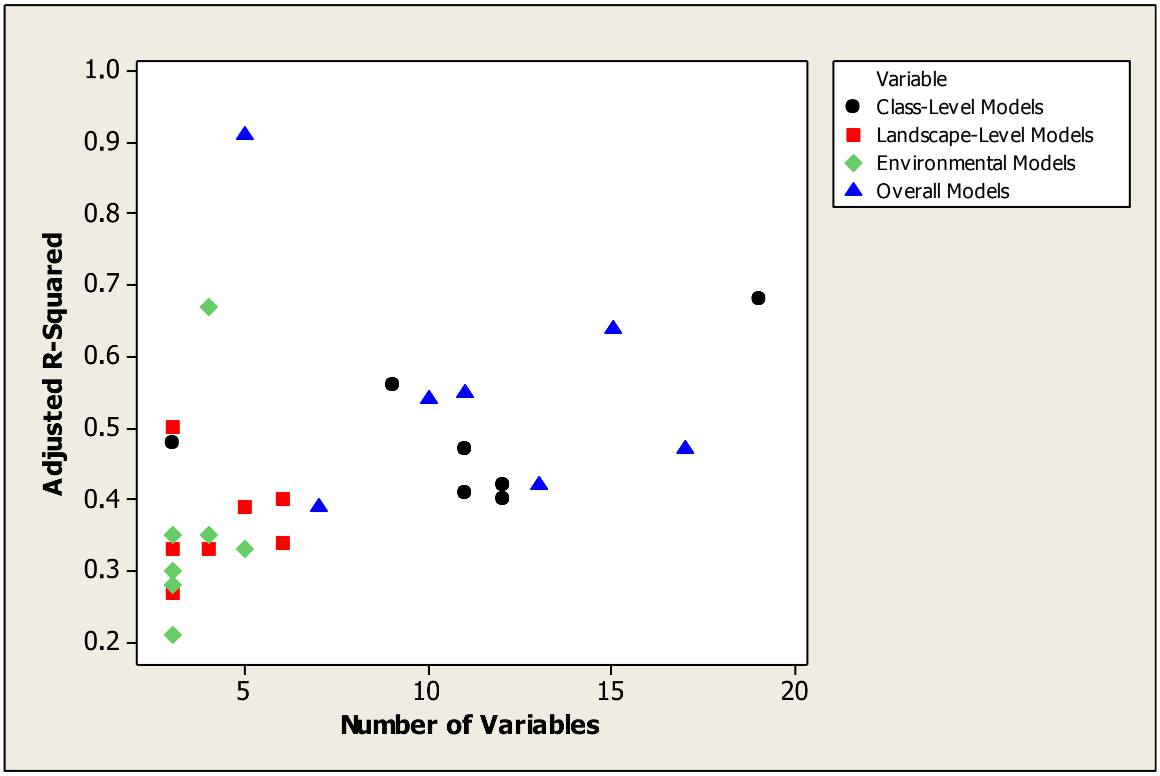

Figure 3. Graph of adjusted R^2 by ecoregion and number of variables for each type of model with the BOVA data.

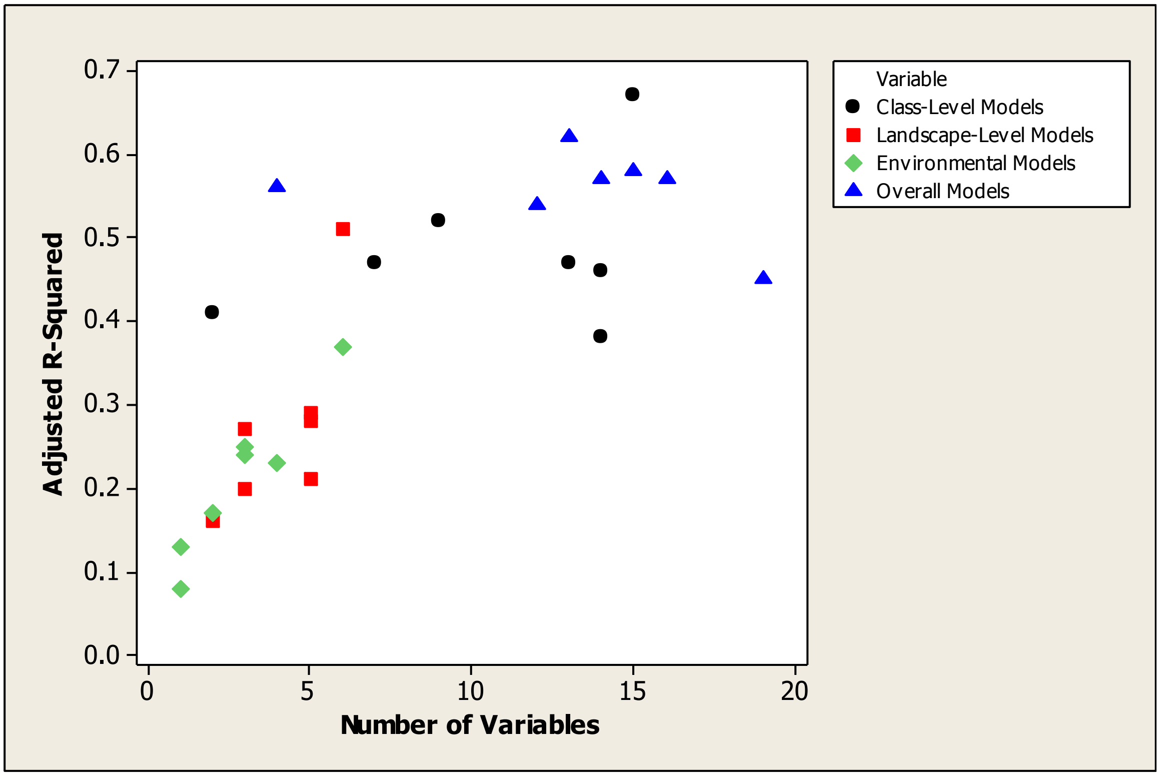

Figure 4. A comparison of the frequency each variable appeared in the geographic point data and BOVA data environmental best subset regression models across the ecoregions.