

Amphibian and Reptile Diversity Distributions in a Complex,  
Human-Dominated Landscape

Abstract of  
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## **Abstract**

Many species of amphibians and reptiles are considered highly vulnerable to habitat fragmentation, due to their complex life cycles and migratory behaviors. Many require connectivity of upland and wetland habitats to meet specific life-history requirements. Previous studies have demonstrated that the remnant herpetofauna of fragmented forests are sensitive to combinations of habitat area, habitat heterogeneity, and surrounding landscape composition. To date, no studies have elucidated the combined contributions of these influences.

I examined species richness and abundance of herpetofauna in forest patches embedded in rural, suburban and urban landscapes of NY, NJ, and CT; visiting 39 patches in 2004. In 2005, I repeated this for 29 patches and added 3 large forest tracts as reference sites. I estimated patch area, quality, and proximity to forests and wetlands, as well as surrounding landcover and road density within 4 different zones (50m, 250m, 500m and 1km buffers). Altogether 24 species were found, representing 80% of the potential species pool. No patches contained the full suite of species. Total species richness, as well as richness within taxonomic subgroupings (Anurans, Caudates, Squamates, Testudines, Ranids) were each correlated positively with patch area, as were subsets of sensitive species and common species. Regression slopes for species/area were in a range suggestive of island-like isolation ( $z = 0.270 - 0.493$ ). Sensitive species were generally restricted to large forests or patches within an agricultural and forest-dominated landscape ( $P < 0.001$ ). Results from two-way ANOVAs indicate significant effects of both patch size and wetland presence on species richness, with a significant interaction due to the higher likelihood of wetlands occurring in larger patches. The

frequency and abundance of common species were positively associated with the presence of wetlands and patch area ( $P < 0.05$ ). In addition, terrestrial salamanders were negatively correlated with earthworm abundance ( $P < 0.05$ ). Presence of most species assemblages were associated with land cover patterns within 500 m of forest patches, whereas individual species were associated with unique landscape variables. Across all patches, I observed a hierarchical pattern of nestedness, with all but the most common taxa declining in frequency as patch size declined; however smaller patches containing wetlands were exceptions. No nested pattern was observed for a matrix of species occurrence versus surrounding landcover, indicating that the landscape matrix has minimal influence on species occurrence.

These forest patches appear to be isolated, with little evidence for immigration or rescue effect from outside sources and the main external determinants of community composition were forest patch area and quality. Although patch size alone was a reasonable estimator of coarse-level diversity, predicting species-specific distributions required more detailed information on patch quality and surrounding land use. Continual fragmentation and development of these landscapes may drive species assemblages towards a more homogeneous group of tolerant species.

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## **1. Introduction**

MacArthur and Wilson's Theory of Island Biogeography (1967) predicts patterns of species richness on islands as a dynamic equilibrium between extinction and immigration. Immigration is limited by distance from source populations and extinctions are a function of habitable area, which sets limits on maximum population size. As species accumulate, niches get filled and immigration becomes a replacement process for those species that become extinct. Although the assumption of species equilibrium is difficult to confirm, many investigations of island-like habitats have relied on Island Biogeography theory (Rosenzweig 1995, Cook et al. 2002). When applied to land-bridge islands or mainland habitat patches, equilibrium species richness is predicted to fall as populations fail and potential replacements get disconnected. In this study I treated forest patches as islands, to test whether distributions of amphibian and reptile species could be predicted on the basis of forest patch size in a fragmented, urbanizing landscape.

Small bodied amphibians and reptiles are exceptionally sensitive to environmental changes because they often require the use of multiple habitats such as wetlands and forests for overwintering, reproducing, and foraging (Ernest et al. 1994, Ernest and Ernest 2003, Lannoo 2005), and because they are sensitive to moisture and temperature changes (Welsh and Droege 2001, Lannoo 2005). In cases such as these, an increase in habitat area increases interior habitat as well as habitat heterogeneity, allowing potentially more species to co-occur. Many species that undergo annual migrations from overwintering to breeding habitat are affected by habitat fragmentation and landuse change, which can degrade, destroy, or shrink habitat as well as fragment patches previously connected. Amphibians and reptiles are thought to function as source-sink or metapopulations requiring connectivity of upland and

wetland habitat for dispersal to suitable habitat, but because they are so sensitive to physical environments, dispersal across unsuitable habitat may be impeded (Gibbs 1998a, Boudjemadi et al. 1999). Connectivity is vital to long-term population survival, so land use change can have dramatic impacts on species survival as habitats become functionally disconnected (Gibbs 1998b). Due to their unique sensitivities, habitat area and connectivity through the landscape can affect species distributions.

Anthropogenic land use converts continuous forest into fragments and eliminates wetland habitats. These losses of habitat area and connectivity can have dramatic impacts on species distribution and persistence (Houlahan and Findlay 2003). High road density and loss of forest cover in urbanizing zones have negative effects on amphibian and reptile population viability and diversity, whereas rural areas (combinations of wetland, agricultural, and forest) support more species and larger populations (Findlay and Houlahan 1997, Gibbs 1998a, Knutson et al. 1999, Findlay and Bourdages 2000, Steen and Gibbs 2004, Andrews and Gibbons 2005, Steen et al. 2006). Fahrig and Merriam (1994) determined that increases in land conversion, road density, and impervious surface cover had profound effects on wetland and forest habitats, altering the structure of the landscape with direct effects on population persistence for herpetofauna. Roads and other terrestrial alterations can cause a shift in community composition and alter species evenness in different habitats, this may be due to species specific sensitivities to edge effects and differences in dispersal abilities (Bennett et al. 1980, Fahrig and Merriam 1994, Demaynadier and Hunter 2002). Forest-dominated landscape matrices offer more habitat, more cover, and more mating opportunities (Guerry and Hunter (2002).

As land use changes from natural systems towards urban, herpetofauna are threatened by several interacting processes: alteration and destruction of wetland and forest habitats, disconnection of populations, and impeded dispersal at multiple scales. It is difficult to sort out the effects of these entangled threats to discover how each influences species distributions. Whether populations are disconnected can be difficult to judge, with some species functionally disconnected and others able to disperse over degraded areas.

A global amphibian decline has been documented, and much research has been devoted to the causes that may be contributing to the loss and degradation of amphibian populations worldwide (Stebbins and Cohlen 1995). Additional research points to similar levels of reptile population declines (Gibbons et al. 2000). The results of these efforts have shown that multiple and diverse factors affect populations, but the most recognized and widespread contributor to these declines is habitat degradation associated with changes in landuse (Lannoo 1998, Semlitsch 2002, Collins and Storfer 2003), with emphasis on habitat fragmentation (Fahrig and Merriam 1985, Venier and Fahrig 1996, Fahrig 1998, and a review by Bender et al. 1998).

Most landuse change in the northeastern US is a result of growth of the urban fringe. Such growth often leads to expansions of road density and urbanization and reductions of forest and wetland habitats, all of which have been shown to have dramatic effects on species survival. In North America, research on responses of amphibians and reptiles to landuse change have found wetland fragmentation, road density, urbanization, and proximity to forest and wetland habitats influence species assemblages and richness (Bennett et al. 1980, Findlay and Houlihan 1997, Gibbs 1998a, Gibbs 1998b, Hecnar and M'Closkey 1998, Knutson et al. 1999, Findlay and Bourdages 2000, Mac Nally and Brown 2001, Templeton et al. 2001,

Demaynadier and Hunter 2002, Guerry and Hunter, 2002, Mann et al. 2003, Steen and Gibbs 2004). Most amphibian studies have concentrated on few aspects, mostly wetland habitat use, with few examining the effects of forested habitat fragmentation on the diverse and dynamic ecologies of amphibians and reptiles. Those that have focused on forest habitat fragmentation were located in agricultural landscapes of the mid western United States (Kolozsvarly and Swihart 1999, Weyrauch and Grubb 2004).

The complexity of urbanizing landscapes makes them difficult targets for research on habitat fragmentation, but their proliferation requires that ecologists pay them more attention. To date, no studies have directed research at the combined effects of declining habitat area, habitat quality and habitat disconnection in within these complex landscapes. Therefore, we have been unable to delineate key factors in the decline of amphibians and reptiles. To sort out these intertwined effects I examined different sized forest patches with differing habitat quality and surrounding landcover types. By relating species richness and abundance to patch area, patch quality, as well as landscape composition, I attempted to infer their relative contributions to species distributions and community structure in an urbanizing landscape.

This study examined the effects of forest patch size, surrounding matrix composition, wetland availability, and road density on amphibian and reptile communities within fragmented landscapes of the northeastern United States. I hypothesized that each species or species group should have unique responses to each variable based on their habitat requirements and sensitivity to environmental factors at a landscape scale. I tested the following hypotheses: 1) forest patches should not support the same assemblages as large contiguous forests, although area should be positively related to species richness, relative abundance and diversity, 2) species sensitivity and response to environmental factors related

to landscape change should be dependent on life history requirements and dispersal ability, in general most species should be correlated with proximity to outside wetland and forested habitats, 3) species distributions should exhibit a nested pattern as sensitive, area-dependant species drop out with decreasing patch area and quality as well as with gradations of development in the surrounding landscape and, 4) sensitive and/or rare species should be less abundant than generalist species in smaller patches and heavily altered landscapes, driving assemblages towards a more homogeneous group of tolerant species.

## **2. Methods**

### 2.1 Study Area

#### 2.1a Site Selection

Thirty-nine forest patches, ranging in size from 0.3 to 19 ha, were selected for the study. Criteria for selection were: deciduous tree canopy, with a distance to the nearest forest patch at least 50m. Landscapes surrounding these patches ranged from agricultural to urban. During the summer field season (April – August) of 2004, surveys were conducted in forest patches in New York, New Jersey and Connecticut. During the summer season of 2005 these surveys were conducted in the NY and CT patches only, and three large forest tracts (250 – 750 ha) in Dutchess County were added as reference sites. The 10 study sites in NJ are in Hunterdon, Somerset and Morris Counties. The 12 CT sites were in Tolland and Hartford Counties and the 17 NY sites are in Dutchess County (Appendix 1).

## 2.1b Survey Methods

I conducted call surveys in each patch containing wetlands in all states during April and May 2004. In 2005, I surveyed NY during April and May, and CT in April and June. This technique provides data on the presence and relative abundance of anurans (Heyer et al. 1994, Sutherland 1996). The 5-minute surveys were conducted at one point at all wetlands in each patch (Gibbs 1998a, Guerry and Hunter 2002, NAAMP 2004). Data were recorded with an abundance index (0-4) (Knutson et al. 1999, Dodd 2003, NEARMI 2004), with 0 = 0 frogs calling; 1 = 1 individual calling; 2 = < 5 individuals calling; 3 = > 5 to 10 individuals calling; 4 = > 10 individuals calling. The surveys took place between sunset and midnight (following Kolozsvary and Swihart 1999, Guerry and Hunter 2002, NAAMP 2004). Environmental variables were recorded for all methods during every sampling period; precipitation, time of last precipitation, percent cloud cover, wind, air and water temperature (following Heyer et al. 1994, Guerry and Hunter 2002, Jung 2002, NEARMI 2004).

In 2004 all sites were surveyed in May and July, in 2005 CT sites were surveyed in June and July and NY sites were surveyed in June, using a visual search for egg masses and adult amphibian and reptile species (Heyer et al. 1994, Lips et al. 2001). Two people walked around each wetland in opposite directions until the other person was encountered (Guerry and Hunter 2002), recording all adults and egg masses seen (Sutherland 1996).

Larval sampling was conducted in May and July 2004, and in 2005, in June and July in CT and June in NY. I used dip netting to search wetlands for tadpoles, metamorphs, and aquatic amphibians and reptiles (Heyer et al. 1994, Sutherland 1996, Kolozsvary and Swihart 1999, Mann et al. 2003). At every 6 meters around wetland margins, we took 2 sweeps, approximately 2 meters into the wetland towards shore and along the bottom, with a 12-inch

D shaped dipnet (Heyer et al. 1994, Dodd 2003). This was done in the opposite direction from the visual search so as not to survey recently disturbed areas. Individuals were counted and tallied, while species and age category were recorded.

A stream search was conducted in July 2004 and 2005, yielding species presence/absence, relative abundance and density of amphibian and reptiles (Heyer et al. 1994). This was done by performing a time search along streams up to 1 person-hour per patch (Heyer et al. 1994), searching under rocks and using a small dipnet (Heyer et al. 1994, Sutherland 1996, Jung 2002, Lowe and Bolger 2002, Dodd 2003).

A terrestrial time search was conducted in July 2004 and CT in 2005 and July and August in NY 2005. I spent 2.5 person-hours per patch or until the whole patch was searched (Gibbs 1998a, Mac Nally and Brown 2001), individuals encountered were tallied, and species and age category were recorded. The patches were surveyed for all species by over turning all cover objects (200cm<sup>2</sup> and larger) and visually searching the ground for what was visible (Heyer et al. 1994, Sutherland 1996, Mac Nally and Brown 2001, Lips et al. 2001).

At each wetland, water samples were collected in 60 ml Polypropylene bottles once from April to June 2004, refrigerated for no more than 3 weeks and analyzed in the lab for conductivity and pH. Throughout each patch vegetative data was collected. Percent cover of herbaceous species were estimated and grouped into 5 categories (forb, grass, fern, moss and impervious) in 8, 2m<sup>2</sup> plots. Tree species were recorded using 5, point-quarter plots. Species, DBH and distance from the center point were recorded. Shrub cover was measured in 4 line transects, where distance of shrub cover along the line and the dominate species were recorded (Sutherland 1996).



During the 2005 field season, earthworms found under cover objects during the terrestrial time search were estimated and grouped into 4 categories. Categories were: no earthworms found (0), from 1 earthworm to less than ½ of all cover objects containing 1 earthworm (1), greater than ½ of all cover objects containing at least 1 earthworm (2), and at least 1 earthworm under all cover objects (3).

### 2.1c Landscape and Habitat Classification

A Geographic Information System (GIS) ArcGIS 8.x, was used to measure patch area, landscape matrix composition (forested, wetland, agriculture, developed), road density (km/km<sup>2</sup>), proximity to wetlands and forests (linear distance from patch edge to wetland or forest edge), and the area of any visible wetland within the study patch. Landcover was quantified by digitizing orthoimagery within a 1km radius of the center of each site. This distance is thought to be biologically relevant due to dispersal estimates of these species (Knutson et al. 1999, Guerry and Hunter 2002, Lannoo 2005). MrSid Digital Ortho Photography of Dutchess County, NY from May 2000 (Coordinate System and Projection: North American Datum (NAD) 1983, NY East, State Plane Feet, Transverse Mercator) was used for NY. The same was performed for NJ sites using MrSid Digital Ortho Photography of the State of New Jersey from February- April 2002 (NAD 83, NJ, State Plane Feet, Transverse Mercator). Connecticut data were digitized from the University of Connecticut Center Land use Education and Research (CLEAR) 2004 digital orthoimages (NAD 83 datum and CT state plane coordinate system).

Shapefiles of landuse/landcover for each state were used beyond each buffer when needed. For Connecticut I used 2002 supervised landcover classification map created by CLEAR with (NAD 1983 horizontal datum, and the Connecticut State Plane coordinate

system in feet, with a Lambert Conic projection). For New York I used landuse/landcover from 1995 (UTM Zone 18 projection, and NAD27 datum) in meters. New Jersey data were from the New Jersey Department of Environmental Protection (NJDEP) 1995/1997 landuse/landcover data in digital vector form (NAD 83 datum with the NJ state plane coordinate system 1983).

All data were categorized by using a modified New York State Land Use and Natural Resources Inventory (LUNR) code. From this, 4 landcover variables were combined, developed (DEV), forested (FOR), agricultural (AGR), and wetland and open water combined as one category (WLD) (Knutson et al. 1999). Percent matrix composition around each patch was quantified at 4 scales, 1km from the center of the patch, as well as 500m, 250m, and 50m radius buffers from the edge of each patch (Findlay and Houlihan 1997, Guerry and Hunter 2002).

Road density estimates were made at the same buffer distances used in the matrix composition to quantify road density at each of the 4 scales (Findlay 1997). For Connecticut I used the United States Geological Survey (USGS) Census TIGER data from 2000, projected in Lambert Conformal Conic in State Plane coordinates, with the horizontal datum NAD 1983. For New York I used USGS TIGER data from 1995, in New York East State Plane in feet, NAD 27 datum. For New Jersey roads I used NJDEP TIGER data from 2000, with NAD 83 datum, in NJ state plane coordinate system.

Forest patch area was calculated from the digitized data, then natural log transformed for analysis [ $\ln(\text{area}+1)$ ]. Four categories of patch area were created for categorical analyses: 1 = 0.30-5.00 ha, 2 = 5.01-10.00 ha, 3 = 10.01 – 20.00 ha, and 4 = 245.00-755.00 ha. Proximity to nearest forest at least 10ha in area was measured manually in the GIS from the

edge of each patch to the edge of the nearest forest. Digitized data were typically used to estimate distance (m) and area (ha) except when a forest exceeded the 1km buffer, where landuse/landcover data was used.

United States Fish and Wildlife Service, National Wetlands Inventory data (NWI) were used to calculate the proximity of the 2 nearest wetlands outside of the forest patch. These were measured manually from edge of the forest patch to edge of the wetland. Distance, wetland type, and size were recorded. NWI data were also used to calculate area of wetland within the forest patches and wetlands were digitized based on field measurements in cases where NWI data did not include a known wetland. Percent wetland and hydroperiod of each wetland within each patch was estimated. Hydroperiod was grouped as temporary or permanent based on observation throughout the season and stream presence was recorded, as was presence of fish in either stream or wetland.

## 2.2 Analytical Procedure

### 2.2a Species and Environmental Variables

Data were organized into three analytical sets; a) 39 forest patches in NY, NJ, and CT surveyed in 2004, b) 29 forest patches in NY and CT and 3 large reference forests in NY surveyed in 2005, and c) 29 forest patches in NY and CT, surveyed in 2004 and 2005. These will be referred to as 2004, 2005, and 2004/2005 data groups throughout. Species were examined individually as well as grouped by order and class: amphibians, reptiles, anurans, caudates, testudines, squamates, and ranid species. Species encountered were further divided into two susceptibility groups based on the literature (Table I). Sub-groupings of orders were divided further into sensitive and/or rare and common groups. Analyses were performed to

determine if these groups of species were valid in that the individuals within responded similarly to patch area and environmental variables.

**Table I.** Species characterized as sensitive/rare or common based on susceptibility to patch area, landscape, and relative occurrence throughout the study area.

Species	Habitat Susceptibility & Occurrence	References
<i>Ambystoma laterale</i> *	Declining due to habitat loss, sensitive to fragmentation and edge effects	Amphibian Declines 2005
<i>A. jeffersonianum</i> *	Special concern in CT, sensitive to habitat disturbance, requires forest and wetlands within 200-250m	Amphibian Declines 2005
<i>Notophthalmus viridescens</i> *	Area sensitive	Hager 1998
	Vulnerable to fragmentation	Gibbs 1998
<i>Terrapene carolina</i> *	Near the edge of range in NY, many killed by cold, sensitive to microclimate, nests destroyed by mesopredators, population numbers are decreasing, sex ratios altered	Turtles of the US and Canada 1994
<i>Bufo americanus</i> **	Not sensitive to area	Hager 1998
	Not very sensitive to fragmentation	Amphibian Declines 2005
<i>Pseudacris crucifer</i> **	Resistant to fragmentation	Amphibian Declines 2005
<i>Hyla versicolor</i> **	Ubiquitous	Kolozsvary and Swihart 1999
<i>Rana palustris</i> **	Inhabits grassy habitats, does not require forest	Amphibian Declines 2005
<i>Rana clamitans</i> **	Common	Amphibian Declines 2005
<i>Rana catesbeiana</i> **	Not sensitive to area	Hager 1998
<i>Ambystoma maculatum</i> **	Widespread, present in fragmented areas	Amphibian Declines 2005
<i>Plethodon cinereus</i> **	Abundant	Burton and Likens 1975
<i>Eurycea bislineata</i> **	Widespread	Amphibian Declines 2005
<i>Thamnophis sirtalis</i> **	Inhabits a variety of habitats, daily movement, can move long distances, generalist feeder	Snakes of US and Canada 2003

\*Sensitive or rare species

\*\*Common species

Species richness was calculated using species occurrences in each patch from all sampling methods. Species abundance was estimated based on the maximum number of individuals found during one sampling method, so as to not over-estimate individuals. For parametric tests, all continuous variables analyzed (richness, abundance, and patch area) were natural log transformed. Species richness was also grouped into categorical groups for more tests as follows: 0 = 0, 1 = 1-4, 2 = 5-10, 3 = 11+ species. Abundance data was classified in a similar manner, with 0 = 0, 1 = 1-30, 2 = 31-90, 3 = 90+ individuals pooling juveniles, subadults, and adults.

## 2.2b Landscape Analyses

A Principle Components Analysis (PCA) on the landscape variables; % cover, road density, and proximity to wetland and forest, was used to reduce dimensionality of the data from seven to one or two composite variables (Kuntson et al. 1999). Based on the Pearson correlation analyses, data at the most significant scale would be incorporated into the PCA. The PCA determined matrix and species associations, and matrix and patch area correlations. An ordination of PCA score and patch size, species richness, and species abundance was graphed to detect any grouping of variables.

A canonical correspondence analysis (CCA) was performed on all groups and individuals, richness and abundance to relate the community composition to environmental variation (ter Braak 1986). The CCA was performed to determine the association of species occurrence along significant environmental gradients and to summarize the relationship between the species and these gradients (Pearman 1997). It was useful in determining how species are affected by the surrounding landscape and what they are associated with. Based upon similarity in responses, a similarity array of species can be determined.

## 2.2c Correlations Among Environmental Variables

To test for correlations between and among species and environmental variables, I performed a pairwise Pearson Correlation Matrix on patch area, perimeter, wetland variables (% cover, presence/absence, hydroperiod), stream presence/absence, fish presence/absence, PCA, % landscape cover, proximity of wetlands and forests, road density, and earthworm abundance category (Guerry and Hunter 2002). Variables with an r-value of 0.330 or higher were considered significant ( $P < 0.05$ ), this was chosen instead of the Bonferroni correction so

as to be more likely to catch confounding variables (Guerry and Hunter 2002). To reduce the number of uncorrelated variables, only significant variables were used in further analyses (Pearman 1997). Additionally, the independent variables with the highest r-value were used when independent variables were inter-correlated. Significant variables were inferred as important to species, which helped determine the most significant scale used in further analysis (Guerry and Hunter 2002).

## 2.2d Species-Area Relationships

Linear regression of ln species richness and ln patch area for the 3 datasets was performed on all richness groups to test for patch size associations with species richness (Findlay and Houlihan 1997, Houlihan and Findlay 2003). I also separated patches with and without wetlands to compare slopes. Species richness data may provide misleading conclusions due to the inclusion of single (possibly ephemeral) occurrences in analyses. Therefore, species abundance may show a more accurate interpretation of how species are utilizing patches.

I also used an analysis of variance (ANOVA) with four size categories, to determine the effect of patch size on species richness and abundance. I ran a post hoc ANOVA with Bonferroni corrections on 2005 abundance data to test for differences between abundance in the patches and large forests. To determine the effects of wetland presence and patch area on species richness and abundance, a 2-way ANOVA was performed on 2004 data (Gibbs 1998a). The other groups of data (2005 and 2004/2005) did not have larger patches without wetlands and therefore I could not perform the same analysis. To determine if earthworm

abundance (grouped into 4 categories) was related to redback salamander occurrence I also used an ANOVA.

## 2.2e Community Analyses

To determine whether species configurations were related to patch area (or a threshold patch size), I measured the distribution of occurrence along the patch size gradient in a nested pattern (Hager 1998, Kolozsvary and Swihart 1999). A matrix of species (columns) and patch area (rows) were arranged in descending order so that presence and absence were documented (Kolozsvary and Swihart 1999). A similar matrix was created for PCA scores 1 and 2 to determine the effects of landscape matrix on species. Nested patterns of species occurrence can display a non random distribution of species occurrence indicating a predictable species dropout rate (Patterson and Atmar 1986, Atmar and Patterson 1993, Wright et al. 1998, Kolozsvary and Swihart 1999).

The Jaccard similarity coefficient was used to measure the degree of change in species assemblages, or Beta diversity between patch size categories (Megurran 1988, Skelly et al. 1999). This allowed inference of community changes as patch size increases.

## 3. Results

### 3.1 Species Distributions

I found 16 species of amphibians and 8 species of reptiles, representing 80% of the total local species pool (Table II). Seven were encountered only in large forests; Jefferson salamander (*A. jeffersonianum*), northern slimy salamander (*P. glutinosus*), four-toed salamander (*Hemidactylium scutatum*), northern water snake (*Nerodia sipedon*), northern

ringneck snake (*Diadophis punctatus*), northern black racer (*Coluber constrictor*), and the black rat snake (*Elaphe obsoleta*).

**Table II.** Species encountered during the 2 year study in 3 states, and their 4 letter species codes.

<b>Common Name (Latin Name)</b>	<b>Abbreviation</b>
American toad ( <i>Bufo americanus</i> )	BUAM**
Spring peeper ( <i>Pseudacris crucifer</i> )	PSCR**
Gray treefrog ( <i>Hyla versicolor</i> )	HYVE**
Wood frog ( <i>Rana sylvatica</i> )	RASY
Southern leopard frog ( <i>Rana utricularia</i> )	RAUT
Pickerel frog ( <i>Rana palustris</i> )	RAPA**
Green frog ( <i>Rana clamitans</i> )	RACL**
Bullfrog ( <i>Rana catesbeiana</i> )	RACA**
Blue-spotted salamander ( <i>Ambystoma laterale</i> )	AMLA*
Jefferson salamander ( <i>Ambystoma jeffersonianum</i> )	AMJE*
Blue-spotted/Jefferson complex ( <i>Ambystoma laterale-jeffersonianum</i> )	AMCO*
Spotted salamander ( <i>Ambystoma maculatum</i> )	AMMA**
Red-spotted newt salamander ( <i>Notophthalmus viridescens</i> )	NOVI*
Redback salamander ( <i>Plethodon cinereus</i> )	PLCI**
Northern slimy salamander ( <i>Plethodon glutinosus</i> )	PLGL
Northern two-lined salamander ( <i>Eurycea bislineata</i> )	EUBI**
Four-toed salamander ( <i>Hemidactylium scutatum</i> )	HESC
Eastern box turtle ( <i>Terrapene carolina</i> )	TECA*
Painted turtle ( <i>Chrysemys picta</i> )	CHPI
Snapping turtle ( <i>Chelydra serpentina</i> )	CHSE
Northern water snake ( <i>Nerodia sipedon</i> )	NESI
Eastern garter snake ( <i>Thamnophis sirtalis</i> )	THSI**
Northern ringneck snake ( <i>Diadophis punctatus</i> )	DIPU
Northern black racer ( <i>Coluber constrictor</i> )	COCO
Black rat snake ( <i>Elaphe obsoleta</i> )	ELOB

\*\*Common Species

\*Sensitive or Rare Species

### 3.2 Habitat and Landscape Classification

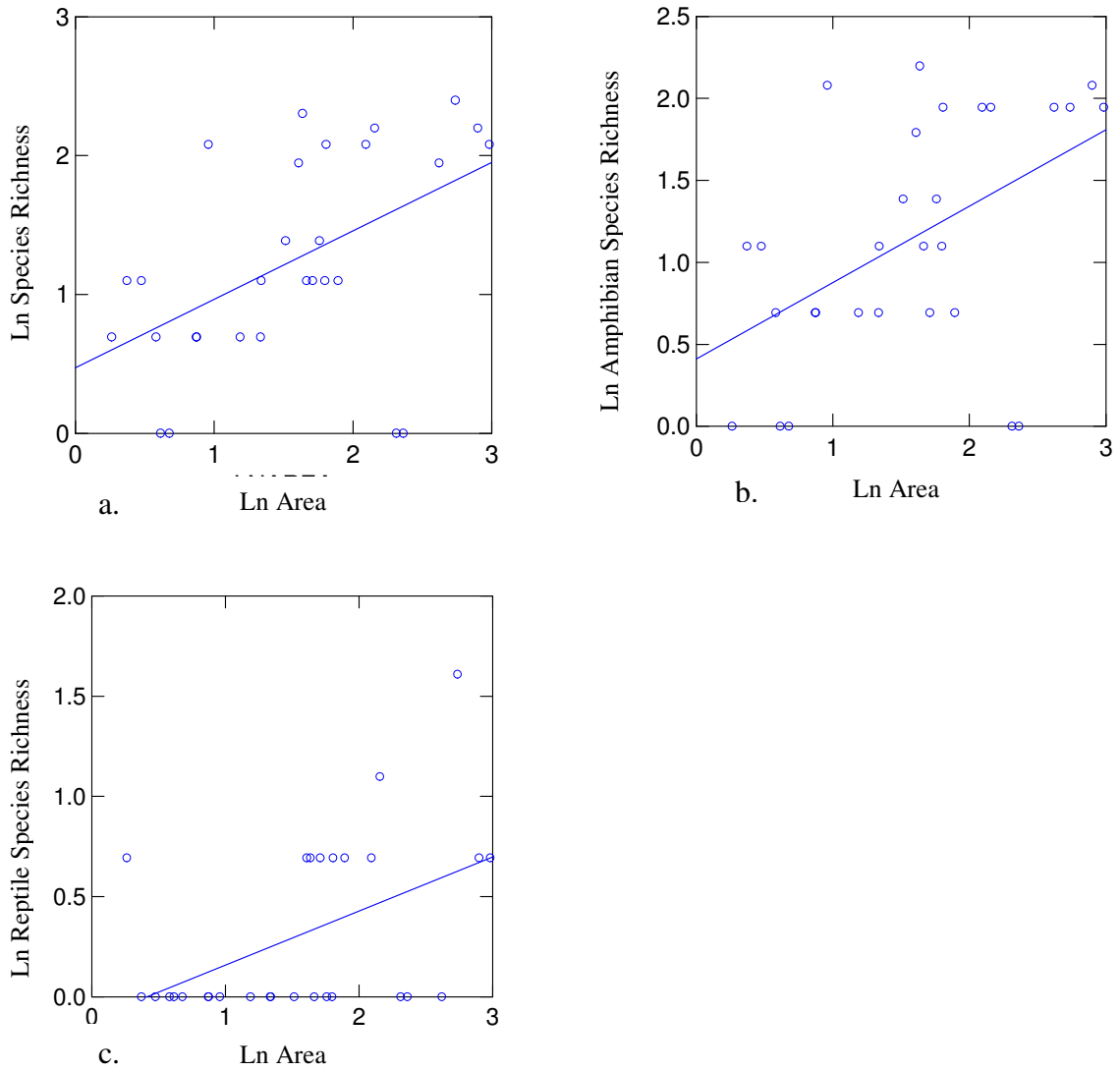
Of the 39 forest patches studied in 2004, 20 contained wetlands, and of the 29 forest patches studied in 2005, 13 contained wetlands. Each patch had some type of wetland habitat within a 1km radius and the three large reference forests in NY each contained at least two wetlands.



The conductivity of wetlands sampled ranged from 38-480, and the pH ranged from 5.78-7.83 (Appendix 2). Road density ranged from 0.01 – 12.47 km/km<sup>2</sup> at the 500m buffer (Appendix 3). Most species were correlated with landscape variables (road density, proximity to forest and wetland, and landscape cover types) within the 50m, 250m and 500m buffer, and wetland presence was correlated with patch area ( $P < 0.05$ ,  $R \geq 0.330$ ).

### 3.3 Species-Area Relationships

Species richness (R) for amphibians ( $\ln \text{Amphibians} = 0.411 + 0.466 \ln \text{Patch Area} + 0.654$ ), reptiles ( $\ln \text{Reptiles} = -0.111 + 0.270 \ln \text{Patch Area} + 0.391$ ) and both amphibians and reptiles combined (i.e. total) ( $\ln R = 0.472 + 0.493 \ln \text{Patch Area} + 0.670$ ) increased with patch area (Figure 1a-c). The other analyses demonstrated a positive species area relationship for all with the exception of caudates in 2004/2005 (Appendix 4). Patches with wetlands had a stronger species area relationship ( $R^2 = 0.336$ ,  $P < 0.005$ ,  $\ln R = 1.156 + 0.379 \ln \text{Patch Area} + 0.431$ ) than those without ( $R^2 = 0.000$ ,  $P > 0.1$ ,  $\ln R = 0.702 + 0.011 \ln \text{Patch Area} + 0.491$ ) in 2004/2005 (Figure 2 & Appendix 5 for all years).



**Figure 1.** Linear regressions of patch area and species richness for 29 patches in 2004/2005. (a) Total species richness,  $R^2=0.253$ ,  $P<0.05$ ,  $z=49$ ,  $c=0.472$ , (b) amphibian species richness  $R^2=0.241$ ,  $P<0.05$ ,  $z=47$ ,  $c=0.411$  and, (c) reptile species richness,  $R^2=0.230$ ,  $P<0.05$ ,  $z=27$ ,  $c=-0.11$ .



**Table III.** Species mean and total abundance (adults, subadults and juveniles) in 2005 (N=32) for each patch and forest size category. Small = 0.30-5.00 ha, Medium = 5.01-10.00 ha, Large = 10.01 – 20.00 ha, and XL = 245.00-755.00 ha. Species codes from Table II.

Species	Small (N=18)		Medium (N=7)		Large (N=4)		XL (N=3)	
	Total	Mean	Total	Mean	Total	Mean	Total	Mean
BUAM	15	0.83	2	0.29	5	1.25	3	1.00
PSCR	13	0.72	11	1.57	15	3.75	16	5.33
HYVE	1	0.06	1	0.14	1	0.25	16	5.33
RASY	2	0.11	11	1.57	13	3.25	178	59.33
RAPA	1	0.06	0	0.00	0	0.00	1	0.33
RACL	34	1.89	35	5.00	26	6.50	193	64.33
RACA	6	0.33	0	0.00	0	0.00	1	0.33
AMLA	1	0.06	0	0.00	0	0.00	3	1.00
AMJE	0	0.00	0	0.00	0	0.00	1	0.33
AMMA	4	0.22	2	0.29	1	0.25	10	3.33
NOVI	0	0.00	1	0.14	0	0.00	17	5.67
PLCI	187	10.39	20	2.86	38	9.50	21	7.00
PLGL	0	0.00	0	0.00	0	0.00	7	2.33
EUBI	5	0.28	3	0.43	40	10.00	8	2.67
HESC	0	0.00	0	0.00	0	0.00	1	0.33
TECA	0	0.00	1	0.14	3	0.75	1	0.33
CHPI	1	0.06	0	0.00	1	0.25	2	0.67
CHSE	0	0.00	0	0.00	1	0.25	0	0.00
NESI	0	0.00	0	0.00	0	0.00	2	0.67
DIPU	0	0.00	0	0.00	0	0.00	1	0.33
THSI	1	0.06	2	0.29	1	0.25	6	2.00
COCO	0	0.00	0	0.00	0	0.00	1	0.33
ELOB	0	0.00	0	0.00	0	0.00	1	0.33

Each one-way ANOVA showed a positive correlation between patch area and species abundance, with the exception of species with insufficient data samples (Appendix 7). The post hoc ANOVA showed that species abundance was significantly different ( $p < 0.05$ ) in large forests from the patches ( $p = 1.00$ ). Abundance did not significantly differ between any patch size category. Each 2-way ANOVA indicated the variable effect of area and wetland presence on richness of each group of species (Appendix 8). Total species richness was positively correlated with patch area and wetland presence as well as by the combination of the two. This relationship may be driven by the influence of common species in that for all other groups area x wetland did not show a significant response. A similar relationship

occurs with species abundance, where area x wetland has a significant affect on total species, again this relationship may be driven by the common amphibians (Appendix 9).

Redback salamander presence was not correlated with patch area, but was negatively correlated with earthworm density ( $F = 9.941$ ,  $P=0.001$ , Appendix 10), and thus may be correlated with a form of patch quality. Earthworm abundance was not correlated with fragment size, matrix or wetland presence ( $P>0.05$  in all cases).

### 3.4 Community Similarity and Patch Size

Results from the Jaccard similarity matrix (Table IV) indicate communities in small and medium patches are more similar to each other than those in large patches.

**Table IV.** Jaccard similarity matrix for pooled samples in 2004/2005, n=29.

	Small	Medium	Large
Small	1	0.93	0.75
Medium		1	0.80
Large			1

### 3.5 Species-Area Nested Patterns

The species-area nested matrix showed a hierarchical nested pattern, with all but the most common species dropping out with patch area; however, many species occurred in small patches with wetlands present (Figures 3-5).



**Figure 4.** 2005, species/area matrix representing presence and absence of species in each patch including the 3 large reference forests. Dark shaded cells represent presence of a species in patches that contain wetlands, light shaded cells represent presence in patches without wetlands, n=32. Species codes as in Table II.

**Figure 5.** 2004/2005, species/area matrix representing presence and absence of pooled species in each patch that were sampled both years. Dark shaded cells represent presence of a species in patches that contain wetlands, light shaded cells represent presence in patches without wetlands, n=29. Species codes as in Table II.

### 3.6 Landscape Influences and Nested Patterns



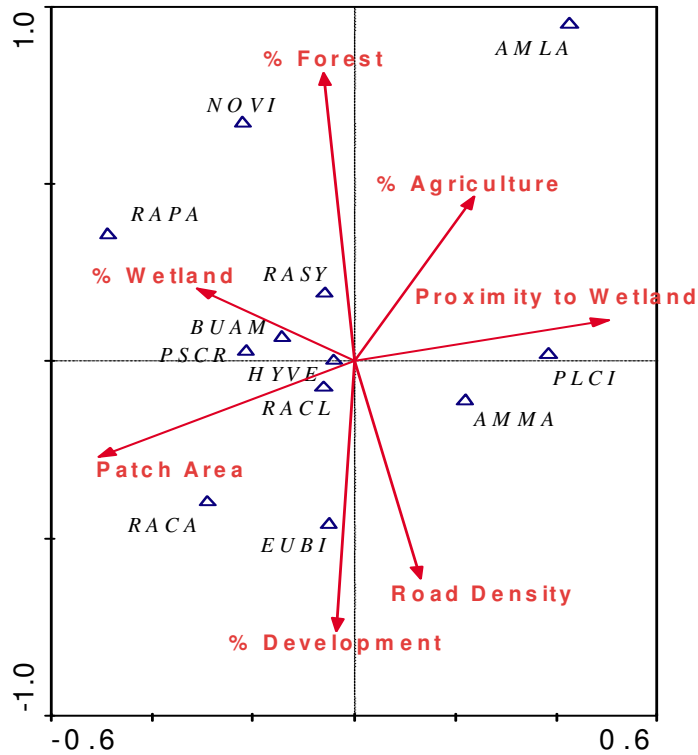
The seven landscape variables were analyzed at the 500m buffer (Appendix 11), and each variable was ordinated on 2 PCA axes (Table V). PCA 1 for 2004 explained 41.146% of the variation in these data (Eigenvalue = 2.880) and was correlated with percent forest area in the surrounding landscapes, PCA 2 explained 20.551% of the variation (Eigenvalue =1.439) and was correlated with percent developed landcover in the surrounding landscape. PCA 1 for 2004/2005 explained 46.616% of these data (Eigenvalue = 3.263) and was correlated with percent developed landcover; and PCA 2 explained 21.937% of the variation in these data (Eigenvalue = 1.536) is correlated with percent forest. PCA 1 for 2005 explained 43.604% of the variation in these data (Eigenvalue =3.052) and was correlated with developed landcover; and PCA 2 explained 19.473% of the variation in these data (Eigenvalue =1.363) and was correlated with forest.

**Table V.** PCA factors for each landscape variable for each sample. Road density is km/km<sup>2</sup> of roads within a 500m buffer from the patch, % Forest, % Agriculture, % Developed, and % Wetland are the % composition of

each landcover category within a 500m buffer of each patch. Proximity to Wetland is the linear distance to the nearest wetland (0m for any wetland within a patch), and Proximity to Forest is the linear distance to the nearest forest >10ha.

<b>Data Set</b>	<b>Landscape Variable</b>	<b>PCA1</b>	<b>PCA2</b>
2004	Road Density	0.845	0.075
	% Forest	-0.393	-0.767
	% Agriculture	-0.842	0.340
	% Developed	0.950	-0.048
	% Wetland	-0.507	-0.027
	Proximity to Wetland	-0.218	-0.027
	Proximity to Forest	0.306	0.705
2005	Road Density	0.954	0.076
	% Forest	-0.468	0.726
	% Agriculture	-0.769	-0.546
	% Developed	0.961	0.167
	% Wetland	-0.409	0.002
	Proximity to Wetland	0.254	-0.059
	Proximity to Forest	0.419	-0.707
2004/2005	Road Density	0.945	0.083
	% Forest	-0.332	-0.804
	% Agriculture	-0.910	0.267
	% Developed	0.970	0.027
	% Wetland	-0.611	0.541
	Proximity to Wetland	0.184	-0.042
	Proximity to Forest	0.291	0.718

The CCA demonstrated that each amphibian species was associated with different landscape variables, in 2004/2005, sensitive amphibians were associated with % forest, wetland and agriculture in the surrounding matrix (Figure 6). Although species were associated with patch and landscape variables, based on Pearson Correlations and linear regressions the proximity to nearest outside wetland and forest (>10 ha) was not correlated with species occurrence in patches ( $P < 0.05$ ).



**Figure 6.** CCA of amphibian species richness with landscape and patch variables in 2004/2005 (N=29). Road density is km/km<sup>2</sup> of roads within a 500m buffer from the patch, % Forest, % Agriculture, % Developed, and % Wetland are the % composition of each landcover category within a 500m buffer of each patch. Proximity to Wetland is the linear distance to the nearest wetland (0m for any wetland within a patch). The distance to nearest forest is excluded due to lack of correlation. Species codes are from Table II.

The species-landscape matrix did not show a nested pattern, although sensitive amphibians occurred in forest/agricultural and wetland dominated landscapes (Figure 7 & Appendix 12).

Figure 7. 2004/2005, species and landscape matrix PCA Score 1, representing presence (shaded) and absence of species (unshaded) in each patch. Species codes are from Table II.

#### **4. Discussion**

In the northeastern United States landscape change is rapidly occurring with specific increases in urbanized landuse and concomitant decreases in rural landuse and natural cover. This variety of landuse creates a complex matrix, which requires a large-scale view to understand the full effects of landuse on herpetofaunal assemblages (Swihart et al. 2003). It is necessary to examine the distribution of forest habitat patches and their surrounding landscape matrix to fully understand amphibian and reptile species landscape-scale habitat requirements and provide theoretically-based, practical tools for guiding conservation efforts for northeastern herpetofaunal communities. As land continues to be “developed” and otherwise altered we must understand how these changes contribute, directly and indirectly, to species survival to better conserve these species. Current work suggests that amphibian and reptile species occurrence is influenced by habitat area and surrounding landscape, although information gaps leave much to be understood. The rapid pace of landuse change makes bridging and filling these gaps increasingly critical, where quantifying species assemblages in forest patches compared to continuous forests in this complex landscape is necessary for understanding species distribution patterns.

In the human dominated landscape within this region, amphibian and reptile occurrences in forest patches are strongly correlated with patch area, and the surrounding landscape may be less important. Several determinants could explain the positive species-area relationship: constraints on population growth by habitat area may drive small populations extinct; habitat heterogeneity that tends to increase with patch size and may be reflected in more kinds of occupants; or small patches may be isolated and inaccessible to

immigrants that would otherwise expand the community or rescue declining populations. My results indicate a role for all three processes.

#### 4.1 Species-Area Relationships

The nesting pattern of species distributions, in combination with the island-like species-area curves, indicate a system with substantial local extinctions and a high degree of isolation. Richness increased steeply with patch area and patches of all sizes are missing species from the full pool, indicating that there are constraints on population growth imposed by habitat area. A full suite of common species, presumably less sensitive to patch area, was found in even the smallest patches (0.45 ha), where none of the less common species were found (Figure 4). Many species may not have been able to survive as small populations in smaller patches. In contrast, high population densities of some species (spring peepers and redback salamanders) indicate that some species are resistant to the habitat loss and isolation imposed by fragmentation, allowing these species to persist where species with low densities (e.g., wood frogs and red-spotted newts) are unable (Gibbs 1998a). Similarly, the ability of the spotted salamander to maintain high densities in this region may buffer the effects of fragmentation more so than for other less abundant mole salamanders. These forest patches may be comparable to land-bridge islands that have a depleted herpetofauna, assuming that they have been isolated long enough to reach some level of community equilibrium (McArthur and Wilson 1967).

As with oceanic and land bridge islands, habitat heterogeneity was inextricably linked to local community diversity, mainly in the form of the presence or absence of wetlands. Larger patches are more likely to contain wetlands, and thus, larger patches are more likely

to contain a greater number of species than smaller patches. A positive species-area relationship held true only for patches that contained wetlands, where area and habitat quality (wetland presence) were both strong predictors of species richness, similar to results found by Kolozsvary and Swihart (1999). High species richness in patches with wetlands can be accounted for by species-specific habitat requirements. Although wetland habitat was very important within the forest patch, the presence of wetlands in the surrounding landscape matrix did not have a significant association with species diversity. Neither distance to nearest wetland nor to nearest forest was correlated with species richness, suggesting that this landscape is not permeable to many species. These results are in contrast with Kolozsvary and Swihart (1999) who found proximity to wetlands correlated species distribution, suggesting greater permeability in agricultural landscapes of the mid-west. This suggests that agriculture-dominated landscapes containing lower road density may be more permeable to these species movements than a highly developed landscape with greater road density. Within a more urbanized landscape, forest patches may be effectively isolated from amphibian and reptile dispersal.

If patches are isolated, small patches may be unimportant to potential immigrants, reducing opportunities for populations to persist by means of dispersal. The nested species-area pattern of occurrence indicates a decline in species richness without a rescue effect from surrounding landscape (Patterson and Atmar 1986, Atmar and Patterson 1993, Wright et al. 1998), and provides evidence for a period of “relaxation” during which more sensitive species dropped out of smaller patches (e.g., Kolozsvary and Swihart 1999). As patch area decreases, there is a predictable drop out of species occurrences, indicating which species are

most susceptible to patch area effects. This interaction may drive species occurrence across the landscape towards assemblages of more tolerant species.

#### 4.2 Role of the Surrounding Landscape

In contrast to the nested species-area pattern, there was no nested pattern for species occurrence and landscape matrix composition, suggesting that species distributions are not driven by landscape composition within this region. This result is similar to the findings of Weyrauch and Grubb (2004) wherein landscape composition had minimal affect on amphibian species distribution, even in a less complex landscape. Other flora and fauna may have a more variable response to fragmentation and landscape composition (Robinson et al. 1992, Holt et al. 1995, Debinski and Holt 2000) but in this case amphibian and reptile sensitivities and their dispersal limitations may confine them to isolation.

The amount of development and high road density in the northeast may create an impermeable landscape for amphibians and reptiles. Agricultural dominated landscapes containing lower road density may be an exception for some species. In particular, some sensitive species, such as the red-spotted newt and blue-spotted salamander, occurred in smaller patches within forested and agricultural matrices, and displayed a negative association with developed landcover. The combination of large patch area and suitable landscape may provide sufficient habitat for occurrence of some sensitive species, such as Ambystomid salamanders. Additionally, maintenance of a more permeable landscape, traversable by these species, may allow many of them to persist in this region. Although I cannot identify threshold parameters of a landscape matrix that would improve dispersal, the



finding that species were associated with specific landscape features is an important starting point for future studies.

#### 4.3 Species-Specific Susceptibility to Fragmentation

Further species declines cannot be ruled out. As patches become isolated, remnant populations may drop out due to sensitivity to edge effects, microclimate, stochastic events and area restraints, leading to additional faunal “relaxation.” This is especially the case when dispersal into new habitats is insufficient to allow for population persistence (Gibbs 1998a, Boudjemadi et al. 1999). Patches are apparently highly isolated within this landscape, and habitat isolation may be increased as habitat conversion and road density increase throughout the area (Gibbs 1998a). This can have detrimental consequences for metapopulation dynamics, genetic diversity, population sustainability and community composition (Templeton 2001, Mann et al. 2003).

I found that urban land cover was correlated with road density, and both were negatively correlated with patch area and wetland presence. Such complex interactions may be reducing species richness and isolating species that occur in these patches (Findlay and Houlihan 1997, Findlay and Bourdages 2000).

Less common species that were found in my study (Table II) may have been affected by habitat heterogeneity, quality, and area. These results support others findings that the wood frog, red-spotted newt, and Ambystomid salamanders are sensitive to forest fragmentation (Guerry and Hunter 2002, Porej et al. 2004, Lannoo 2005). Abundance of wood frog, gray tree frog, green frog, red-spotted newt, and Ambystomid salamanders were much greater in larger forests than in patches with wetlands (Table III), suggesting that long

term population survival of these species may require large forests. The wood frog was found in low abundance in patches as small as 1.6 ha that contained wetlands, and its occurrence was not related to surrounding landscape matrix. In contrast to Kolozsvary and Swihart's (1999) work in Indiana, the gray tree frog was not ubiquitous and its abundance dramatically increased in large forests, suggesting that in the northeastern US it may be more sensitive to forest fragmentation. This may be due to species sensitivity to urbanizing landscapes, which may impede movement to breeding habitat more than agricultural lands. More sensitive species may be affected by forest floor structure, their physiological tolerances, dispersal distances, and home range sizes, all of which are factors that leave them sensitive to both immediate and surrounding landuse changes (Demaynadier & Hunter 2002). Also, Gibbs (1998a) has suggested that susceptibility to mesopredators such as skunks and raccoons in human dominated landscapes, where the wood frog is especially at risk, influenced sensitivity to fragmentation.

Matrix variables, such as cover type and road density sorted out some species as would be expected based on their life history requirements (Figure 7). This suggests that although landscape matrix is not the driving factor to predict species occurrence in this region, species were influenced by combinations of habitat types necessary for their specific life history requirements. For example, spotted and redback salamanders were not highly associated with patch area, but rather with landscape matrix type and patch quality. This may be suggestive of the strong dispersal ability of the spotted salamander within undeveloped landscapes and the sensitivity of the redback salamander to microclimate. Species thought to be sensitive to fragmentation (Gibbs 1998b, Weyrauch and Grubb 2004), such as Ambystomid salamanders and the red-spotted newt only occurred in patches within a

less developed, more agricultural/forested landscape matrix. More common species such as redback salamanders, green frogs, and toads were found in patches within a variety of landscape types, suggesting that for these species sufficient breeding and overwintering habitat on site are sufficient for occurrence.

Niche breadth is one important indicator of the potential responses of a species to fragmentation (Swihart et al. 2003); those species that can survive in many habitat types may be less affected by the effects of increased habitat fragmentation. Species with a wide niche breadth that occurred in many patches were the American toad, spring peeper, bullfrog, and redback salamander, suggesting that their ability to occur in many habitat types enables them to withstand forest fragmentation. These species had similar relative abundances in forest patches and in large forests, suggesting that they are relatively tolerant of forest fragmentation. Kolozsvary and Swihart (1999) found the same pattern for the American toad, spring peeper, and bullfrog in their sites in Indiana. This result can be attributed to the abundance of these species in this landscape. Toads inhabit disturbed areas and open habitats, spring peepers inhabit wetlands in open or wooded habitats, and bullfrogs inhabit and overwinter in permanent waterbodies, which explains why these species are not very sensitive to forest fragmentation (Lannoo 2005). It is not well documented whether the gray treefrog is affected by patch size (Lannoo 2005), although in my study they appear to be somewhat sensitive, with a minimum area of occurrence of 4.14 ha, occurring in only 3 of the patches with wetlands and in all large reference forests.

My finding that dispersal abilities are important is consistent with Gibbs (1998b) in that the redback salamander was not as sensitive as the red-spotted newt. According to Gibbs (1998b), within an urbanized landscape species with high dispersal capabilities may be at a

disadvantage in that movement through the landscape may leave them stranded in unsuitable habitats, suggesting that more vagile species are at a disadvantage in developed landscapes. This landscape matrix may be impermeable to movement and dispersal may be a liability in fragmented areas, which is why linkages within the landscape matrix are necessary (Gibbs 1998a).

#### 4.4 Detection Thresholds

There is no specific patch threshold where a full assemblage of species was found, rather patch area, quality, and landscape composition were related to species-specific occurrences. Some species occurred only in large forests, these species could be sensitive to area requirements, connectivity between habitat types and/or habitat heterogeneity. The Jefferson salamander, northern slimy salamander, four-toed salamander, northern water snake, northern ringneck snake, northern black racer, and the black rat snake have a wide range of differing habitat requirements (Ernest et al. 1994, Ernest and Ernest 2003, Lannoo 2005), so it would be difficult to generalize precise reasons for their co-occurrence patterns.

Ranids, as a group, had the same richness in patches with wetlands as they did in large forests, and my results indicate that they can occur in fragmented habitats whenever a wetland is present. The bullfrog is sensitive to loss and degradation of water bodies, and the green frog is common, occurring in great abundance throughout the landscape (Lannoo 2005), so they may not be sensitive to forest fragmentation. The pickerel frog breeds in pools, ponds, and wetlands adjacent to the forested adult habitat (Lannoo 2005), suggesting they might be minimally affected by forest fragmentation provided they have access to breeding habitat.

All common amphibians as a group (Table II), as well as anurans alone, tended to have similar species richness in large habitat patches as in forests, but salamanders and snakes did not, perhaps due to their high dispersal abilities or specific habitat requirements. Salamanders and snakes may require larger forests. I have insufficient data for separate tests for turtles, although the relationship appears similar to frogs, which can occur in smaller forest patches with wetlands.

The single factor that had a negative correlation with redback salamander occurrence and abundance was density of earthworms. Earthworms affect forest floor microclimate, soil pH, and prey base, all of which are important for the salamander, thereby affecting redback occurrence (Wyman and Hawksley-Lescault 1987, Frisbie and Wyman 1992, Sugalski and Claussen 1997, Grover 1998). Also, because small patches, with their strong edge effects, are less moist than larger forests, they may be unsuitable to redbacks during hot, dry summer months. This stress, in combination with the unknown interactions of earthworms, may exclude or decrease redback abundance in particular kinds of patches.

## **5. Conclusion**

In this complex landscape matrix, amphibian and reptile species distributions appear to be driven mainly by forest patch area and quality as determined by wetland presence on site. Many species are able to occur in larger patches containing wetlands and a diversity of habitat types within a less disturbed landscape, but with an increase in urbanized landcover and accompanying forest fragmentation, species composition may be driven towards a more homogeneous assemblage where only common species are able to occur in patches. Isolated patches within developed matrices may eventually lose most, if not all amphibian and reptile

species due to population dynamics, genetic degradation and/or stochastic events. This may lead to eventual species extirpation in the region. All of these results suggest that a full suite of species assemblages in complex, human dominated landscapes may not survive without strong connections to large forests containing wetland habitats.

It is critical to study amphibian and reptile species distributions in these urbanizing landscapes, which are becoming increasingly common. My results indicated that species assemblages are reacting to current landcover changes in forested systems, and demonstrated the importance of forest area and habitat availability. Better landuse planning and practices will be required for long-term conservation of these and other groups of sensitive species.

### **Literature Cited**

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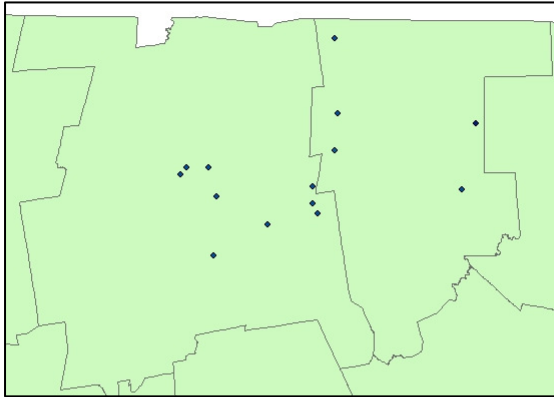
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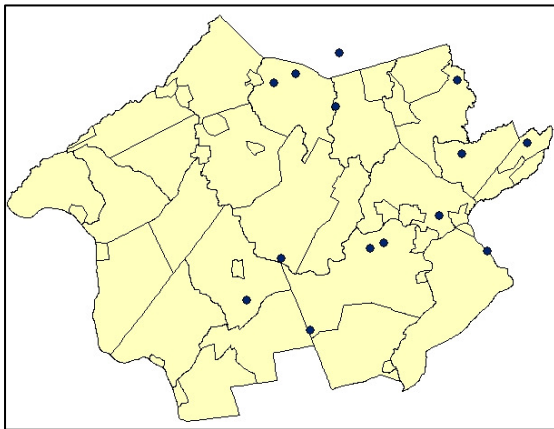
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**Appendix 1.** Center point locations of forest patches and three large forests in NY, NJ, and CT.

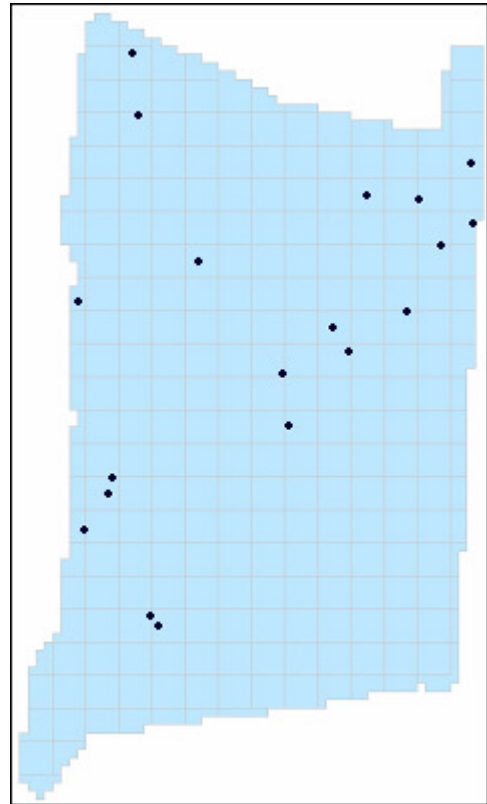
1.1 Patch center in each state: a) CT, b) NJ, and c) NY.



a.



b.



c.

1.2 X and Y coordinates for each forest patch and large forest in NY, NJ, and CT in NAD 1983, New York State Plane.

State	Patch ID	X	Y
CT	12c	1005468.87965000000	867866.95165700000
CT	13c	1002835.46808000000	864695.17456299900
CT	2a	1074957.88073000000	928647.49740400000
CT	19	1076621.25038000000	892947.28556999900
CT	12a	1141238.76862000000	888618.37067800000
CT	17a	1075082.24683000000	875734.20122100000
CT	10	1134548.52566999000	857766.52186500000
CT	11c	1018317.81233999000	826791.27451999900
CT	8c	1043557.03684000000	841289.87060100000
CT	5c	1064853.22664000000	859126.37909399900
CT	2b	1067248.51041999000	846318.43188000000
CT	6c	1064483.21595999000	850970.83123200000
NJ	w	473795.60728499900	631732.63260300000
NJ	q	482800.79532199900	656927.11326599900
NJ	o	409927.09516400000	614664.42655400000
NJ	k	492943.93633499900	617354.25159100000
NJ	43a	395800.44170400000	597810.56313000000
NJ	34	451404.69712299900	620807.18552499900
NJ	24	415564.95115300000	688950.42586500000
NJ	23	406969.64804100000	685433.59122099900
NJ	14	480854.39224800000	686537.48990299900
NJ	l	431821.22193499900	675991.86955700000
NY	H	683871.63454999900	1115624.35896000000
NY	I	702329.86620100000	1081451.20641000000
NY	M	645421.95759300000	1097293.74824999000
NY	69	754801.14374099900	1114808.98622000000
NY	68	669910.79411699900	999643.81733800000
NY	67	666998.63968899900	1002401.22778000000
NY	56	647130.63898399900	1029001.23835000000
NY	67	655401.88841200000	1044716.00948000000
NY	52	654575.15887900000	1039410.83271000000
NY	5	663646.16259299900	1154169.42387999000
NY	40	708581.60268999900	1060008.51113000000
NY	39	706424.31091700000	1075813.36726000000
NY	37	727104.90281200000	1082520.74056999000
NY	36	721713.17485499900	1089791.43656000000
NY	35	744785.73704899900	1094982.69835000000
NY	32	764265.89601200000	1121449.81085000000
NY	22	748233.46069700000	1128295.73181000000
NY	2	661485.34092700000	1172557.65757000000
NY	19	763839.57180599900	1139264.83728000000
NY	59	649826.62473100000	1014474.29688000000

**Appendix 2.** pH and Conductivity of wetlands in 39 forest patches in 2004.

<u>Date</u>	<u>State</u>	<u>Site</u>	<u>Wetland</u>	<u>pH</u>	<u>Conductivity</u>
6/11/2004	CT	10	1	7.73	323
5/10/2004	CT	19	1	7.49	480
5/10/2004	CT	19	2	7.44	306
5/10/2004	CT	12A	1	7.39	114
5/10/2004	CT	12C	1	7.83	248
5/10/2004	CT	13C	1	7.54	233
5/10/2004	CT	13C	2	6.67	87
5/10/2004	CT	13C	3	6.95	79.4
5/10/2004	CT	2A	1	7.08	218
5/10/2004	CT	5C	1	7.64	260
5/10/2004	CT	5C	2	5.78	37.8
5/10/2004	CT	6C	1	7	150
4/20/2004	NJ	23	1	7.49	158
4/20/2004	NJ	23	2	7.81	64.9
4/20/2004	NJ	23	3	7.55	121
4/20/2004	NJ	23	1	8	126
4/20/2004	NJ	34	1	6.38	141
4/20/2004	NJ	34	2	5.98	90.8
4/20/2004	NJ	43a	1	7.6	249
4/20/2004	NJ	K	1	7.84	592
4/20/2004	NJ	K	2	7.55	234
4/20/2004	NJ	K	3	7.56	485
4/20/2004	NJ	O	1	6.76	92.3
4/26/2004	NY	2	1	8.08	539
4/26/2004	NY	2	2	8.08	548
4/26/2004	NY	2	3	8.13	544
4/26/2004	NY	19	1	8.01	879
4/26/2004	NY	39	1	7.86	130
4/26/2004	NY	56	1	8.2	843
4/26/2004	NY	67	1	7.8	874
4/26/2004	NY	68	1	7	77.2
4/26/2004	NY	69	1	8.21	555

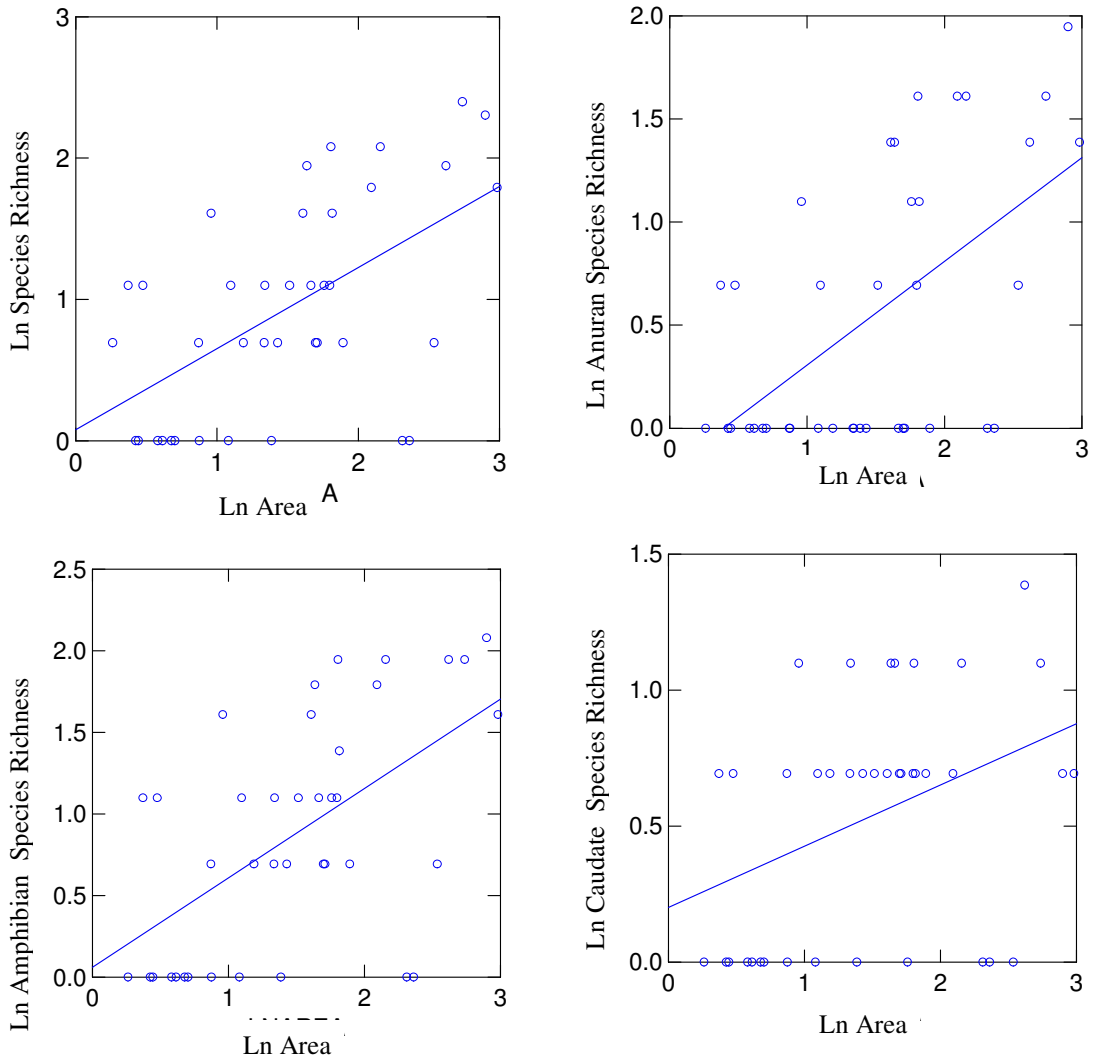
**Appendix 3.** Road density (km/km<sup>2</sup>) at each buffer distance around each forest patch and large forest.

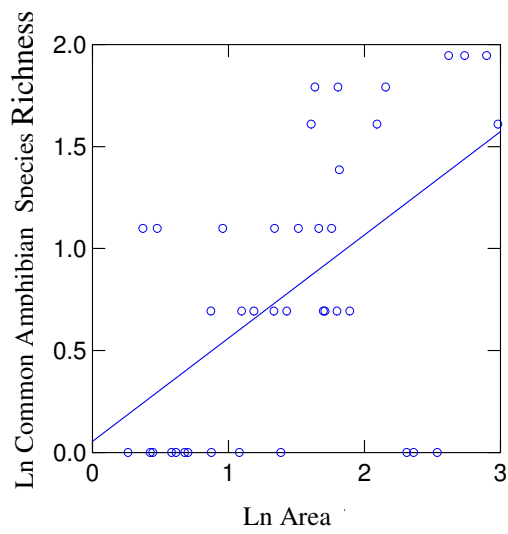
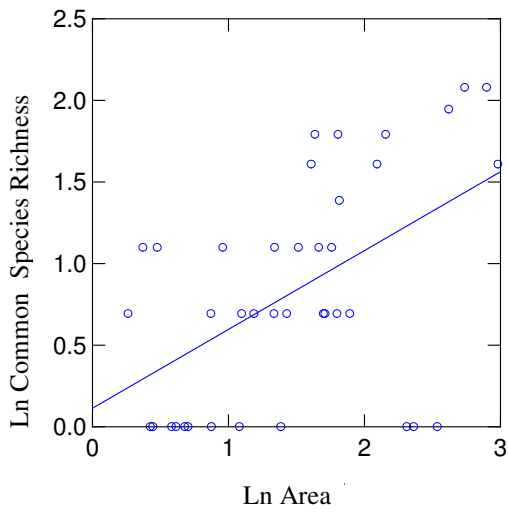
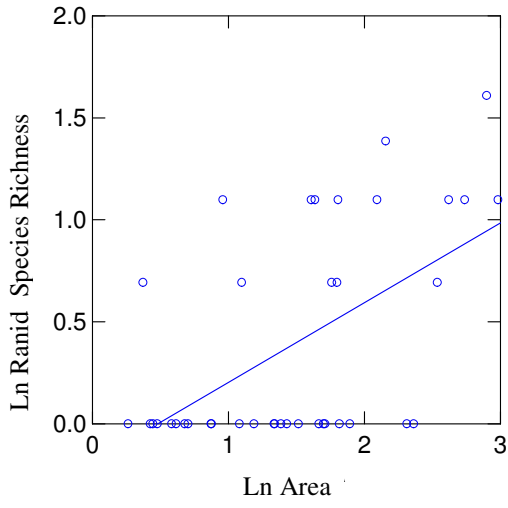
State	Site ID	1kmRD	500mRD	250mRD	50mRD	
CT	10	1	4.71	5.90	6.57	4.16
CT	19	2	2.82	0.64	0.01	0.00
CT	11C	3	9.45	9.57	8.83	10.59
CT	12A	4	1.39	2.27	2.58	4.60
CT	12C	5	4.78	4.32	3.89	1.73
CT	13C	6	7.14	5.62	3.97	2.31
CT	17A	7	4.35	7.86	9.49	11.56
CT	2A	8	2.28	0.01	0.00	0.00
CT	2B	9	11.25	10.83	11.53	5.75
CT	5C	10	6.63	6.08	5.09	3.02
CT	6C	11	8.62	8.80	7.40	3.06
CT	8C	12	6.77	6.38	5.57	0.00
NJ	1	13	2.25	3.26	3.76	6.81
NJ	14	14	4.25	3.09	4.97	7.11
NJ	23	15	1.62	1.95	2.84	1.20
NJ	24	16	1.73	2.61	4.10	5.96
NJ	34	17	1.72	1.97	0.36	0.00
NJ	43A	18	1.62	1.26	1.41	5.39
NJ	K	19	7.05	5.22	3.96	5.57
NJ	O	20	3.76	4.62	4.96	2.31
NJ	Q	21	4.04	4.34	4.63	0.00
NJ	W	22	7.34	6.86	7.88	9.88
NY	2	23	2.27	2.63	2.82	5.70
NY	5	24	5.18	3.73	2.98	0.00
NY	19	25	5.02	5.15	5.06	8.41
NY	22	26	1.62	1.18	1.77	3.36
NY	32	27	1.38	1.70	2.30	6.09
NY	35	28	1.37	1.10	0.53	0.00
NY	36	29	0.93	1.75	2.91	2.81
NY	37	30	2.19	2.90	3.29	0.00
NY	39	31	1.06	0.66	0.00	0.00
NY	40	32	2.04	1.93	1.01	0.00
NY	51	33	8.28	8.43	7.96	8.88
NY	52	34	10.76	12.47	11.92	9.68
NY	56	35	4.40	4.34	6.27	0.00
NY	59	36	5.50	5.46	5.60	6.44
NY	67	37	4.80	5.58	6.68	4.12
NY	68	38	4.46	3.66	3.17	2.69
NY	69	39	1.14	1.52	1.84	0.44
NY	H	40	2.83	3.04	3.56	2.58
NY	I	41	2.07	2.03	2.73	1.71
NY	M	42	1.72	1.72	1.61	0.76

**Appendix 4.** Linear regression of species richness and patch area in 2004, 2005, and 2004/2005.

<b>Species Area Linear Regressions</b>	<b>R<sup>2</sup></b>	<b>P Value</b>	<b>Z Value</b>	<b>C</b>
<b>2004 (N=39)</b>				
Ln Species Richness	0.323	<0.001	57	0.079
Ln Amphibian Richness	0.332	<0.001	55	0.061
Ln Common Species	0.275	0.001	48	0.113
Ln Common Amphibians	0.302	<0.001	51	0.055
Ln Anurans	0.327	<0.001	50	-0.196
Ln Caudates	0.147	<0.05	23	0.202
Ln Ranid Species	0.309	<0.001	39	-0.187
<b>2005 (N=32)</b>				
Ln Species Richness	0.491	<0.001	40	0.470
Ln Amphibian Richness	0.426	<0.001	47	0.356
Ln Reptile Richness	0.619	<0.001	27	-0.223
Ln Sensitive/Rare Species	0.589	<0.001	19	-0.207
Ln Common Species	0.396	<0.001	30	0.527
Ln Common Amphibians	0.352	<0.001	29	0.516
Ln Ranid Species	0.386	<0.001	26	0.010
Ln Anurans	0.404	<0.001	34	0.064
Ln Caudates	0.448	<0.001	24	0.298
<b>2004/2005 (N=29)</b>				
Ln Species Richness	0.253	<0.05	49	0.472
Ln Reptile Richness	0.230	<0.05	27	-0.111
Ln Amphibian Richness	0.241	<0.05	47	0.411
Ln Anurans	0.264	<0.05	52	-0.084
Ln Caudates	0.073	>0.1	14	0.475
Ln Common Species	0.217	<0.05	41	0.490
Ln Common Amphibians	0.232	<0.05	43	0.403

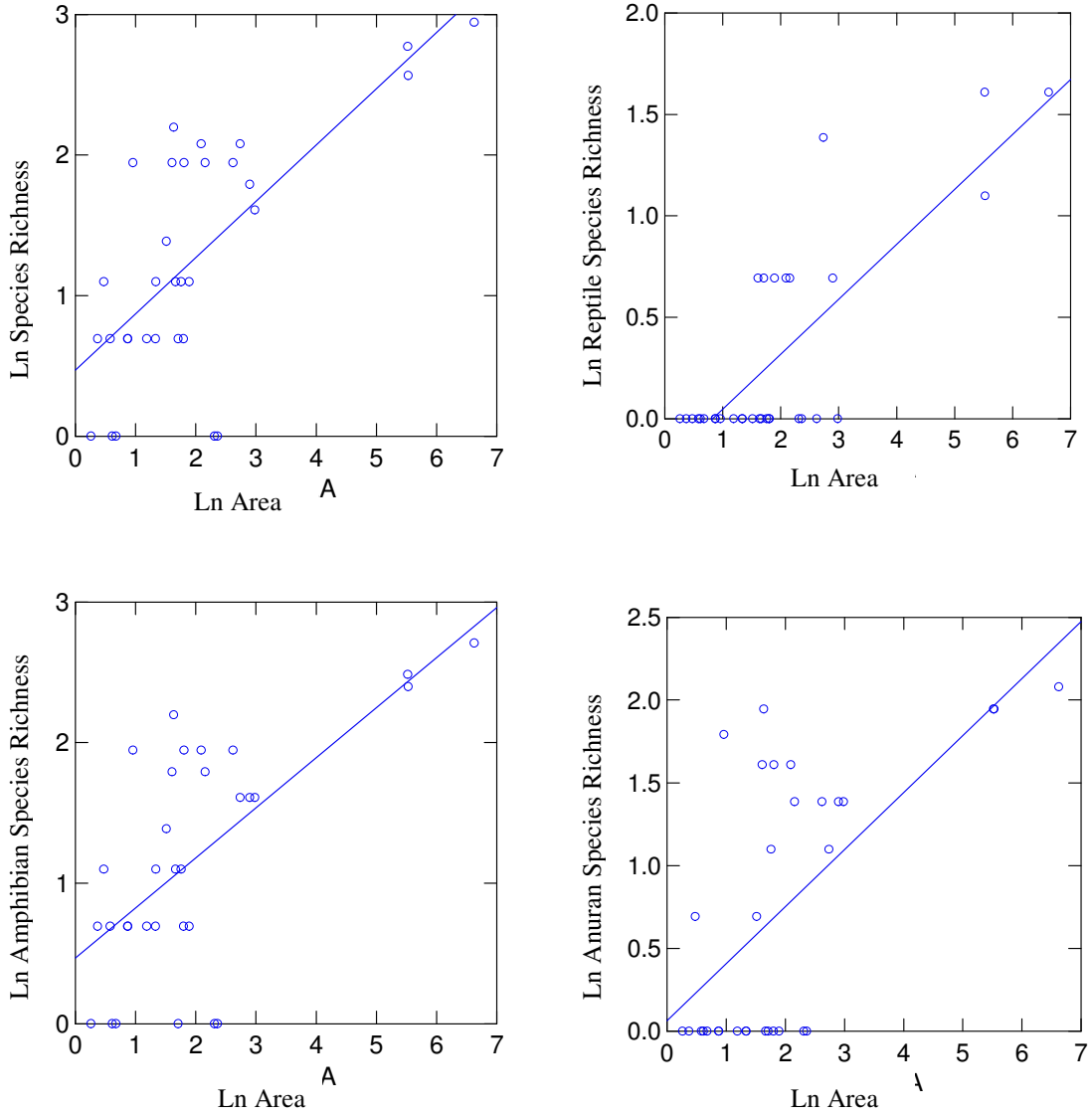
4.1. Scatter plot of logged species richness and patch area for 39 patches in 2004.

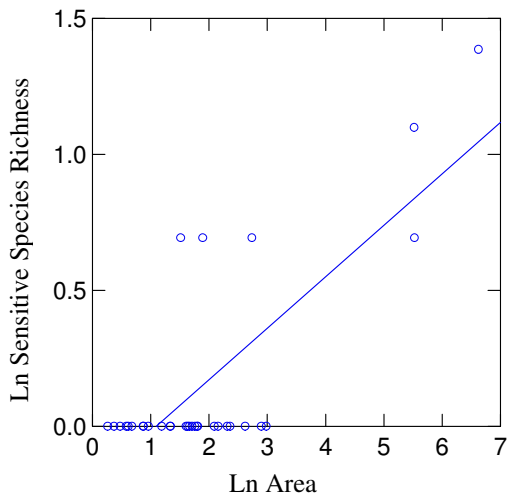
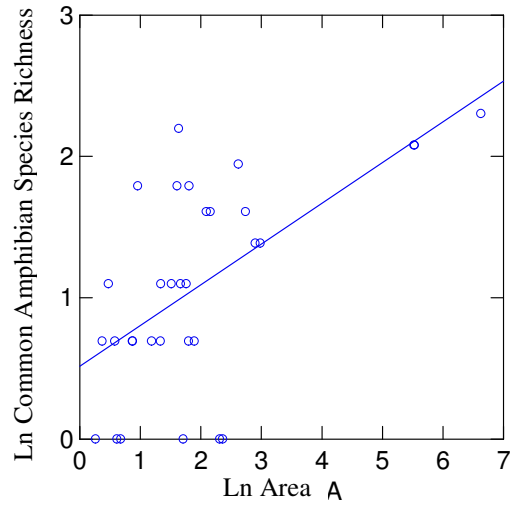
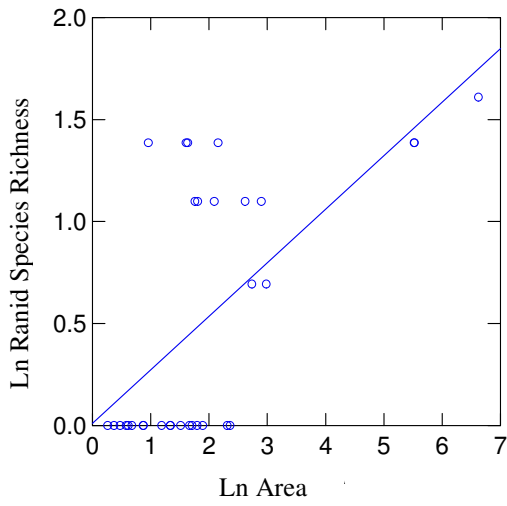
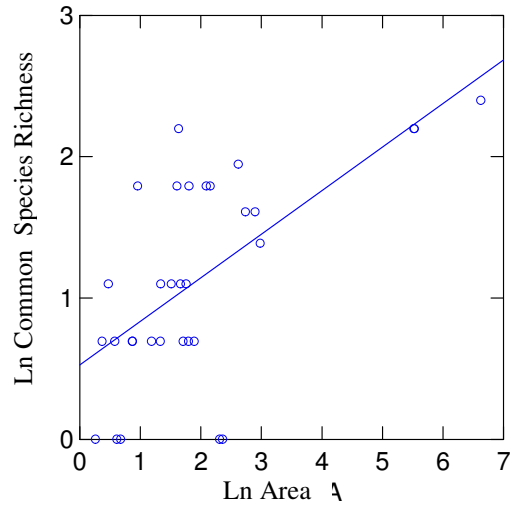
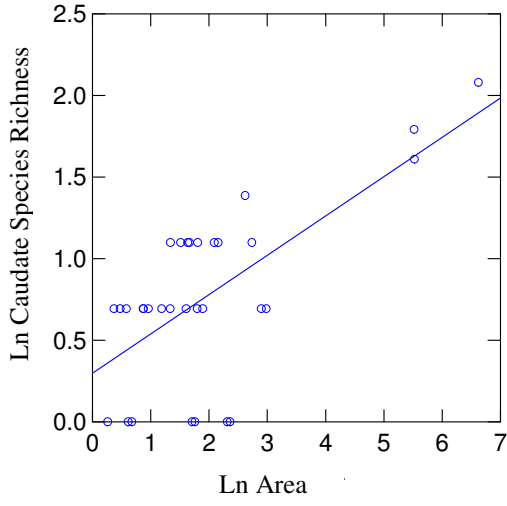




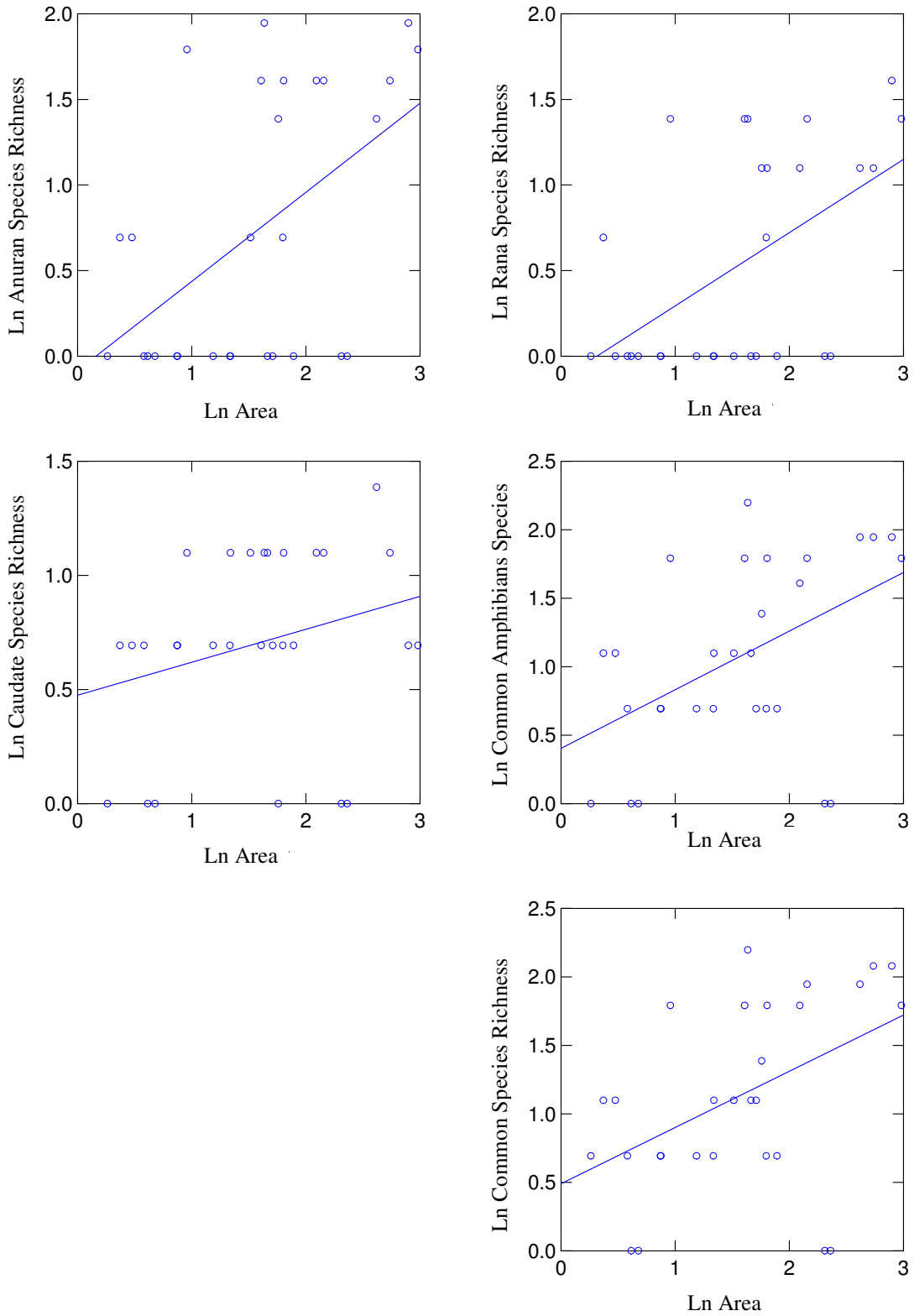


4.2 Scatter plot of logged species richness and patch area for 29 patches in 2005.



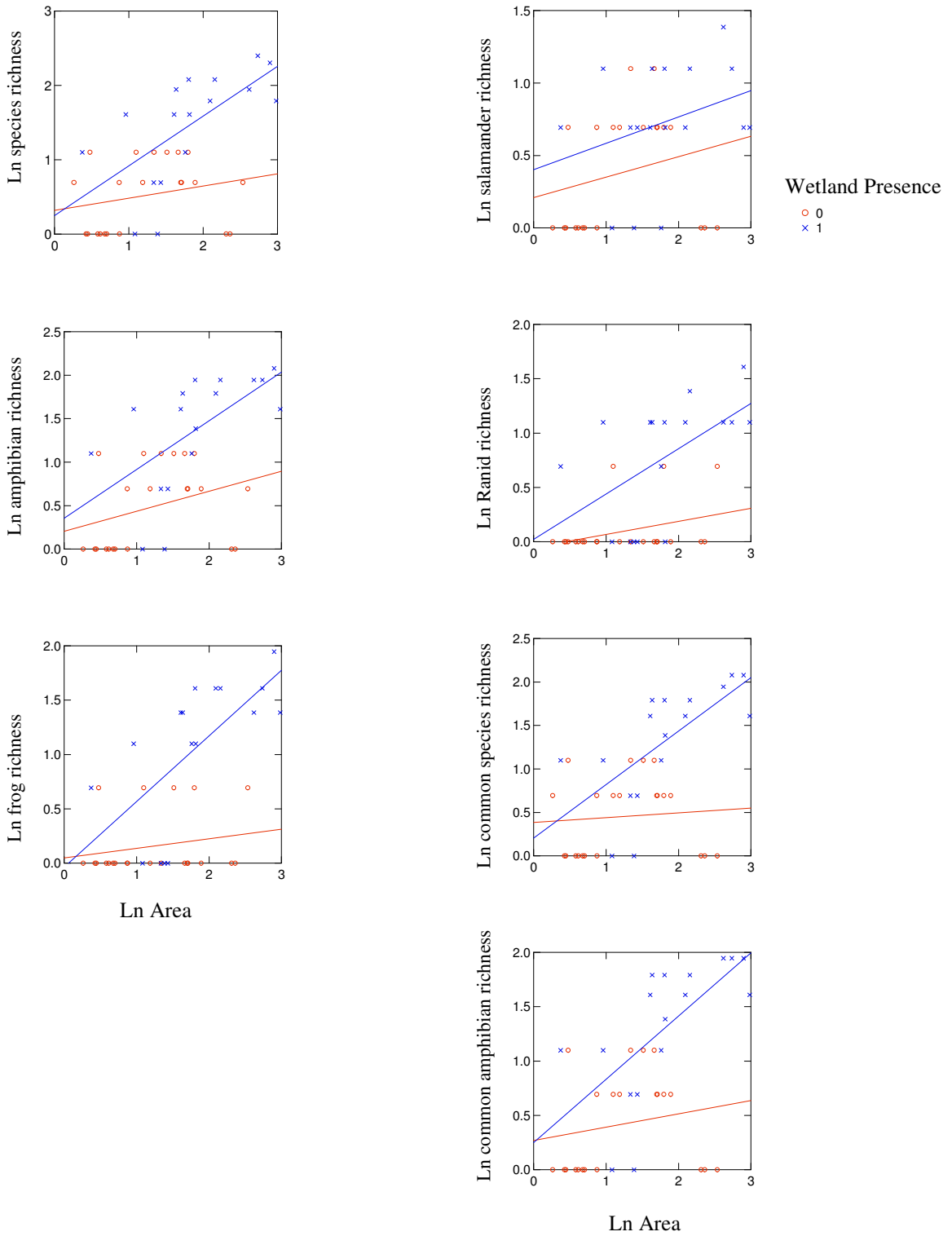


4.3. Scatter plot of logged species richness and patch area for 31 sites in 2004/2005.

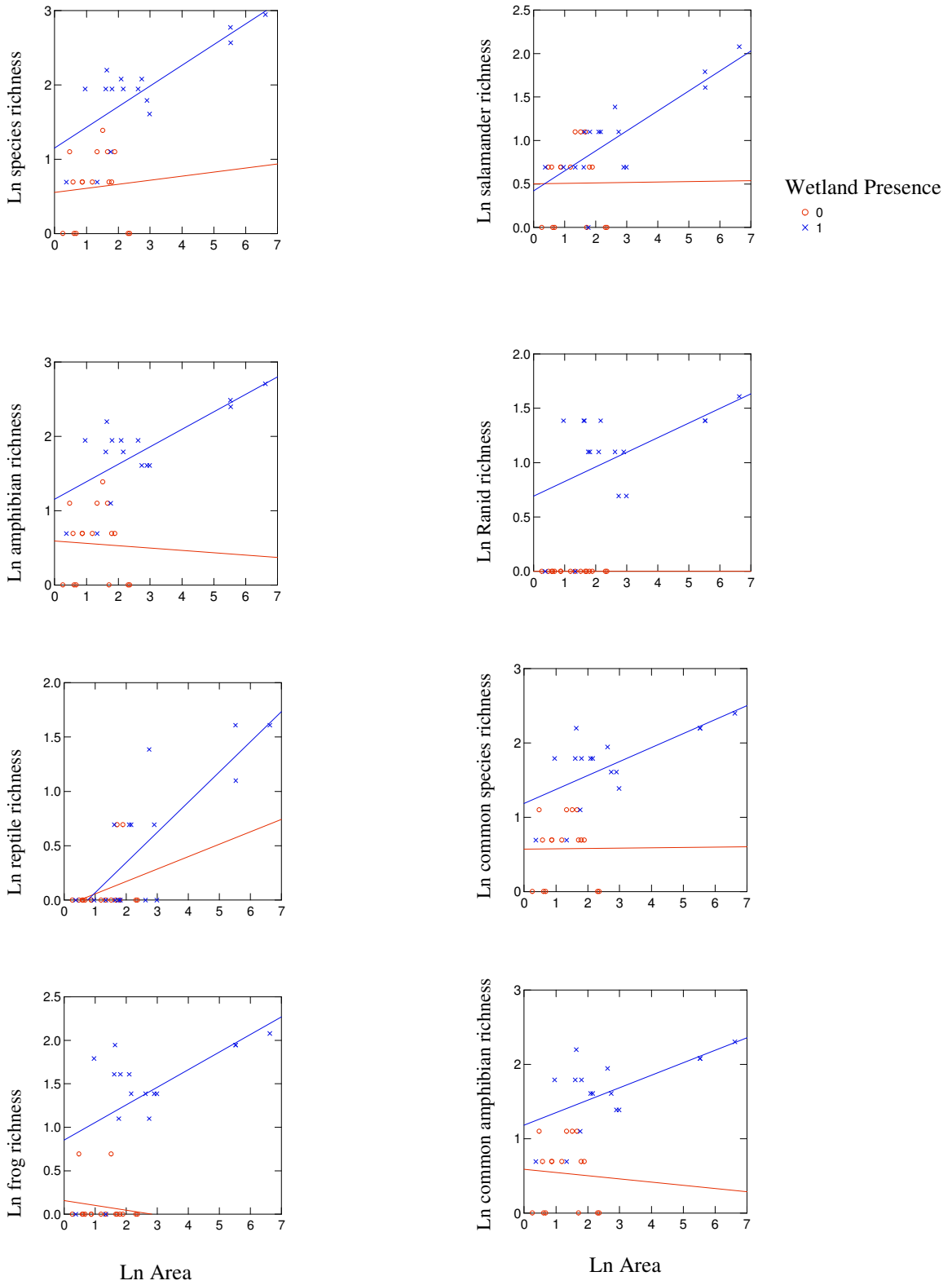


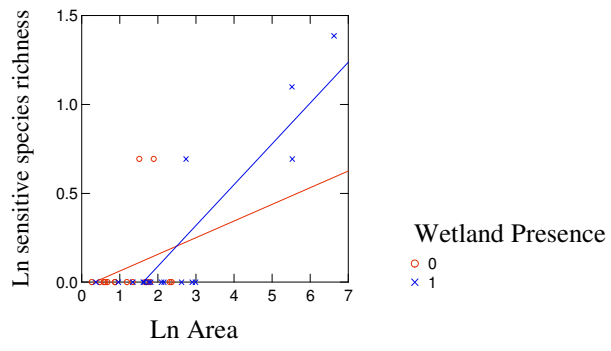
**Appendix 5.** Linear regression of species richness and patch area by wetland presence.

5.1. 2004 logged species richness and patch area in 39 patches.

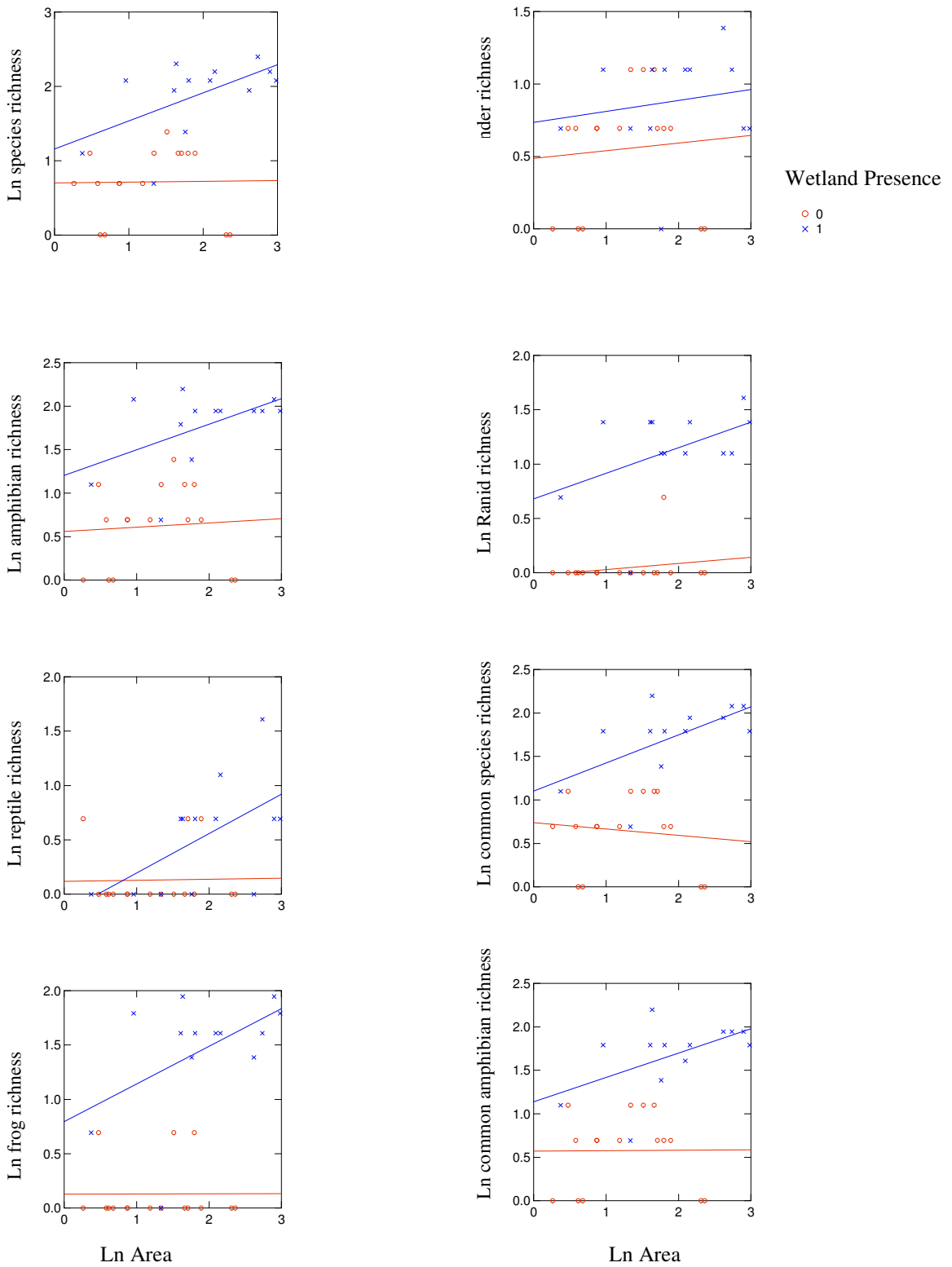


5.2. 2005 logged species richness and patch area in 39 patches.





5.3. 2004/2005 logged species richness and patch area in 39 patches.

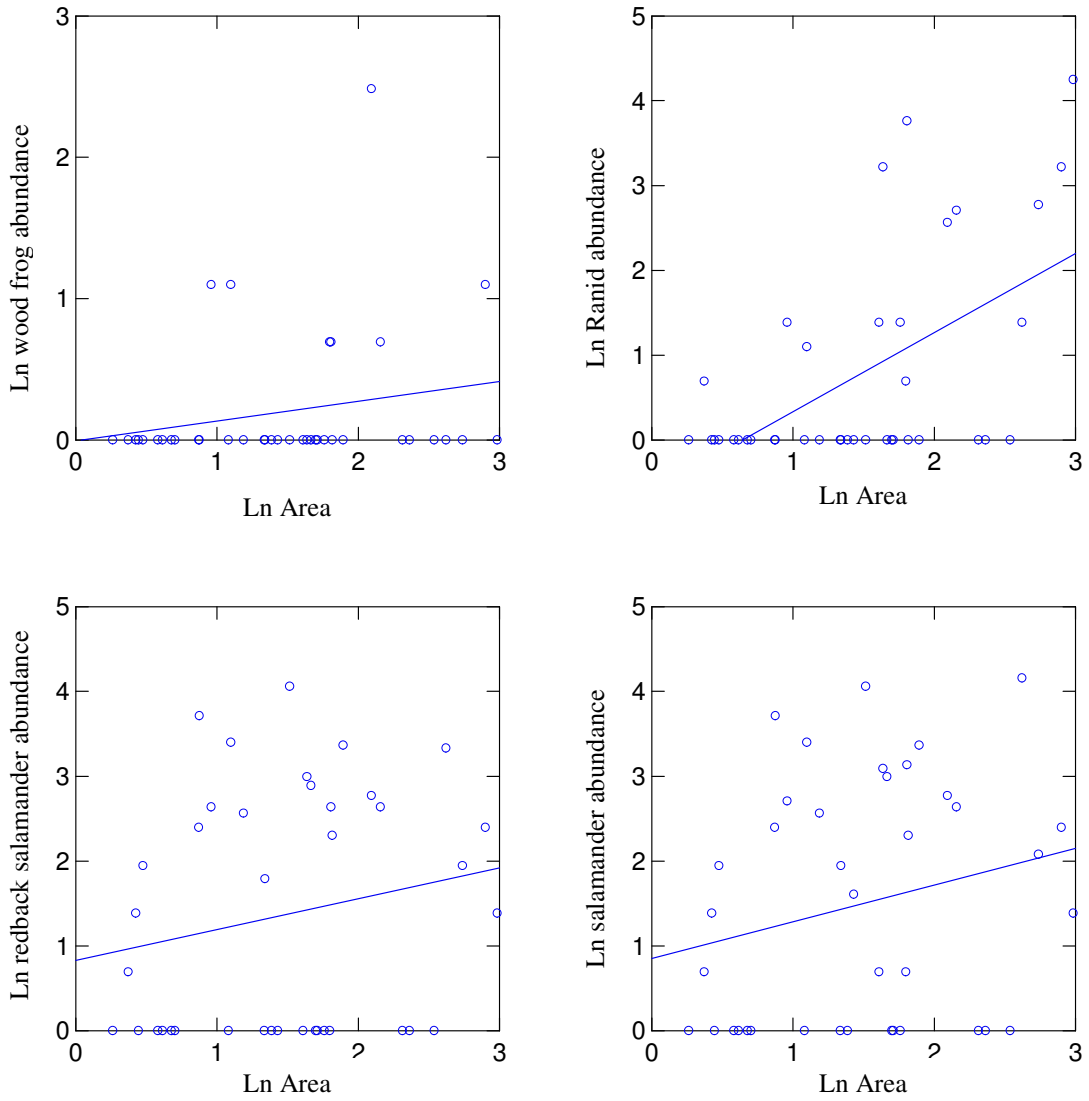


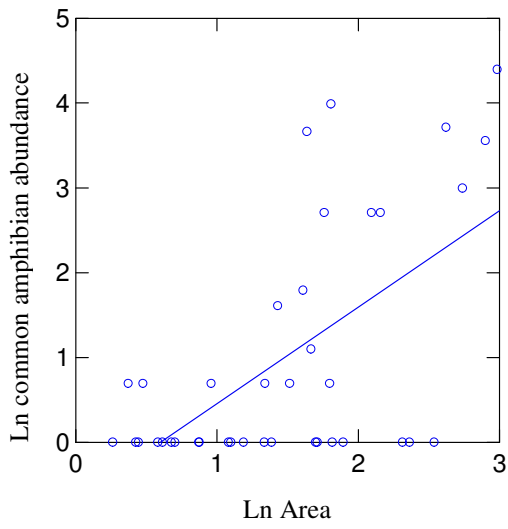
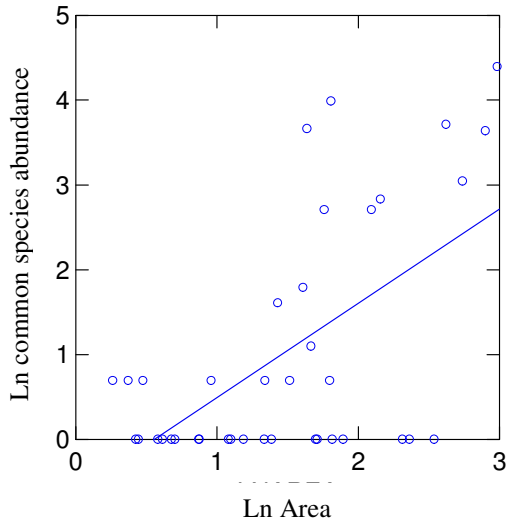
**Appendix 6.** Linear regression of species abundance for each year.

	<b>R<sup>2</sup></b>	<b>P value</b>
<b>2004 (N=39)</b>		
Total Species	0.166	<0.05
Amphibians	0.172	<0.05
Anurans	0.294	<0.001
Caudates	0.052	>0.1
Common Species	0.345	<0.001
Common Amphibians	0.363	<0.001
RASY	0.044	>0.1
Ranids	0.309	<0.001
PLCI	0.037	>0.1
<b>2005 (N=29)</b>		
Total Species	0.284	<0.05
Amphibians	0.263	<0.05
Anurans	0.42	<0.001
Caudates	0.121	>0.05
Common Species	0.388	<0.001
Common Amphibians	0.374	<0.001
RASY	0.572	<0.001
Ranids	0.434	<0.001
PLCI	0.025	>0.1
<b>2004/2005 (N=31)</b>		
Total Species	0.119	>0.05
Amphibians	0.11	>0.05
Anurans	0.29	<0.05
Caudates	0.01	>0.1
Common Species	0.349	0.001
Common Amphibians	0.337	0.001
Ranids	0.363	0.001
PLCI	0.001	>0.1

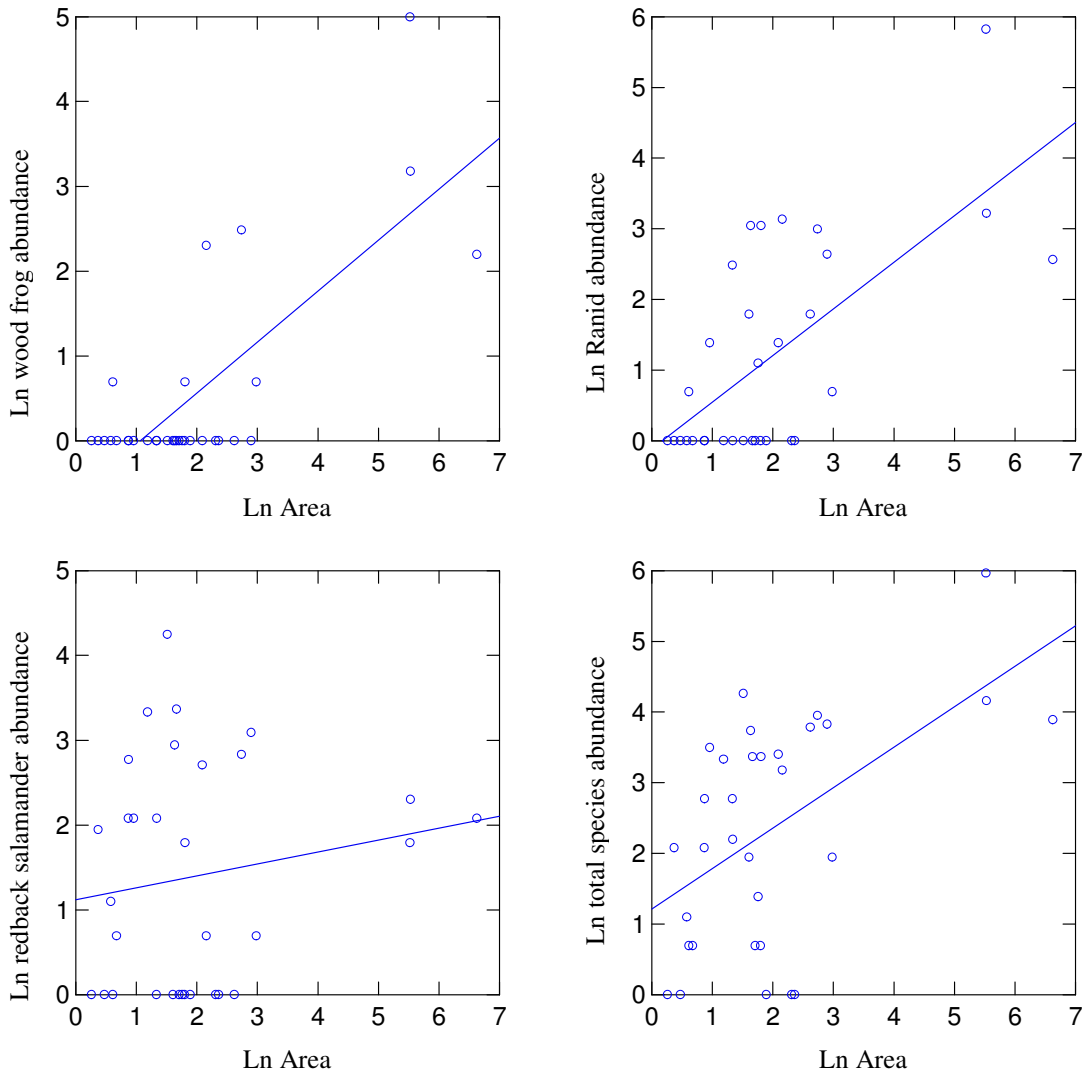


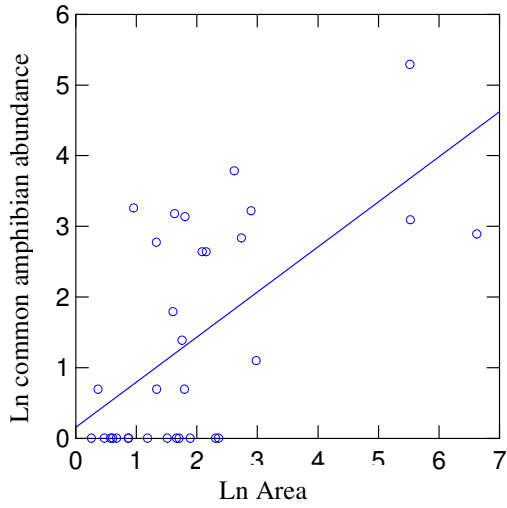
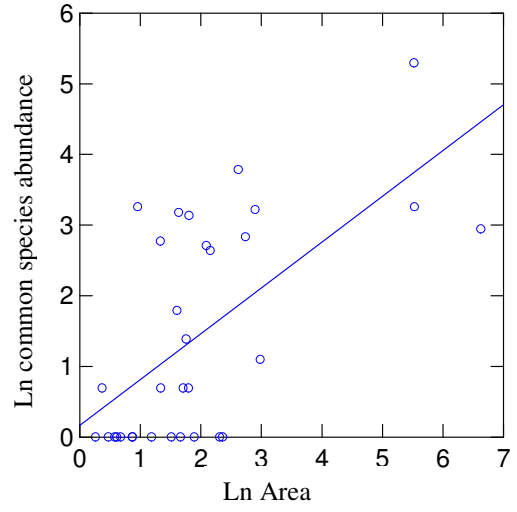
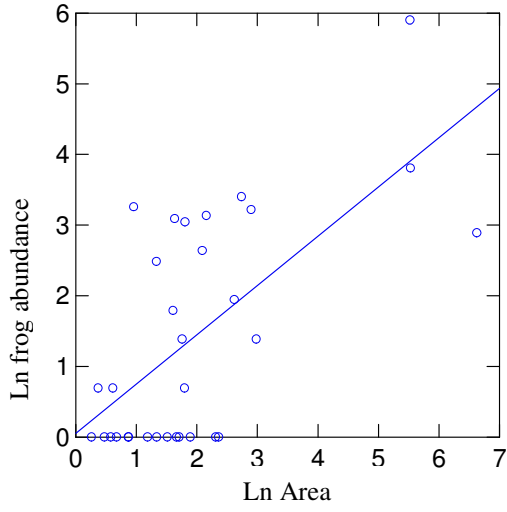
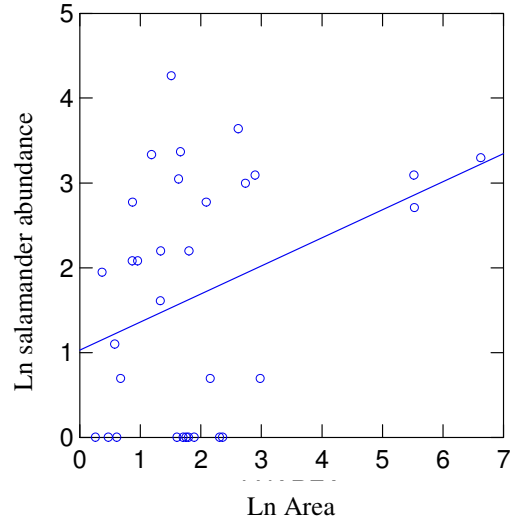
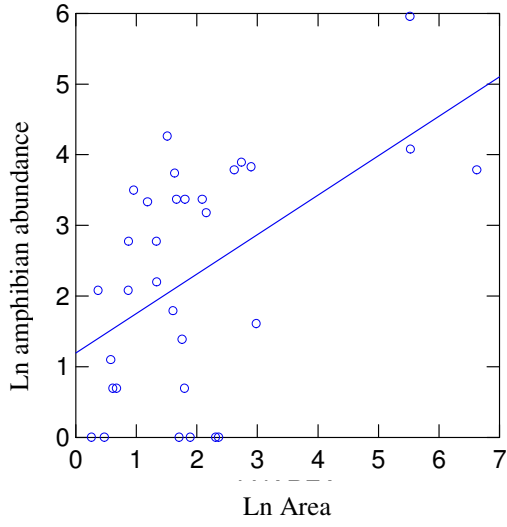
6.1. Scatter plot of logged species abundance and patch area for 39 patches in 2004.



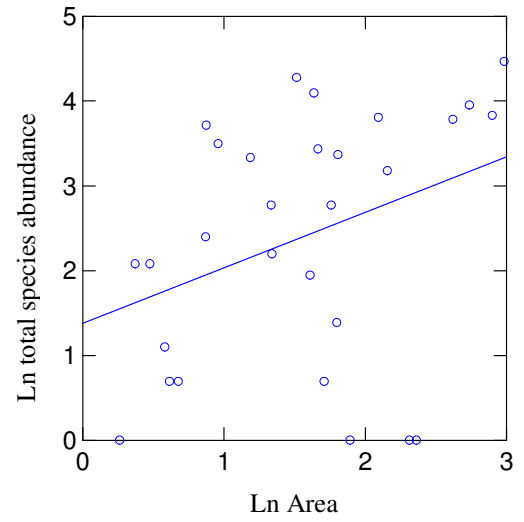
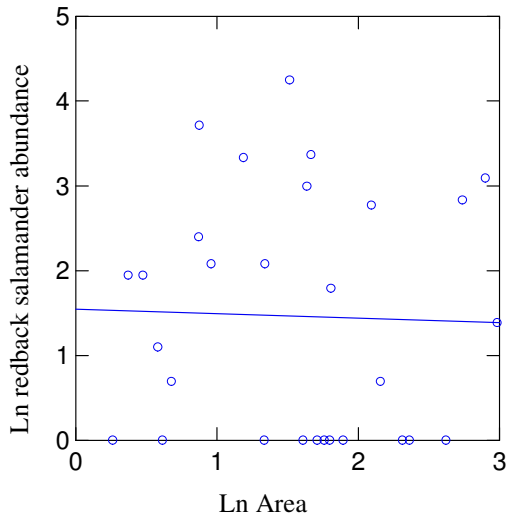
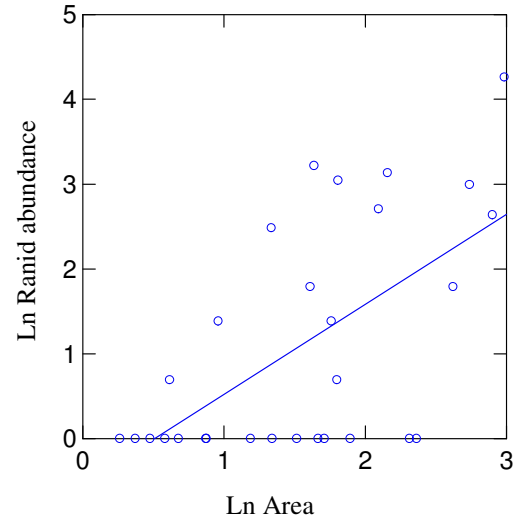
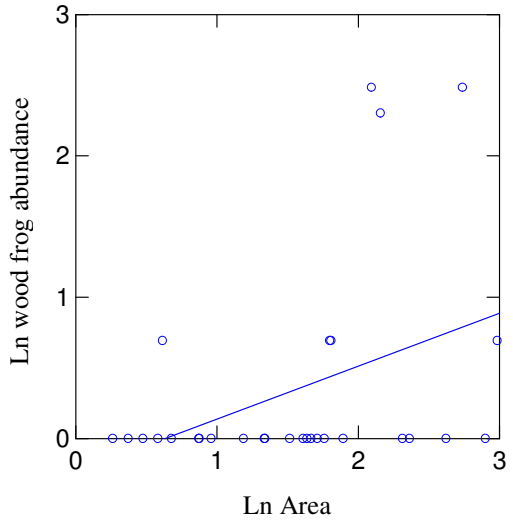


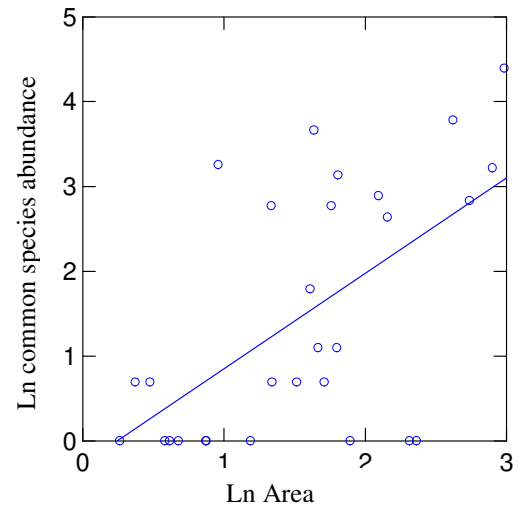
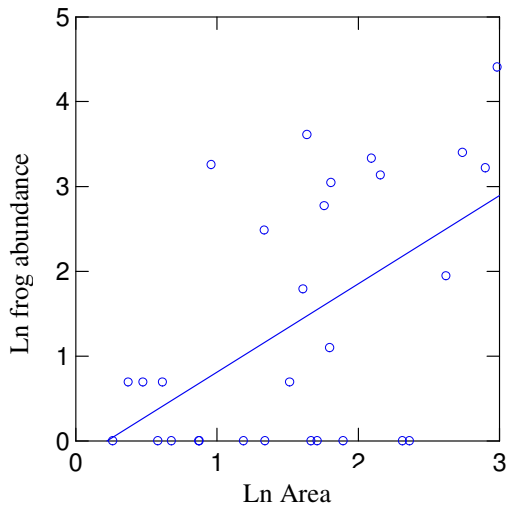
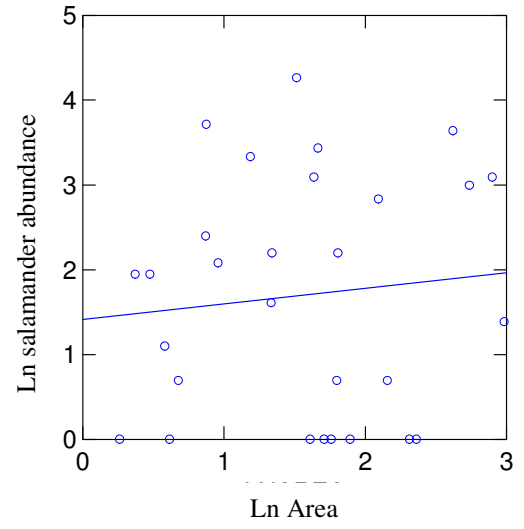
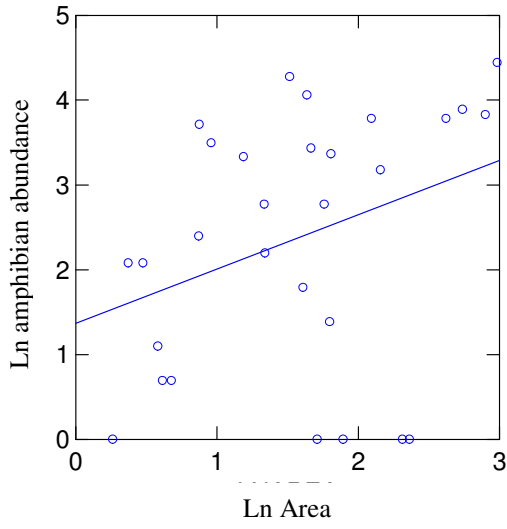
6.2. Scatter plot of logged species abundance and patch area for 39 patches in 2005.

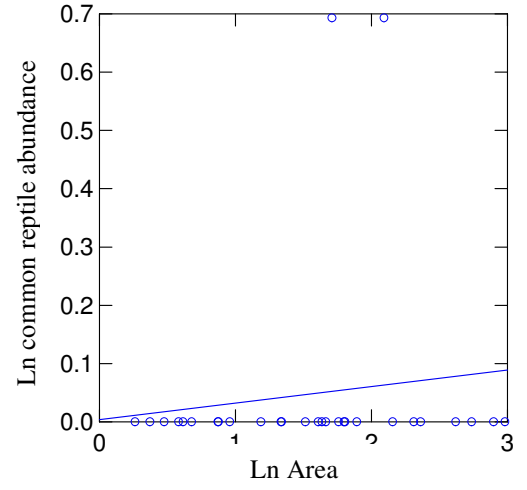
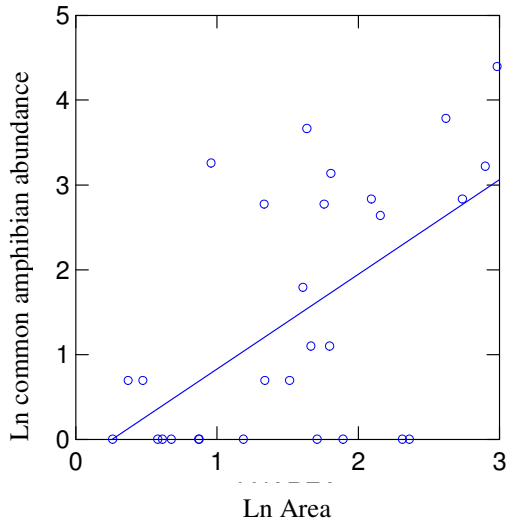




6.3. Scatter plot of logged species abundance and patch area for 39 patches in 2004/2005.

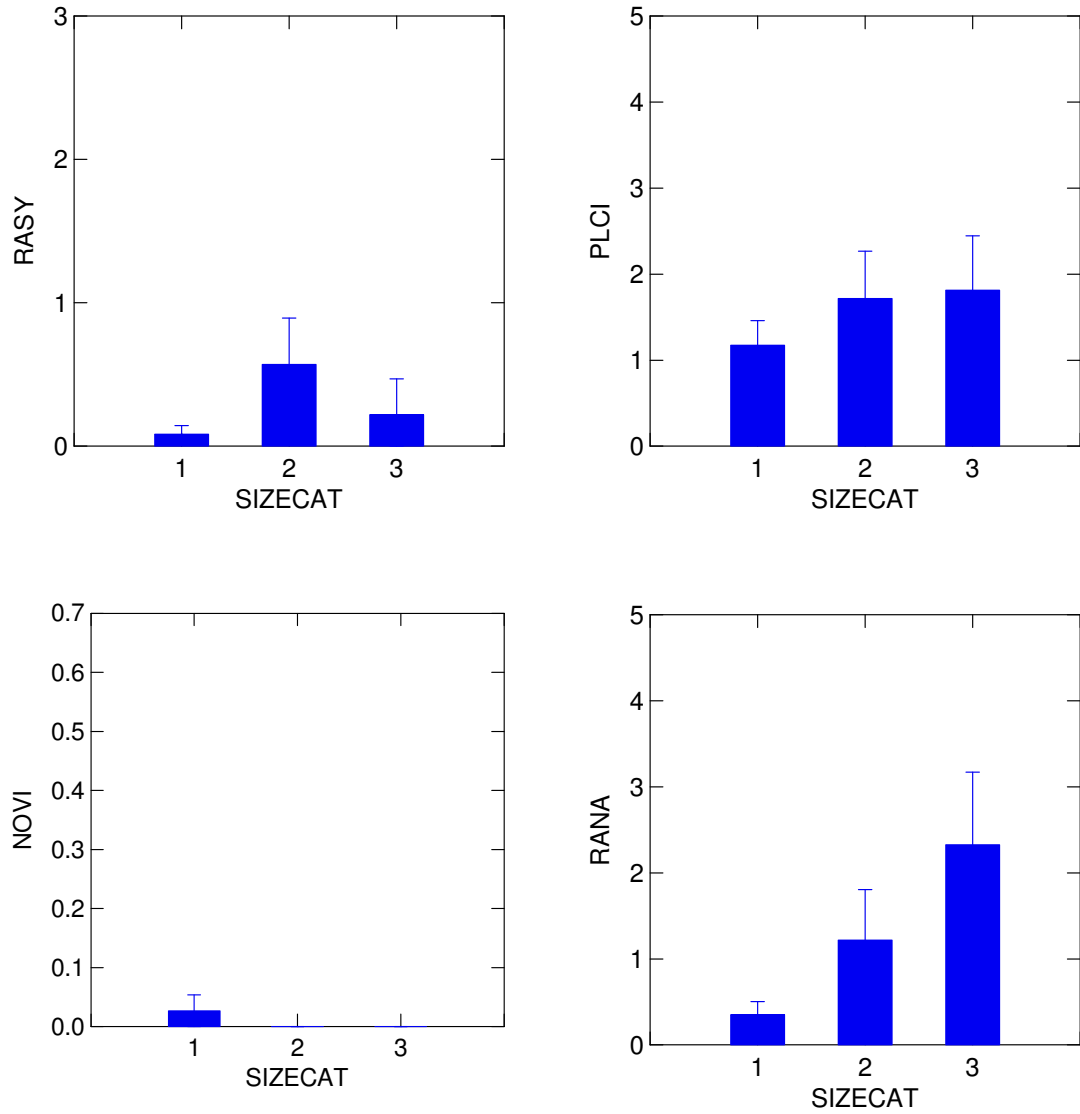




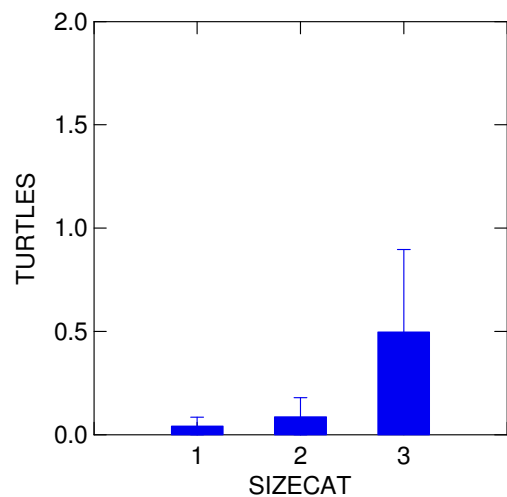
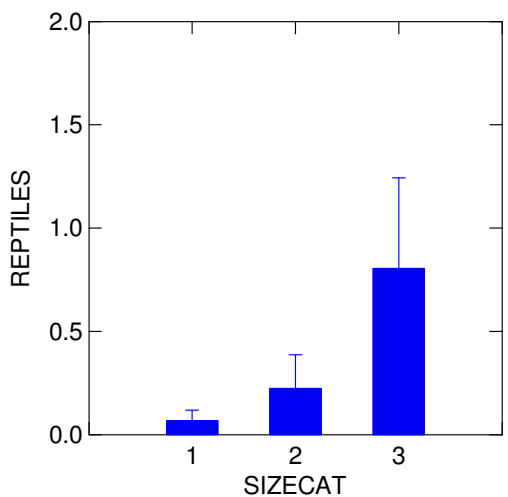
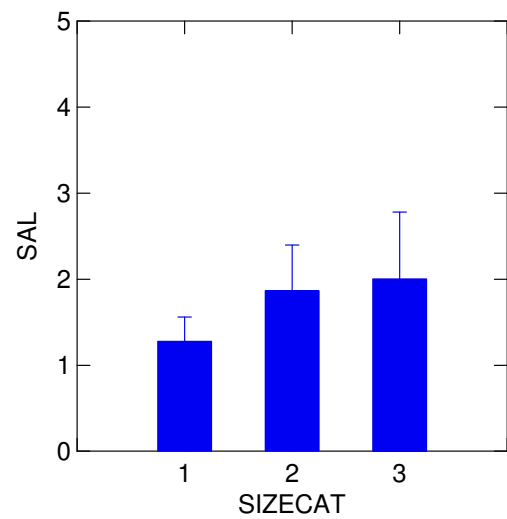
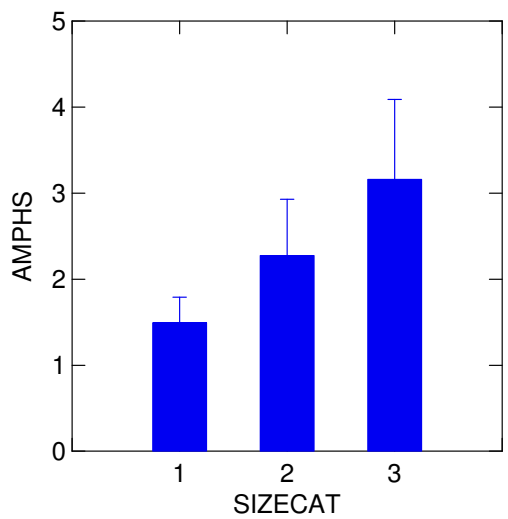
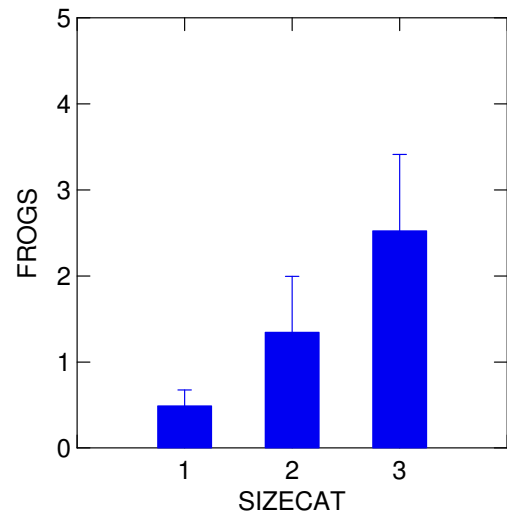
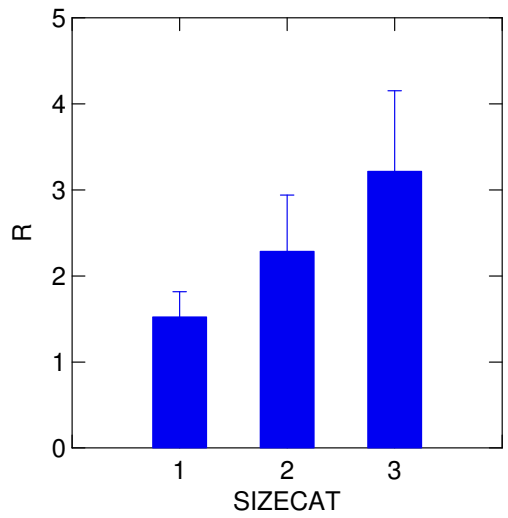


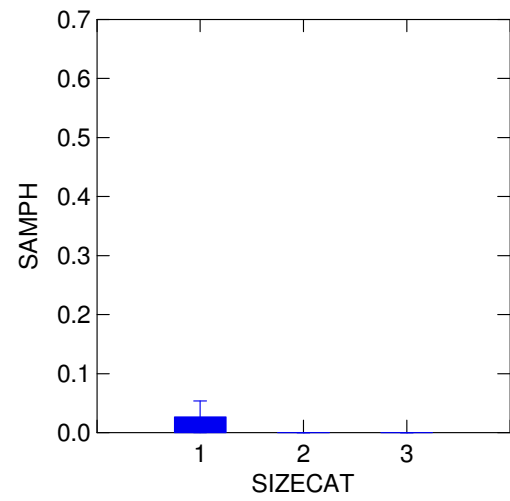
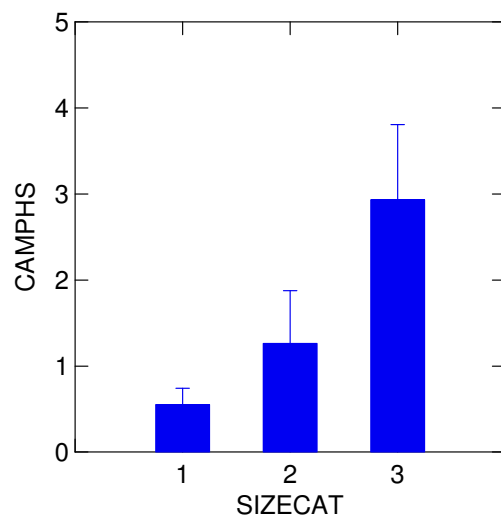
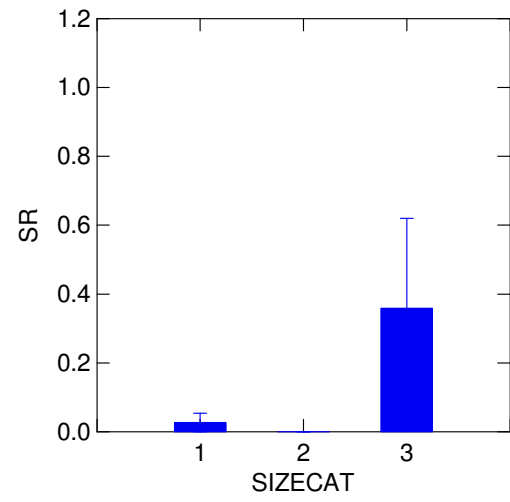
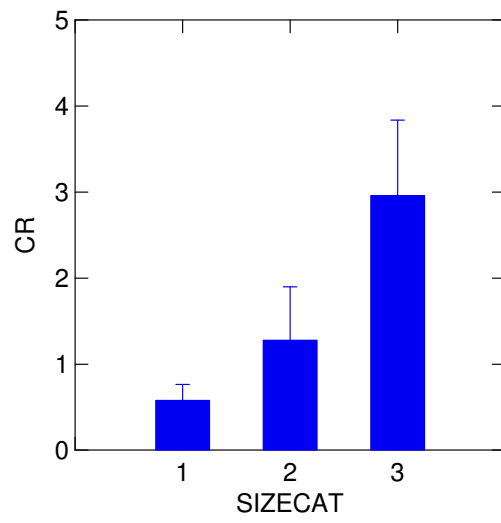
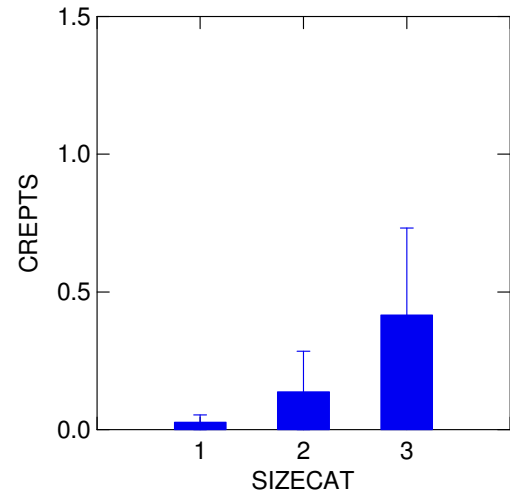
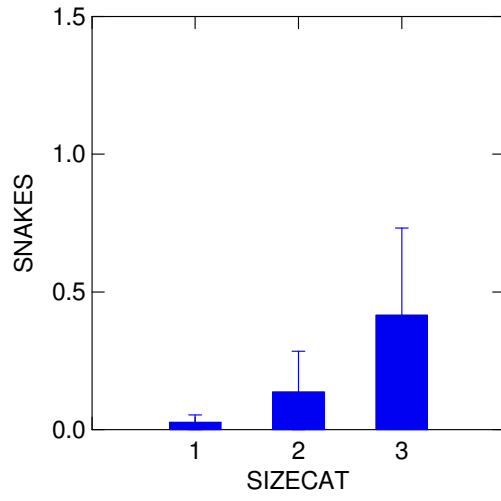
**Appendix 7.** 2004 Abundance and patch size ANOVA. SIZECAT = Patch Size Category; 1 = 0.30-5.00 ha, 2 = 5.01-10.00 ha, 3 = 10.01 – 20.00 ha, and 4 = 245.00-755.00 ha. Species codes from Table II.

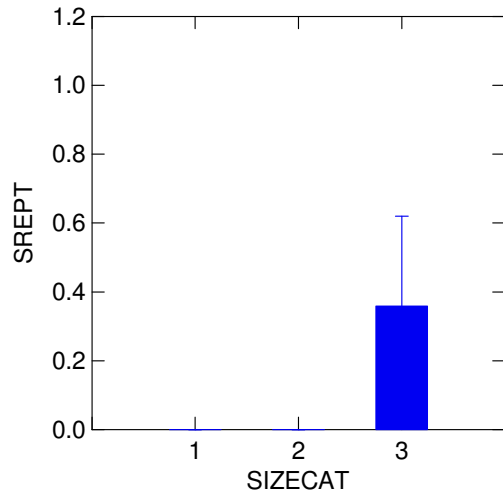
7.1 2004 Abundance ANOVA, N = 39.



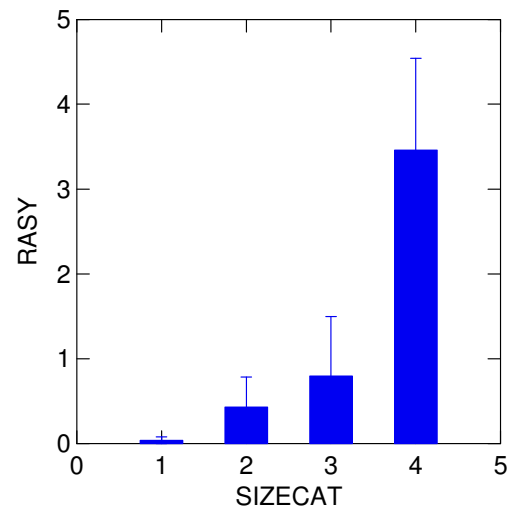
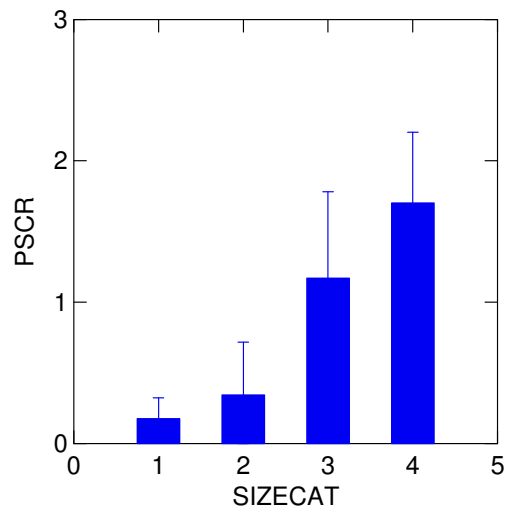
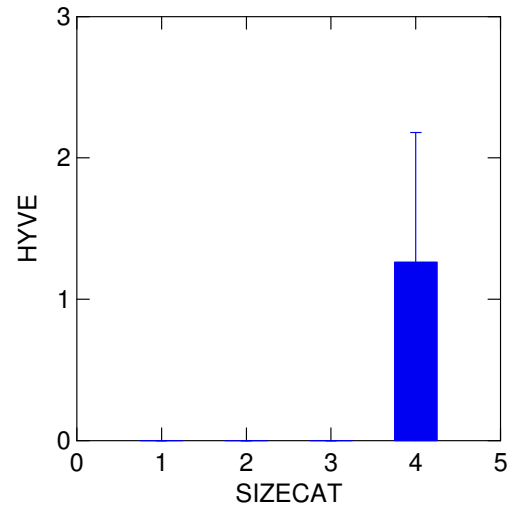
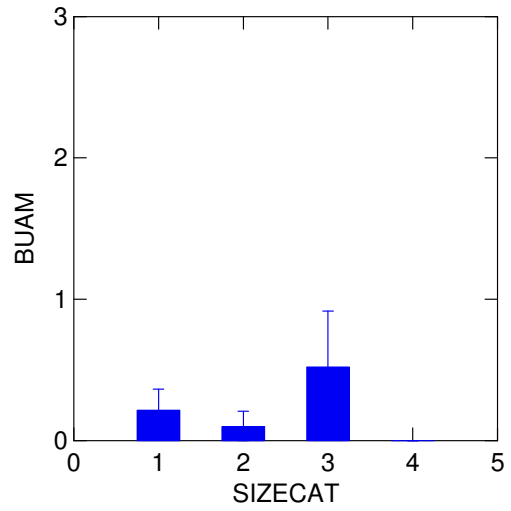


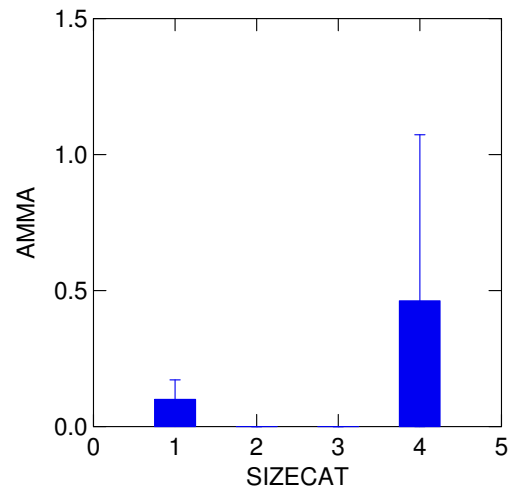
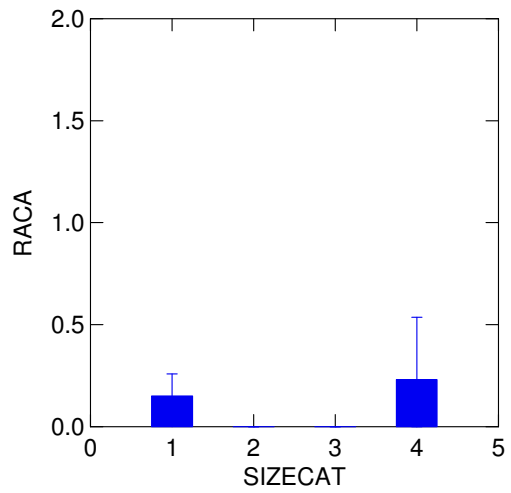
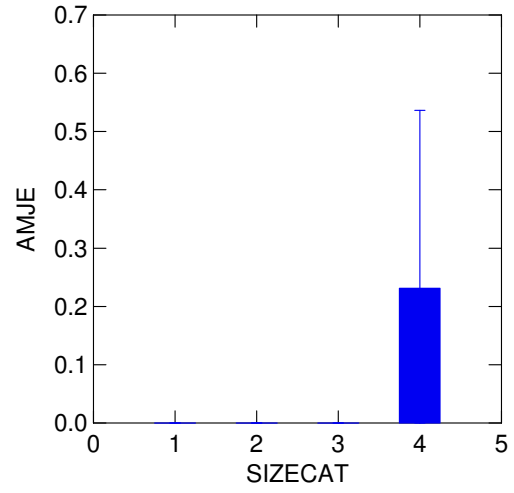
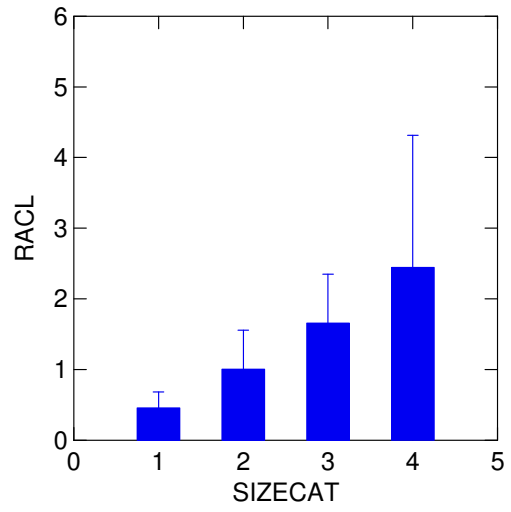
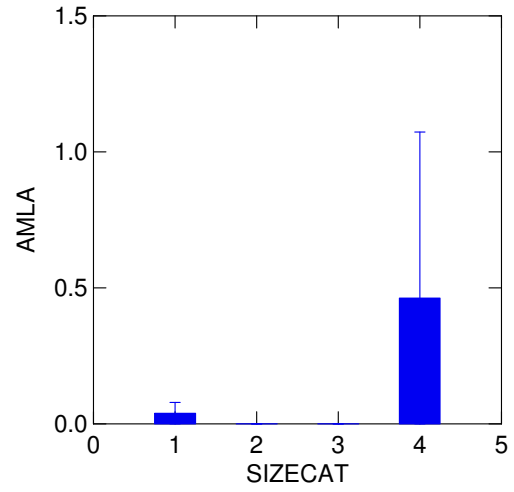
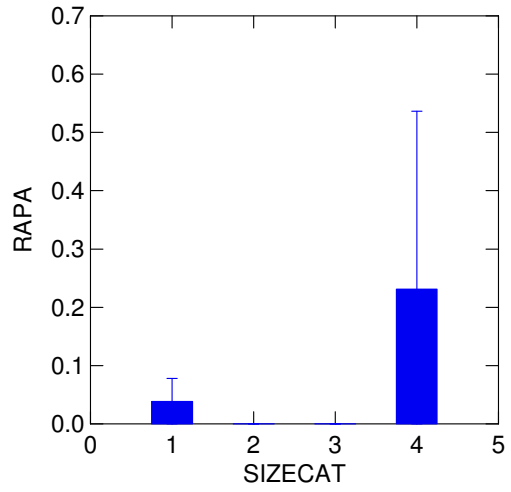


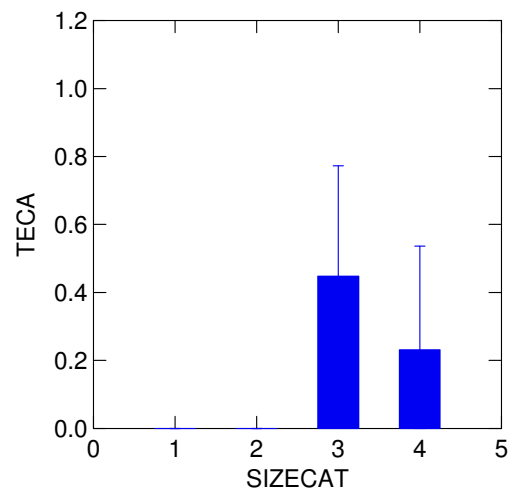
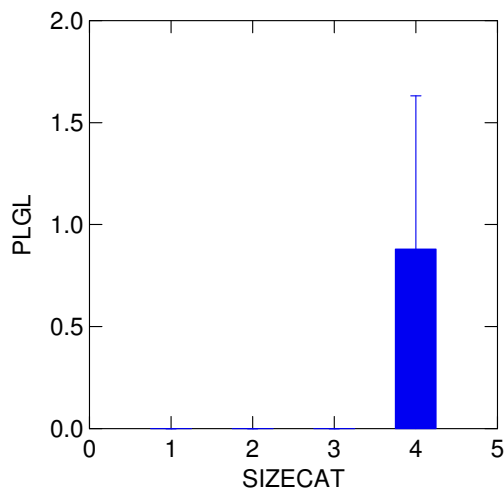
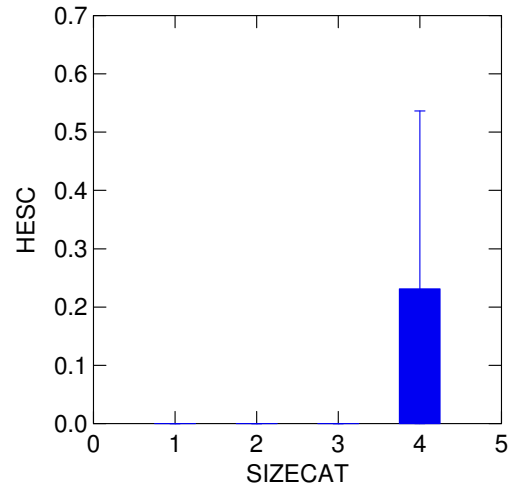
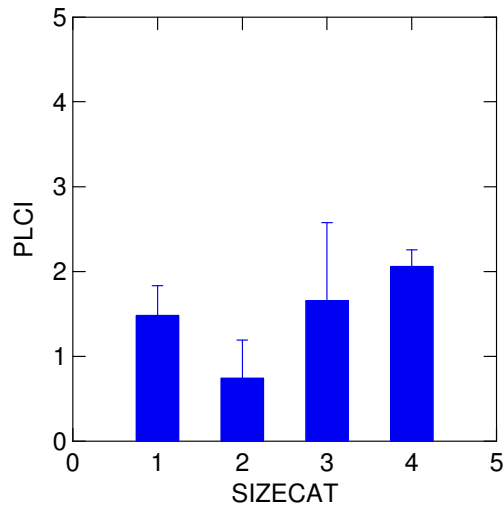
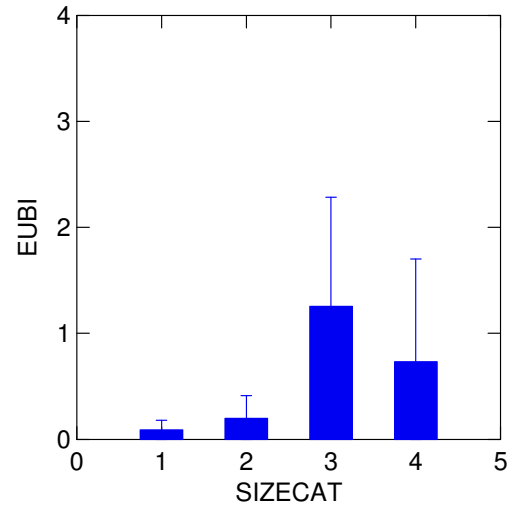
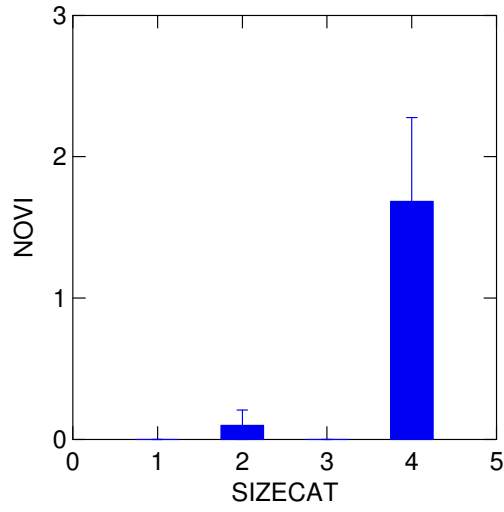


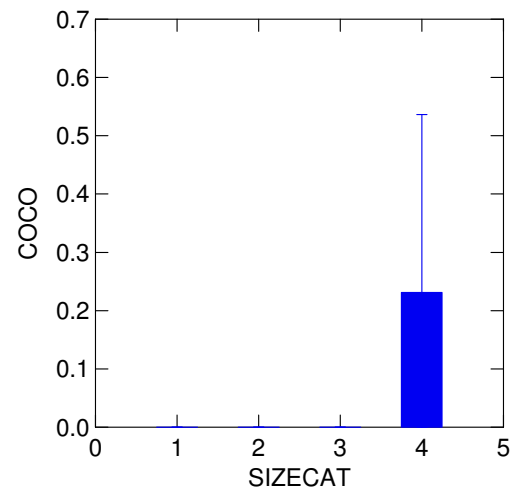
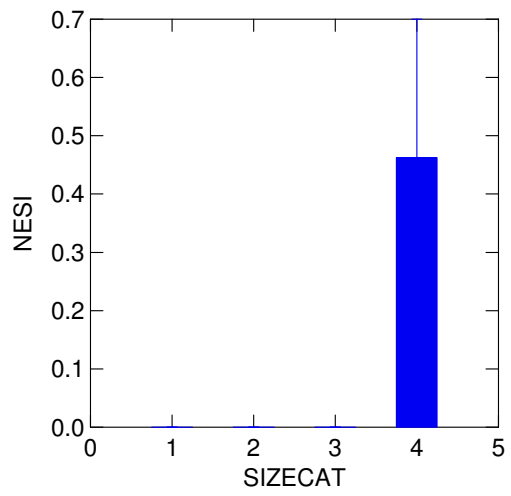
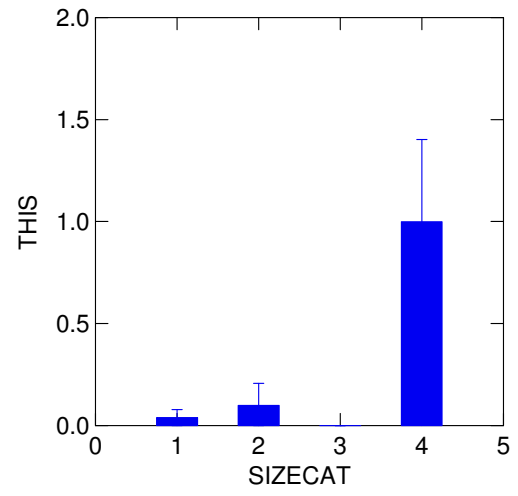
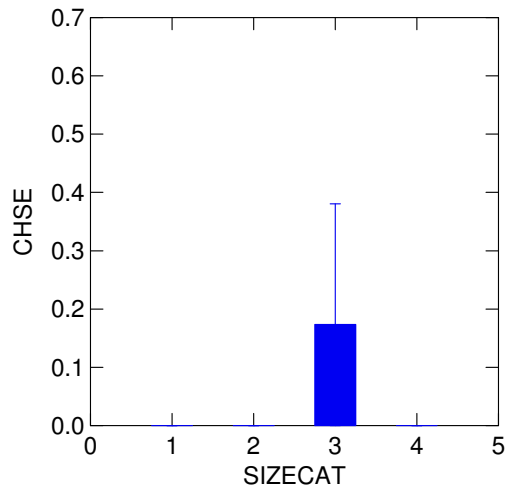
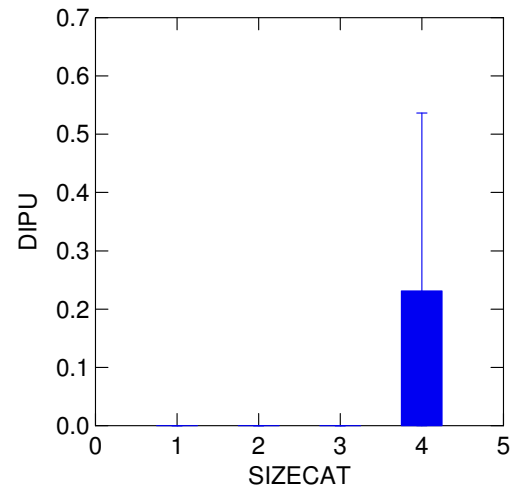
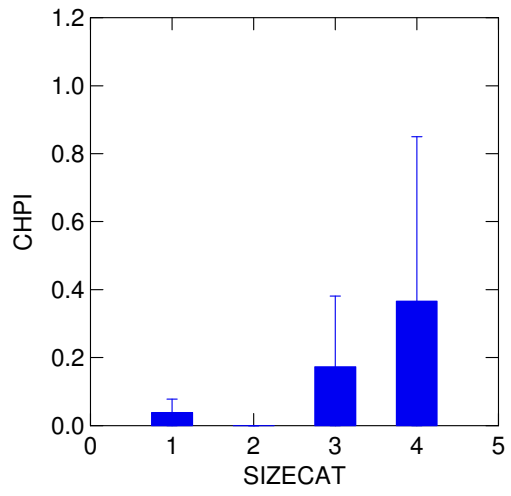


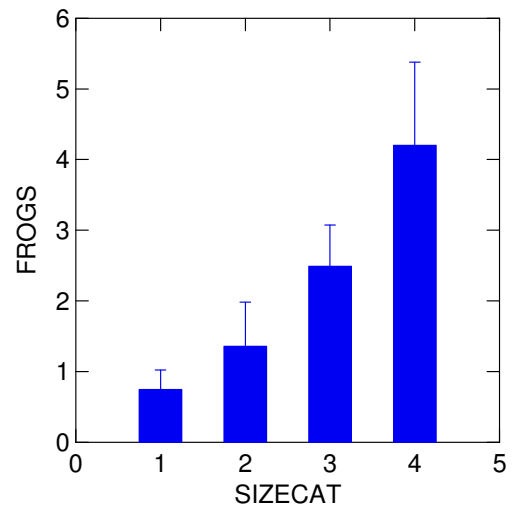
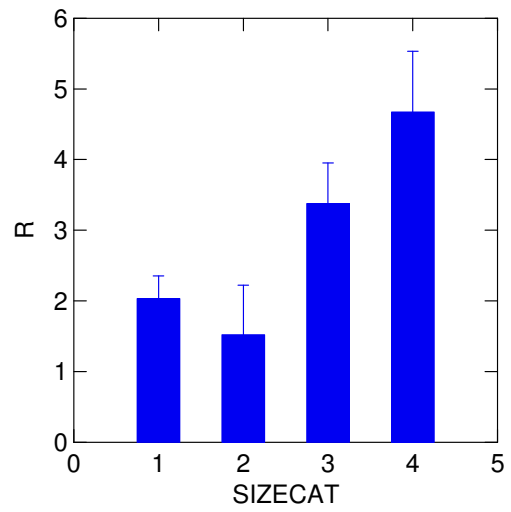
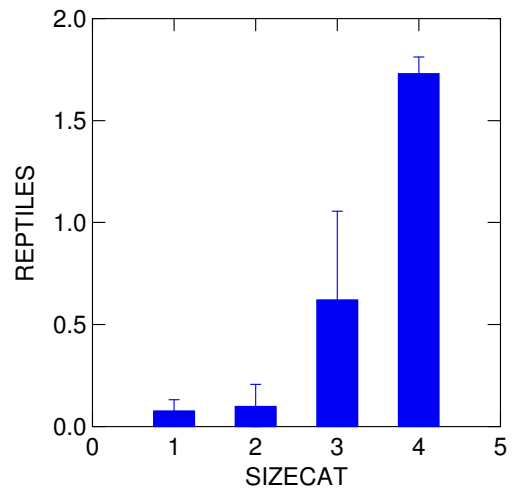
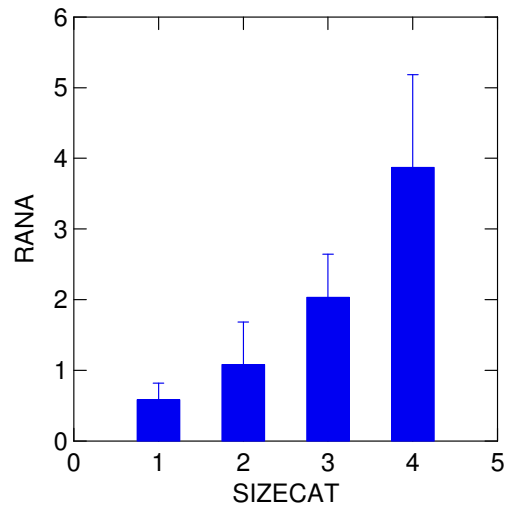
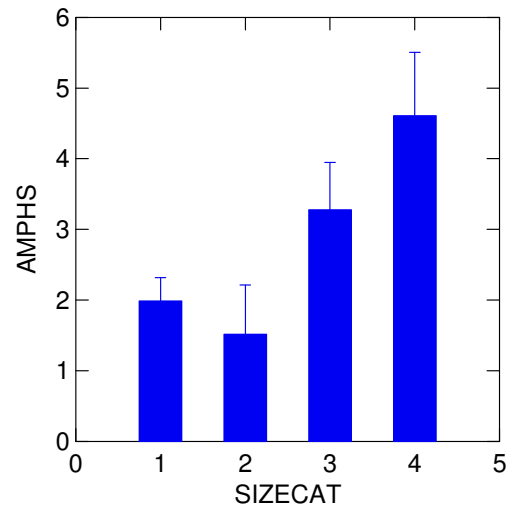
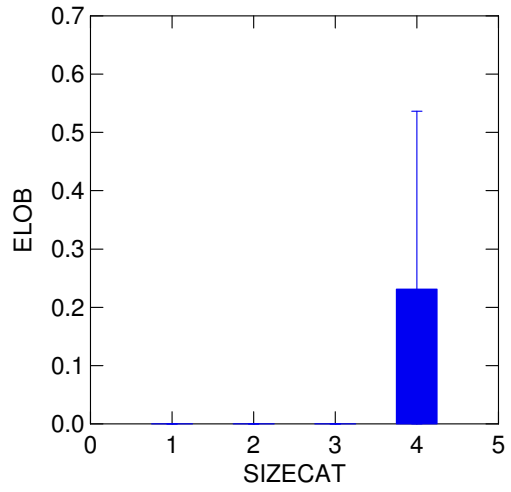
7.2. 2005 Abundance ANOVA, N = 31.



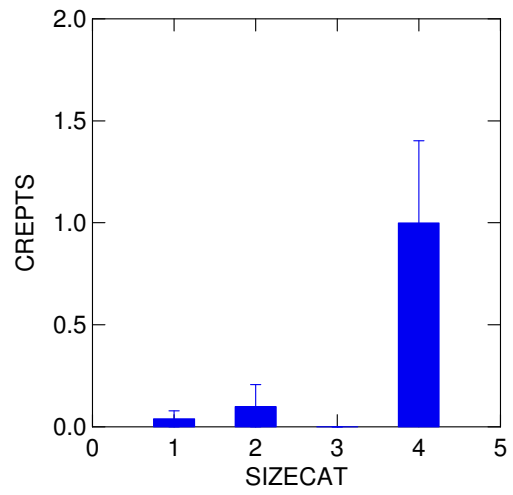
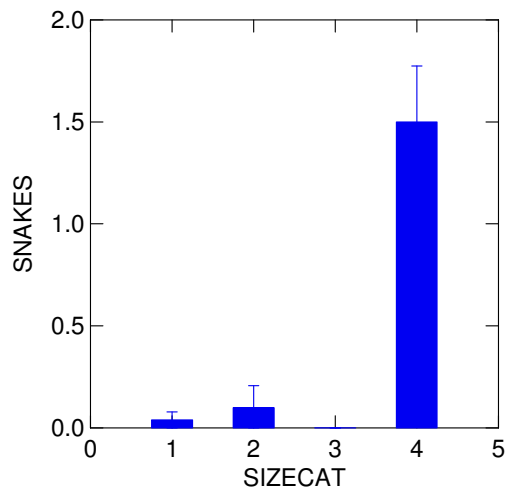
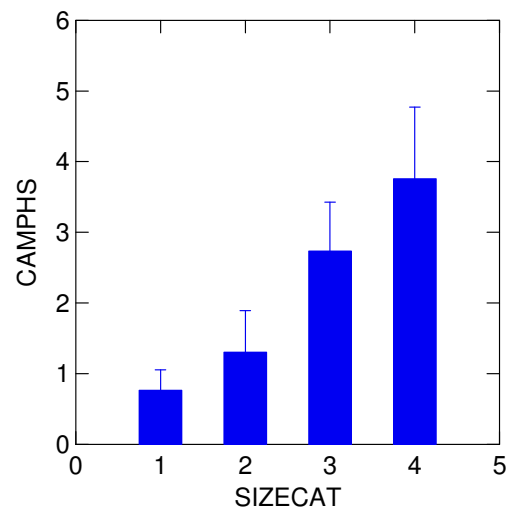
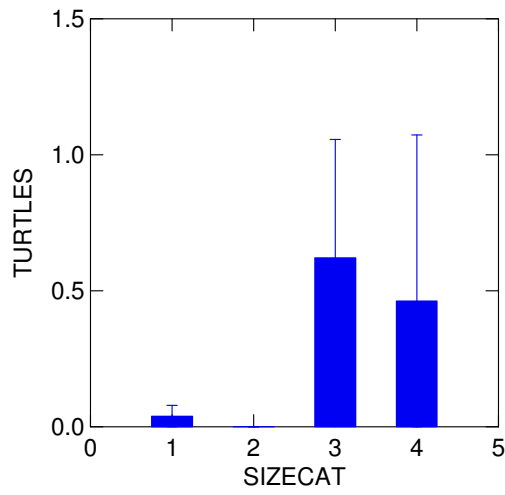
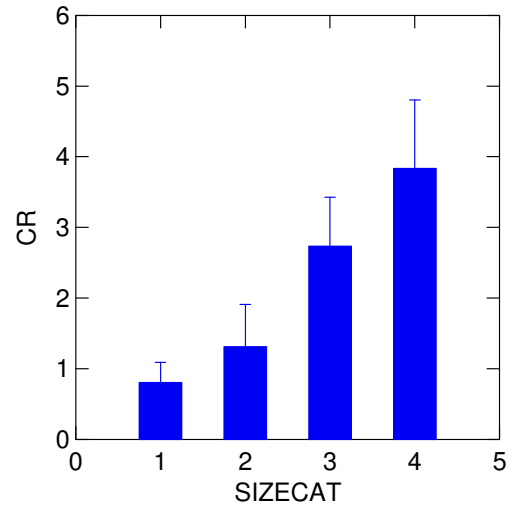
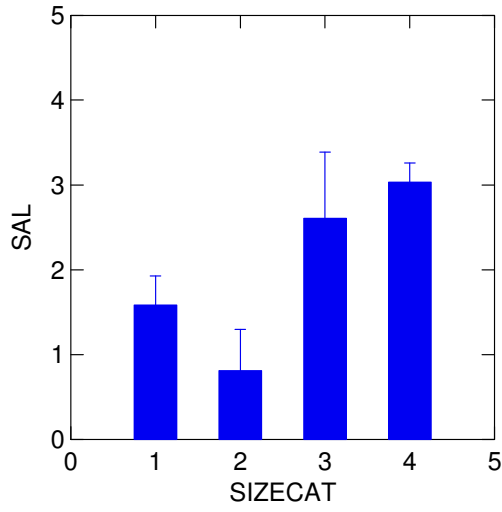


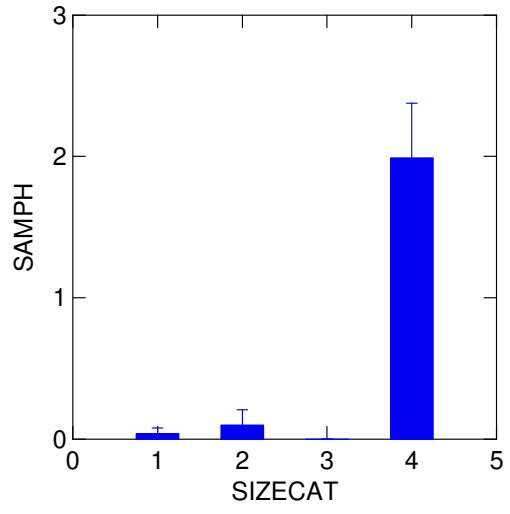
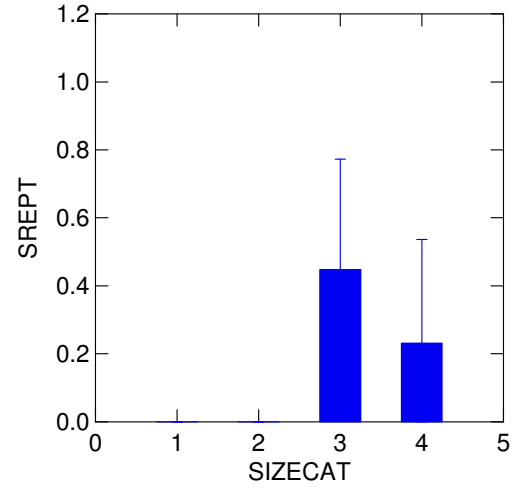
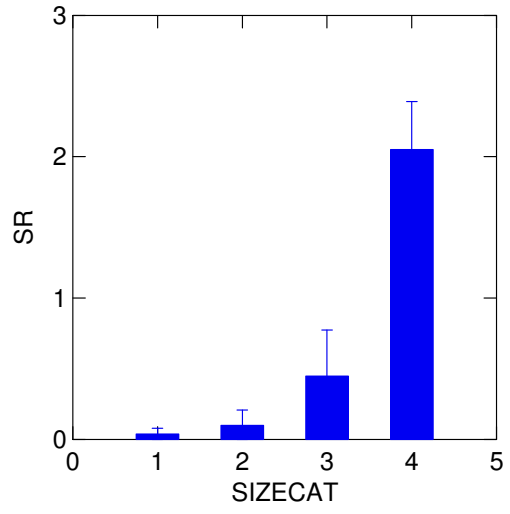




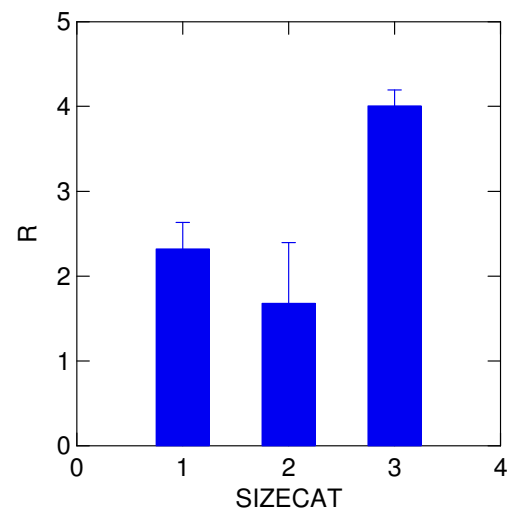
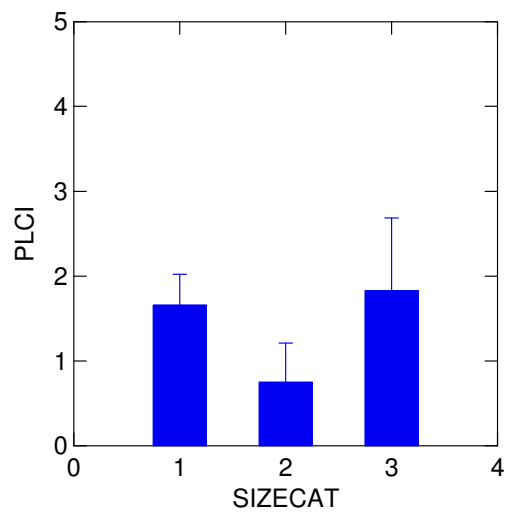
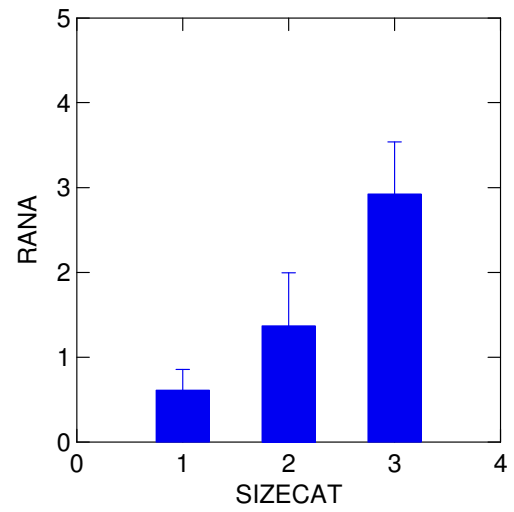
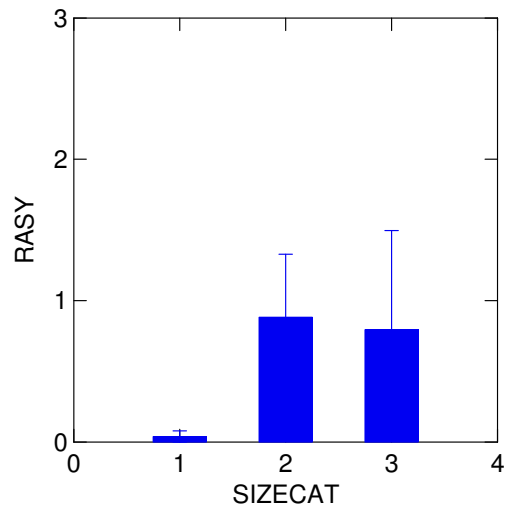


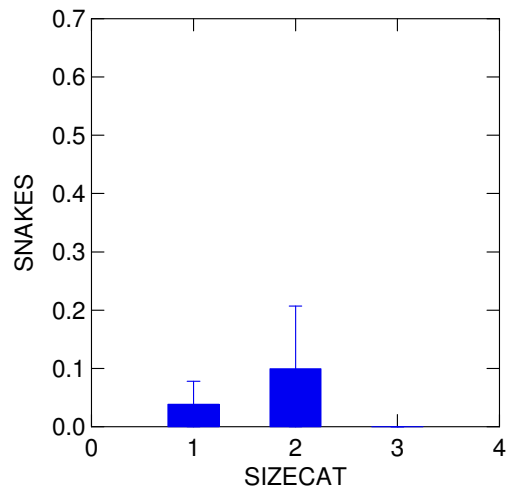
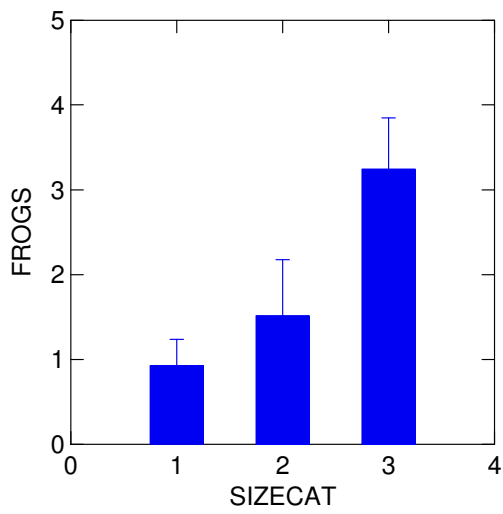
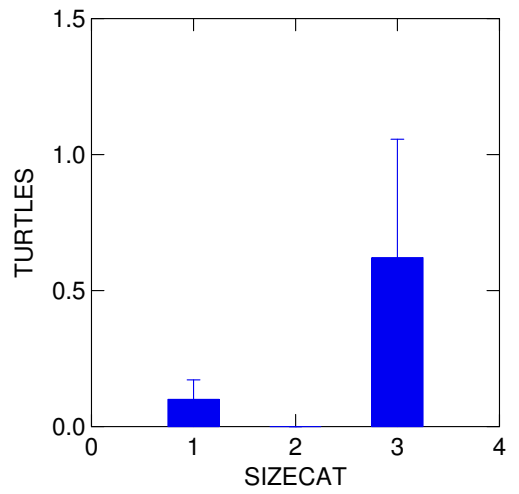
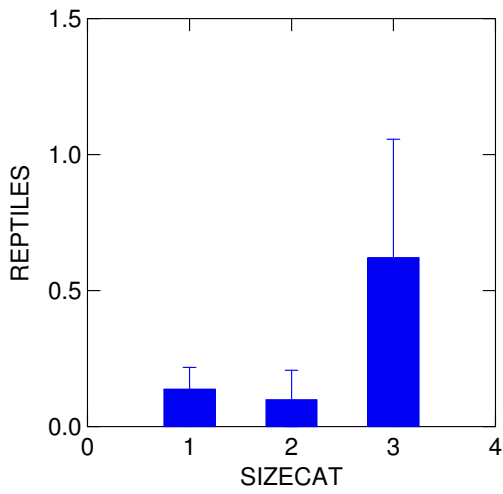
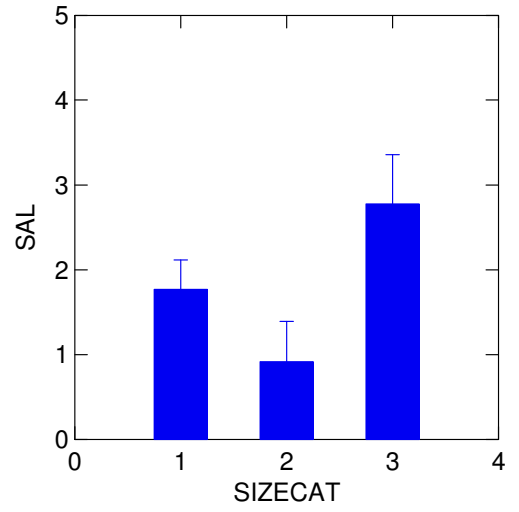
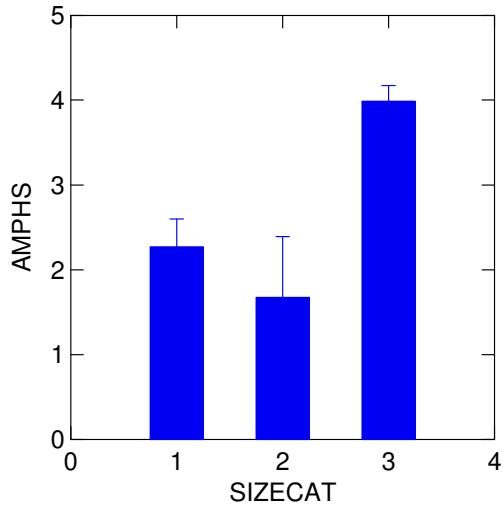


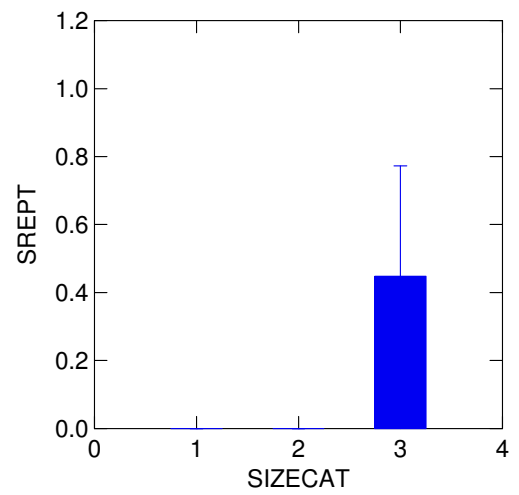
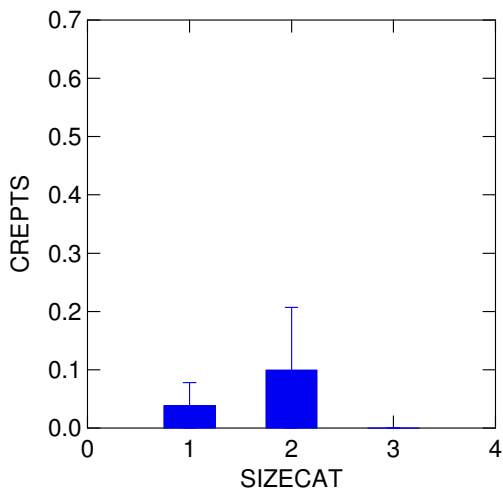
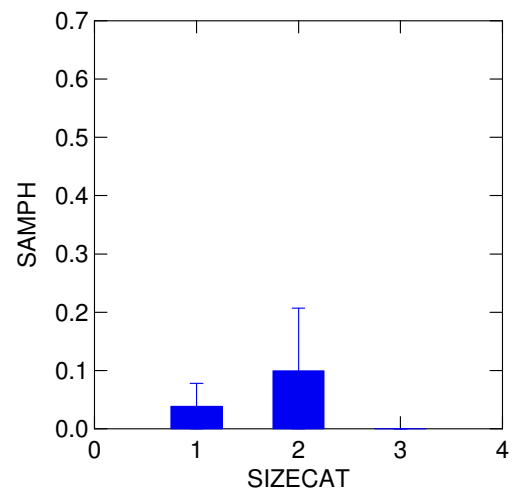
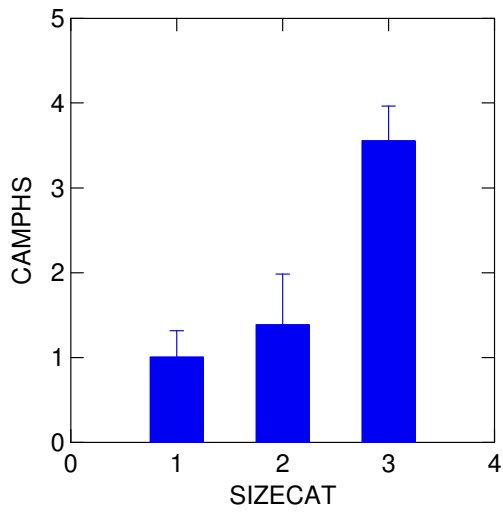
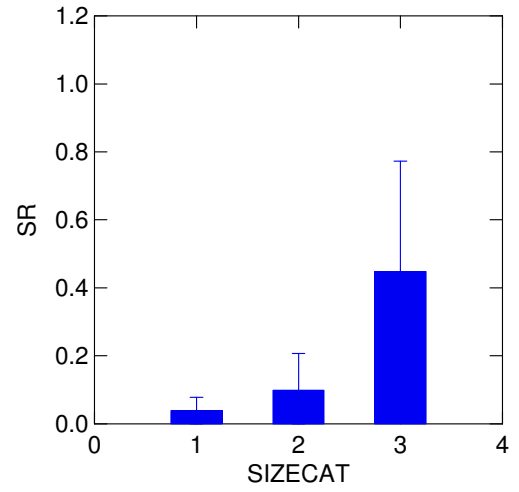
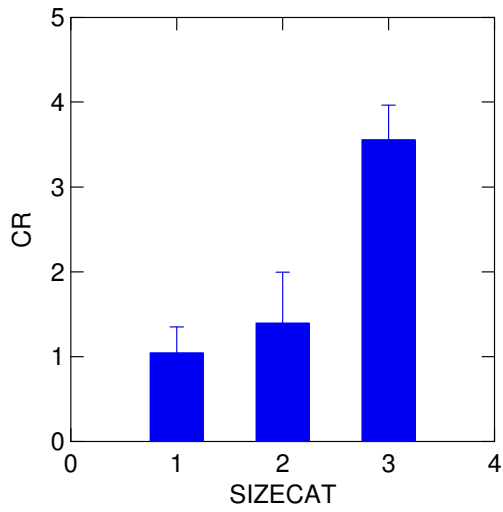




7.3. 2004/2005 Abundance ANOVA, N= 29.







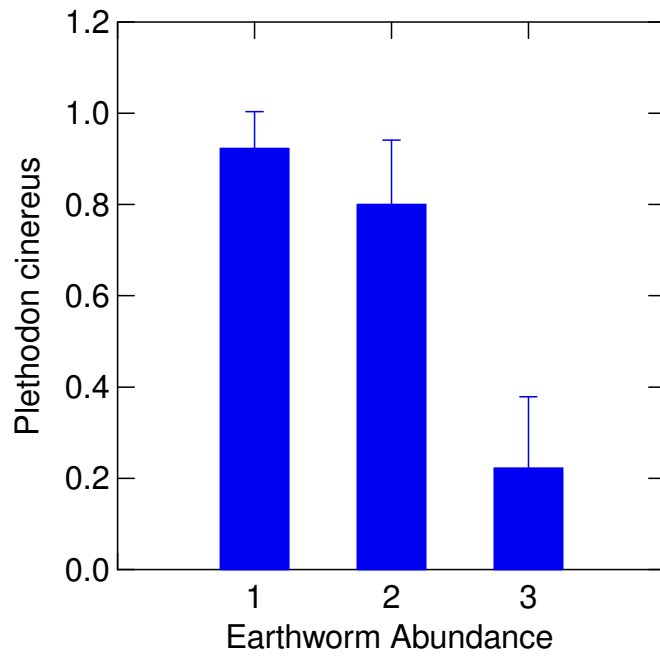
**Appendix 8.** 2004 species richness 2-way ANOVA of patch area and wetland presence, N=39.

		df	F-ratio	P	R <sup>2</sup>
<b>Ln Species Richness</b>	Size Category	2	3.571	0.039	0.595
	Wetland Presence	1	21.202	0.000	
	Size Category x Wetland Presence	2	3.467	0.043	
<b>Ln Amphibians</b>	Size Category	2	2.938	0.067	0.552
	Wetland Presence	1	17.641	0.000	
	Size Category x Wetland Presence	2	2.415	0.105	
<b>Ln Reptiles</b>	Size Category	2	1.959	0.157	0.423
	Wetland Presence	1	8.254	0.007	
	Size Category x Wetland Presence	2	2.695	0.082	
<b>Ln Anurans</b>	Size Category	2	7.837	0.002	0.691
	Wetland Presence	1	24.512	0.000	
	Size Category x Wetland Presence	2	3.161	0.055	
<b>Ln Caudates</b>	Size Category	2	0.355	0.704	0.264
	Wetland Presence	1	8.661	0.006	
	Size Category x Wetland Presence	2	1.931	0.161	
<b>Ln Testudines</b>	Size Category	2	1.557	0.226	0.345
	Wetland Presence	1	6.864	0.013	
	Size Category x Wetland Presence	2	1.557	0.226	
<b>Ln Squamates</b>	Size Category	2	1.328	0.279	0.299
	Wetland Presence	1	1.723	0.198	
	Size Category x Wetland Presence	2	1.87	0.170	
<b>Ln Ranids</b>	Size Category	2	5.72	0.007	0.597
	Wetland Presence	1	12.093	0.001	
	Size Category x Wetland Presence	2	0.34	0.714	
<b>Ln Common Species Richness</b>	Size Category	2	1.415	0.257	0.601
	Wetland Presence	1	31.018	0.000	
	Size Category x Wetland Presence	2	5.57	0.008	
<b>Ln Common Amphibians</b>	Size Category	2	1.514	0.235	0.595
	Wetland Presence	1	30.053	0.000	
	Size Category x Wetland Presence	2	4.839	0.014	
<b>Ln Common Reptiles</b>	Size Category	2	1.328	0.279	0.299
	Wetland Presence	1	1.723	0.198	
	Size Category x Wetland Presence	2	1.87	0.170	
<b>Ln Sensitive/ Rare Species Richness</b>	Size Category	2	0.115	0.892	0.034
	Wetland Presence	1	0.063	0.803	
	Size Category x Wetland Presence	2	0.115	0.892	
<b>Ln Sensitive/Rare Amphibians</b>	Size Category	2	0.435	0.651	0.088
	Wetland Presence	1	0.239	0.628	
	Size Category x Wetland Presence	2	0.435	0.651	
<b>Ln Sensitive Reptiles</b>	Size Category	2	2.185	0.128	0.368
	Wetland Presence	1	5.525	0.025	
	Size Category x Wetland Presence	2	2.185	0.128	

**Appendix 9.** 2005 species abundance 2-way ANOVA of patch area and wetland presence, N=29.

		df	F-ratio	P	R <sup>2</sup>
<b>Ln Species Richness</b>	Size Category	2	0.924	0.407	0.369
	Wetland Presence	1	11.166	0.002	
	Size Category x Wetland Presence	2	4.045	0.027	
<b>Ln Amphibians</b>	Size Category	2	0.923	0.407	0.358
	Wetland Presence	1	10.713	0.002	
	Size Category x Wetland Presence	2	3.739	0.034	
<b>Ln Reptiles</b>	Size Category	2	2.007	0.150	0.437
	Wetland Presence	1	8.912	0.005	
	Size Category x Wetland Presence	2	2.552	0.093	
<b>Ln Anurans</b>	Size Category	2	2.533	0.095	0.593
	Wetland Presence	1	24.073	0.000	
	Size Category x Wetland Presence	2	2.818	0.074	
<b>Ln Caudates</b>	Size Category	2	0.701	0.503	0.202
	Wetland Presence	1	3.907	0.056	
	Size Category x Wetland Presence	2	2.992	0.064	
<b>Ln Testudines</b>	Size Category	2	0.809	0.454	0.271
	Wetland Presence	1	4.033	0.053	
	Size Category x Wetland Presence	2	0.809	0.454	
<b>Ln Ranids</b>	Size Category	2	3.643	0.037	0.624
	Wetland Presence	1	25.628	0.000	
	Size Category x Wetland Presence	2	3.326	0.048	
<b>Ln Squamates</b>	Size Category	2	1.291	0.288	0.277
	Wetland Presence	1	3.645	0.065	
	Size Category x Wetland Presence	2	1.948	0.159	
<b>Ln Common Species Richness</b>	Size Category	2	2.907	0.069	0.665
	Wetland Presence	1	31.929	0.000	
	Size Category x Wetland Presence	2	4.007	0.028	
<b>Ln Common Amphibians</b>	Size Category	2	2.962	0.066	0.667
	Wetland Presence	1	31.983	0.000	
	Size Category x Wetland Presence	2	3.758	0.034	
<b>Ln Common Reptiles</b>	Size Category	2	1.291	0.288	0.277
	Wetland Presence	1	3.645	0.065	
	Size Category x Wetland Presence	2	1.948	0.159	
<b>Ln Sensitive/Rare Species Richness</b>	Size Category	2	1.504	0.237	0.347
	Wetland Presence	1	3.611	0.066	
	Size Category x Wetland Presence	2	1.504	0.237	
<b>Ln Sensitive/Rare Amphibians</b>	Size Category	2	0.435	0.651	0.088
	Wetland Presence	1	0.239	0.628	
	Size Category x Wetland Presence	2	0.435	0.651	
<b>Ln Sensitive Reptiles</b>	Size Category	2	2.718	0.081	0.449
	Wetland Presence	1	3.898	0.057	
	Size Category x Wetland Presence	2	2.718	0.081	

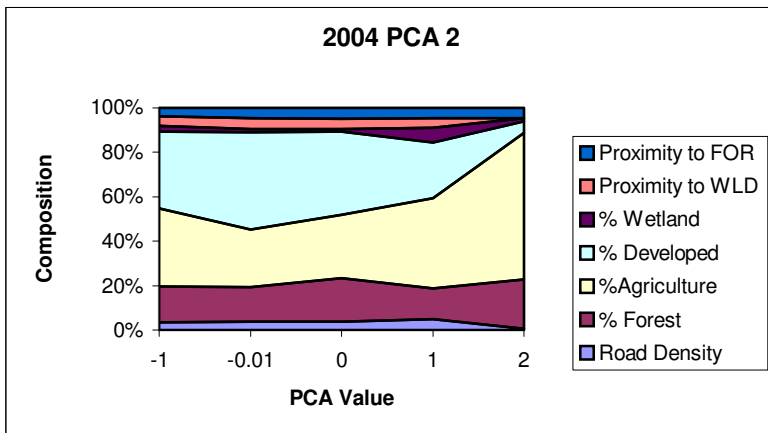
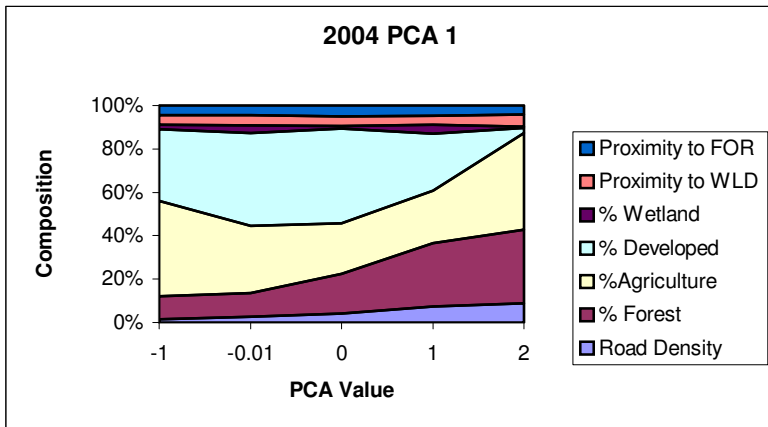
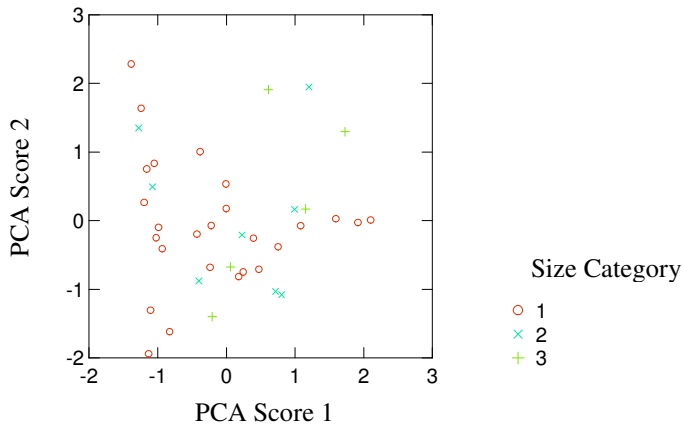
**Appendix 10.** Redback salamander abundance and earthworm density ANOVA in 2005, N=31. F-ratio = 9.941, df = 2, P = 0.001.



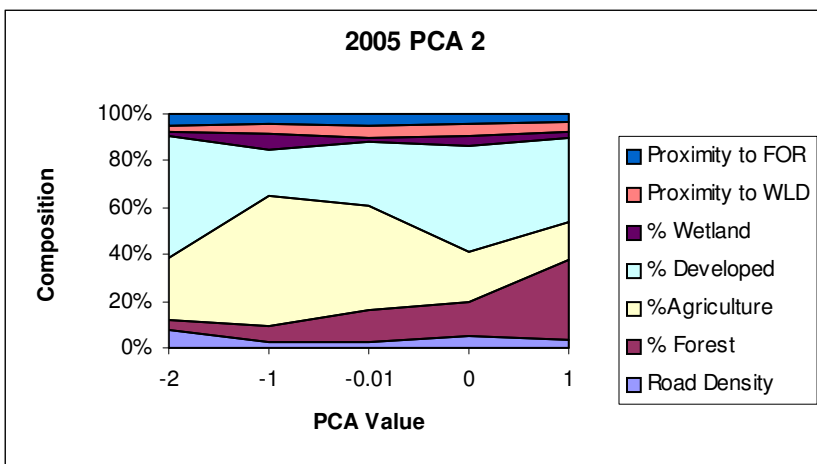
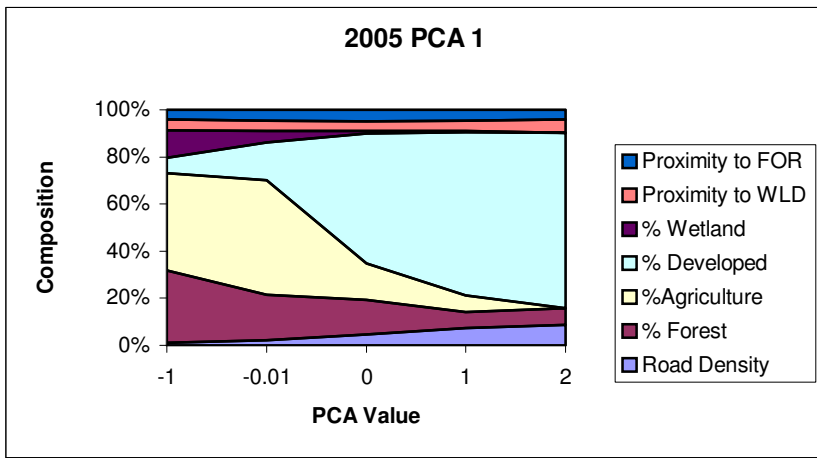
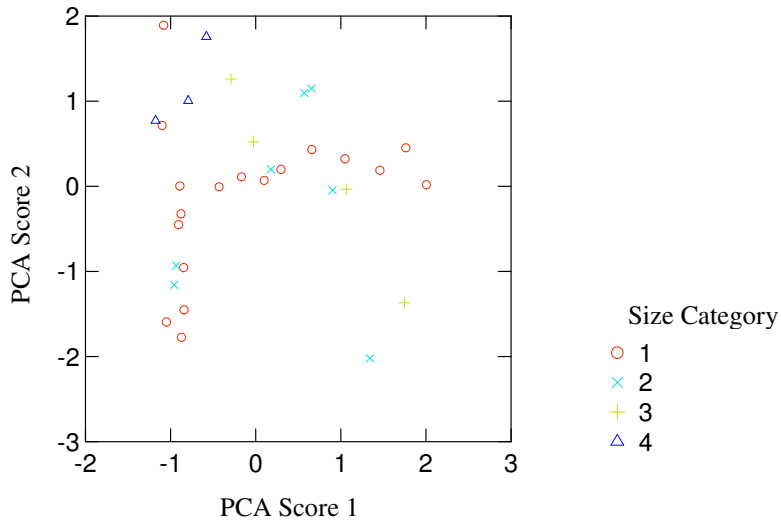


**Appendix 11.** Principal Components Analysis (PCA) of surrounding landcover variables (proximity to forest, proximity to wetland, road density, and % landscape composition of wetland, developed, agriculture, and forest) for each patch and reference forest. Patch size categories: 1 = 0.30-5.00 ha, 2 = 5.01-10.00 ha, 3 = 10.01 – 20.00 ha, and 4 = 245.00-755.00 ha.

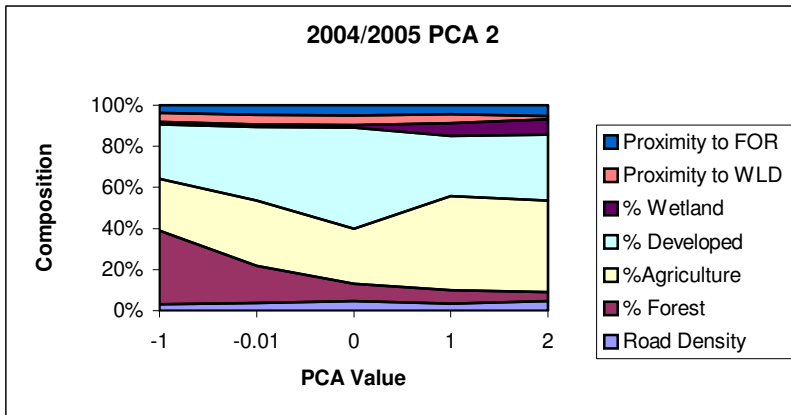
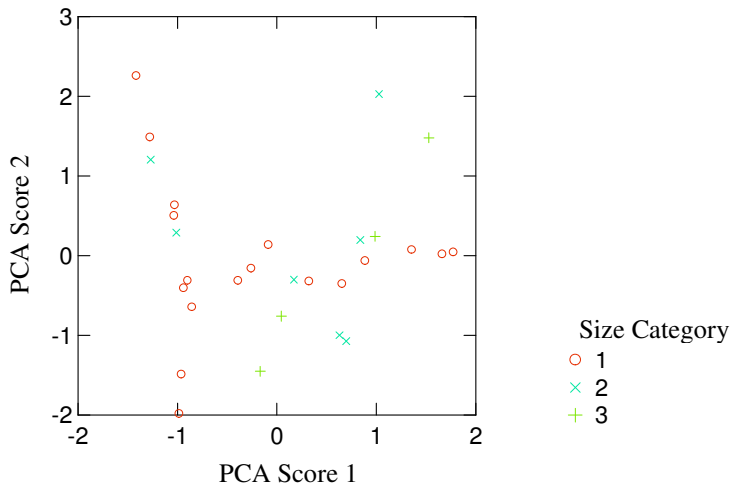
11.1. 2004 PCA and patch area ordination and visual interpretation for PCA Scores 1 and 2, N=39.



11.2. 2005 PCA and patch area ordination and visual interpretation for PCA Scores 1 and 2, N=31.



11.3. 2004/2005 PCA and patch area ordination for PCA Scores 1 and 2 and visual interpretation of PCA Score 2, N=29.



**Appendix 12.** Nested matrix of PCA score and species occurrence. The shaded cells indicate species presence and the white cells indicate species absence.

12.1. 2004 PCA Score 1, N=39.

PCA1	PLCI	RACL	PSCR	BUAM	RASY	RACA	AMMA	EUBI	HYVE	TECA	CHPI	THIS	RAPA	RAUT	NOVI	CHSE
2.10																
1.92																
1.73																
1.60																
1.20																
1.15																
1.08																
0.99																
0.80																
0.76																
0.72																
0.61																
0.47																
0.40																
0.25																
0.23																
0.18																
0.06																
0.00																
0.00																
-0.21																
-0.22																
-0.24																
-0.38																
-0.40																
-0.43																
-0.82																
-0.93																
-0.99																
-1.02																
-1.05																
-1.08																
-1.10																
-1.13																
-1.16																
-1.20																
-1.24																
-1.28																
-1.38																

12.2. 2004 PCA Score 2, N=39.

PCA2	PLCI	RACL	PSCR	BUAM	RASY	RACA	AMMA	EUBI	HYVE	TECA	CHPI	THIS	RAPA	RAUT	NOVI	CHSE
2.28																
1.95																
1.91																
1.64																
1.35																
1.30																
1.00																
0.83																
0.75																
0.53																
0.49																
0.26																
0.17																
0.17																
0.16																
0.03																
0.01																
-0.03																
-0.07																
-0.08																
-0.10																
-0.20																
-0.21																
-0.25																
-0.26																
-0.38																
-0.41																
-0.67																
-0.68																
-0.71																
-0.75																
-0.82																
-0.88																
-1.03																
-1.08																
-1.31																
-1.40																
-1.62																
-1.94																





12.5. 2004/2005 PCA Score 2, N=29.

PCA2	PLCI	RACL	BUAM	PSCR	RASY	RACA	AMMA	THIS	RAPA	EUBI	HYVE	TECA	CHPI	NOVI	AMLA	CHSE
2.26																
2.03																
1.49																
1.48																
1.21																
0.64																
0.50																
0.29																
0.24																
0.20																
0.14																
0.08																
0.05																
0.02																
-0.06																
-0.16																
-0.30																
-0.31																
-0.31																
-0.32																
-0.35																
-0.41																
-0.64																
-0.76																
-1.00																
-1.07																
-1.45																
-1.49																
-1.98																