ABSTRACT

MILLER, JENNIFER ELIZABETH. Impervious Surface Cover: Effects on Stream Salamander Abundance and A New Method of Classification Using Feature Analyst.
(Under direction of George R. Hess)

Increasing impervious surface cover associated with urbanization degrades water quality and alters wildlife habitat. Forested riparian buffers are one popular method of mitigating the effects of impervious surface cover. My study was designed to investigate the effects of impervious surface cover and forested riparian buffer width on the abundance of larval southern two-lined salamanders (*Eurycea cirrigera*). I sampled 50-meter reaches of 43 streams, representing the range of impervious surface cover and forested riparian buffer width combinations across Wake County, North Carolina, USA in 2004. Additionally, I measured physical and chemical stream properties to account for local habitat effects.

Percent impervious surface cover in the catchment, percent detritus cover in the stream, percent pebble substrate in the stream, and average water conductivity were significant predictors of larval *E. cirrigera* abundance. Forested riparian buffer width was not a significant predictor. Larval *E. cirrigera* abundance was lower than anticipated in several streams that appeared to provide good habitat. I discovered that salamander abundance was low in intermittent streams with substrate that is highly sedimented below the surface layer. I suspect that intermittency combined with filled substrate interstices reduced the ability of salamanders to migrate with the water column during dry periods, resulting in low abundances. My research is consistent with a growing body of literature documenting the negative effects of impervious surface on stream biota. In my study, low flow events significantly affected larval *E. cirrigera* abundance. My findings also suggest that salamander abundance cannot be predicted by measuring the forested

buffer width only at the sampling location. A catchment-wide quantification of the stream buffer system, accounting for culverts and other breaches, might yield a better predictive model.

Environmental, economic, and resource management research and decision-making requires current, accurate spatial information. Mapping with aerial imagery can play an important role in providing such information, if it can be done in a cost effective and accurate manner. For my research, I needed an efficient technique for identifying impervious surfaces in urbanizing Wake County, North Carolina, USA. The objectives of my study were to develop an accurate classification of impervious surface using high-resolution aerial imagery and to provide insight into the practical application of Feature Analyst, an object-oriented classification extension within ArcGIS. Feature Analyst utilizes advanced, object-oriented classification algorithms that incorporate spatial context with color and tone to classify high-resolution imagery. I trained Feature Analyst to differentiate pervious and impervious surfaces and classified 111 United States Geological Survey images with a spatial resolution of 33-cm. My classification results yielded an overall accuracy of 92%, with a user's accuracy of 95.2% for the impervious surface class. These results show improvement over historical accuracies of 85% or less. Feature Analyst is most beneficial when spectral value alone will not distinguish classes, object-oriented output is desired, and the time or knowledge for developing complex, customized algorithms is unavailable. I recommend Feature Analyst for classification of high-resolution imagery when object-oriented output is desired and hand-digitizing is impractical.

Impervious Surface Cover:
Effects on Stream Salamander Abundance and A New Method of Classification Using Feature Analyst.

By

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BIOGRAPHY

Jennifer Elizabeth Miller was born in St. Louis Park, Minnesota in 1980. She grew up in Eden Prairie and Jordan, Minnesota and graduated magna cum laude from Eden Prairie High School in 1999. Jennifer attended The Pennsylvania State University, graduating in magna cum laude in 2003 with simultaneous Bachelor of Science degrees in Environmental Resource Management and Wildlife & Fisheries Science, wildlife option. While attending Penn State, Jennifer worked with local, state, and federal government conservation efforts, working with the USDA/NRCS, Pennsylvania Game Commission, Pennsylvania Fish & Boat Commission, Shenandoah River State Park, and Millbrook Marsh Nature Center. She was also an active teaching assistant for the Biology Department, teaching Introductory Biology and Environmental Science, for non-majors. As a graduate student at North Carolina State University, Jennifer continued her interest in teaching and outreach, assisting with graduate-level Geographic Information Science (GIS) instruction. She presented her research to the Department of Forestry as well as presenting at the inaugural Urban/Rural Interface Conference. Jennifer is a departmental ambassador for the Department of Forestry to international students and currently in the Certificate of Accomplishment in Teaching inaugural program.

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Chapter 1

Effects of Impervious Surface Cover and Forested Riparian Buffer Width on Southern Two-lined Salamander (*Eurycea cirigera*) Abundance

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Abstract: Increasing impervious surface cover associated with urbanization degrades water quality and alters wildlife habitat. Forested riparian buffers are one popular method of mitigating the effects of impervious surface cover. Our study was designed to investigate the effects of impervious surface cover and forested riparian buffer width on the abundance of larval southern two-lined salamanders (*Eurycea cirrigera*). We sampled 50-meter reaches of 43 streams, representing the range of impervious surface cover and forested riparian buffer width combinations across Wake County, North Carolina, USA in 2004. Additionally, we measured physical and chemical stream properties to account for local habitat effects. Percent impervious surface cover in the upstream catchment, percent detritus cover in the stream, percent pebble substrate in the stream, and average water conductivity were significant predictors of larval *E. cirrigera* abundance. Larval *E. cirrigera* abundance was lower than anticipated in several streams that appeared to provide good habitat. Additional analysis indicates that decreased larval *E. cirrigera* abundance occurred in intermittent streams with substrate that was highly sedimented below the surface layer. We suspect that intermittency combined with filled substrate interstices reduced the ability of salamanders to migrate with the water column during dry periods, resulting in low abundances. Our research is consistent with a growing body of literature documenting the negative effects of impervious surface on stream biota. However, in our study low flow, not high flow, events significantly affected larval *E. cirrigera* abundance. Forested riparian buffer width was not a significant predictor of larval *E. cirrigera* abundance. We suggest that salamander abundance cannot be predicted by measuring the forested buffer width only at the sampling location. A catchment-wide quantification of the stream buffer system, accounting for culverts and other breaches, might yield a better predictive model.

Introduction

Urbanization is one of the major concerns of the twenty-first century, affecting transportation, urban planning, water resources, parks and recreation, commerce, taxation, emergency services, utilities, and people (Jensen & Cowen 1999). Much of urban development has moved away from city-center designs to a sprawling, dendritic pattern (Carlson & Arthur 2000). Commercial development has followed the major roadways while residential development follows a more dispersed pattern, converting agricultural and forest land along rural roads (Carlson &Arthur 2000). In the United States, the conversion of land to urban and suburban uses is driven by changing social conditions as well as human population growth. Even in regions with stable or decreasing populations, land is still being converted as society trends towards fewer people per house and more second and vacation home ownership (Burchell et al. 2002).

Urbanization causes many changes in the landscape, including increased impervious surface cover. Impervious surfaces, such as roof-tops and roads, prevent water from penetrating into the soil. Increased impervious surface cover changes stream flow patterns through more rapid peaking of floods, greater peak discharge, reduced groundwater recharge, and reduced base-flow. This modifies channel dimensions (width and depth), bankfull discharge, and sediment supply (Paul & Meyer 2001; Wang et al. 2001; Jennings & Jarnagin 2002), and results in decreased substrate and bank stability, accelerated channel erosion, and habitat simplification (Booth et al. 2002). As runoff increases, chemical changes to waterways also occur, including increased suspended solids, increased concentrations of heavy metals, and a decrease in dissolved oxygen (Paul & Meyer 2001; Gray 2004).

Relatively small changes in impervious surface cover can cause major changes in aquatic biota. These changes are often detected before physical or chemical changes in the water (Wang et al. 2001; Wang et al. 2003). Aquatic macroinvertebrate responses are best studied, with increased impervious surface cover resulting in decreased abundance and rapid loss of sensitive species, resulting in decreased diversity (Paul & Meyer 2001; Gray 2004). As little as 6% impervious surface cover can affect aquatic macroinvertebrates, while changes in water quality might not be detected until 45% impervious surface cover (Morse et al. 2003).

Forested riparian buffers often are used to mitigate the effects of impervious surface cover. Buffers are permanent areas of vegetation between pollutant sources and a receiving water body, managed separately from adjacent land (Viaud et al. 2004). Forested buffers can provide stream bank stability, maintain thermal and hydrologic regimes, and reduce pollution from sediment, nutrients, and pesticides (Muscott et al. 1993; Jones et al. 1999; Tomer et al. 2003; Viaud et al. 2004). Forested riparian buffers also can provide critical habitat for semi-aquatic species, including herptile breeding, foraging, and migration habitat (Semlitsch & Bodie 2003). Because of their benefits, governments at many jurisdictional levels have recommended or implemented forested riparian buffer standards (Tomer et al. 2003; Wilson & Dorcas 2003). Forested riparian buffers typically are regulated by their width (Lee et al. 2004); however, the effectiveness of this approach is still debated (Tomer et al. 2003).

Stream plethodontid salamanders are widespread, abundant, and have been suggested as an effective bioindicator of water quality (Rocco & Brooks 2000). Salamanders serve as an important predator in aquatic systems and a main prey species for many terrestrial animals, facilitating an essential energy flow from aquatic to terrestrial. The loss of salamander abundance and diversity in urban streams critically modifies trophic relationships, altering small stream ecology (Minton 1968, Orser & Shure 1972; Rocco & Brooks 2000; Wilson & Dorcas 2003). Despite these qualities, salamanders are notably under-studied in urban environments. Two studies that investigated the effects of urbanization on stream salamanders revealed that urbanization and other land disturbance reduces stream salamander abundance and diversity (Orser & Shure 1972; Wilson & Dorcas 2003). Our research builds on this previous work by examining a wider range of buffer width and impervious surface combinations at a greater number of sites. We used continuous measurements of impervious surface cover and forested riparian buffer width in our analysis with hopes of identifying critical threshold values at which salamander abundance was greatly reduced.

Objective

Our study was designed to investigate the effects of impervious surface cover and forested riparian buffer width on diversity and abundance of stream salamanders. Physical and chemical stream properties were measured to account for local habitat effects. We sampled salamanders in 43 streams, representing the range of impervious surface cover and forested riparian buffer width combinations across Wake County, North Carolina, USA in 2004.

Methods

Study Area

Wake County is located in central North Carolina and home to the state capital, Raleigh. With an area of 2,225 km^2, Wake County is experiencing rapid population growth. The population reached 750,000 people in the year 2005 and is expected to exceed one million people by 2016 (Wake County 2005). The number of houses in Wake County is projected to increase 37.5% between 2000 and 2025 (Burchell et al. 2002). Wake County is in the Piedmont region of North Carolina with a primary underlying geology of Triassic and Raleigh Metamorphic Belt. It is part of the Neuse and Cape Fear River Basins that drain south-east to the Atlantic Ocean (Wake County 2005). The average annual temperature ranges from 4.2°C to 26.0°C with a mean annual rainfall of 115 cm (NOAA et al. 2000). The County exhibits a gradient from urban to rural land use, including industrial, commercial, residential, agriculture, open grass, coniferous forest, deciduous forest, mixed forest, and open water land cover types (Wake County 2005).

Site Selection and Sample Design

We sampled streams associated with greenways in Wake County. Working along the greenways provided a consistent linear feature, facilitated access, and ensured some degree of protection against forest buffer modifications during sampling. We used a geographic information system (GIS) to select potential sites from all the greenways in Wake County associated with stream corridors. We measured the upstream catchment area of each potential site using United States Geological Survey (USGS) 10-m Digital Elevation Model (DEM), ArcGIS 8.3, and the ArcGIS extension ArcHydro. We identified all sites with (1) a flowing stream; (2) a catchment between

0.65 km^2 and 1.95 km^2 to control for stream size; and (3) a forested buffer of constant width for a 50-m reach along which there were no culverts, dams, or other direct human disturbance. Thirty-nine sites met these criteria and provided a wide range of impervious surface cover and riparian buffer width combinations (Fig. 1). We also included four reference sites within William B. Umstead State Park, in a 22-km^2 protected area in Wake County. Though historically disturbed for agriculture, these sites served as a reference for larval *E. cirrigera* abundance in streams with almost completely forested catchments. Impervious surface in the reference sites was less than 6% and limited to park roads and low-density residential development at the extreme upstream portions of the catchments.

Of the 43 sites, three sites were sampled each day and all sites were sampled three times—once in April, May, and November. We used Latin Squares to randomize sampling order by day and time to avoid, for example, always sampling wide buffers in the morning.

Salamander Sampling

The initial design of our study included sampling five historically common stream salamander species: northern dusky salamander (*Desmognathus fuscus*), southern two-lined salamander (*Eurycea cirrigera*), three-lined salamander (*Eurycea guttolineata*), mud salamander (*Pseudotriton montanus*), and red salamander (*Pseudotriton ruber*). Mud and red salamanders never were observed during preliminary sampling, and northern dusky and three-lined salamanders were very rare. Southern two-lined salamanders (*E. cirrigera*), however, were found in varying abundances and became the focus of our study. Our focus narrowed further to larval *E. cirrigera.* Larval *E. cirrigera* hatch in the spring and remain in the stream for two full years, metamorphosing into adults the summer of their second year. The larval life stage is most affected by stream changes, being obligate-aquatic, whereas adults can seek refuge in terrestrial environments. Because up to three age classes of larvae can be present in a stream at one time, they are abundant at all times of year, allowing easier, consistent sampling.

To sample *E. cirrigera* larvae, we established a 50-m reach at each stream site (Jones et al. 1999). During preliminary sampling, the general condition and character of each stream was observed. Sample reaches of 50-m length were used because that length provided a good sample of the habitat variability in these small streams. Within each reach, we sub-sampled three 10-m segments: 0-10 m, 20-30 m, and 40-50 m. We searched for salamanders in each 10-m segment from downstream to upstream, removing all surface substrate including rocks, debris, and detritus. Salamanders were captured using a bait net or dip net and placed in a bucket. At the end of the segment, we recorded the age class and length of all individuals before releasing them at the downstream end of the segment. Substrate was replaced to its original condition, and the process was repeated for the second and third segments within a reach.

Habitat Sampling

We collected physical, chemical, and biological habitat data at each site to account for the influence of local habitat on salamander abundance. During salamander sampling, we measured date, time, air temperature, and general weather (clear, partly cloudy, partly sunny, or overcast). At each of the three segments within a site, we recorded water temperature, pH, and conductivity using a Hanna combination tester.

We collected additional habitat data for each 10-m segment at all sites in June. Stream width and maximum depth, typically at thalweg, were averaged from three measurements at downstream, mid-section, and upstream locations. We estimated canopy cover using a spherical densiometer at the downstream and upstream points of the segment. The percent of the 10-m segment that was riffle, run, or pool was estimated visually. We visually estimated percent substrate in the classes silt (<0.062mm), sand (0.062 – 2mm), pebble (2.1 – 45mm), cobble (46 – 256mm), boulder (257 – 4096mm), and bedrock to the nearest 5% (USDA 2005). Detritus, woody debris, and litter were estimated visually as 0%, 1%, 5%, or the nearest 5% of substrate covered, as were the percent of the stream bank that was undercut and the percent of the bank that had exposed roots. We surveyed the channel profile and calculated a bank-height ratio (top of low bank : bankfull) to determine degree of incision.

Impervious Surface Cover

We measured impervious surface cover in each catchment using USGS 2003 high-resolution, true color, digital orthoimagery of the Raleigh-Durham area. Feature Analyst, Visual Learning Systems' extension, was used within ArcGIS to map impervious surface cover in the imagery (Miller 2005). With training, Feature Analyst can identify classes with similar combinations of color, texture, shape, and pattern. We trained Feature Analyst to identify impervious surfaces using three randomly selected images and applied this training to the 111 images covering our study sites. We used the area of impervious surface within the upstream catchment as the impervious surface cover value for each site.

We conducted an accuracy assessment using 252 randomly generated points, with half in areas classified as impervious and half in areas classified as pervious (Congalton 1991). We compared the Feature Analyst classification to the imagery for each point. Using a classification error matrix (Landis & Koch 1977; Congalton 1991), we calculated the overall accuracy to be 91.7%. To determine the agreement between the Feature Analyst classification and the true ground cover, as represented in the imagery, a Kappa Test was used. The Kappa statistic ranges from 0 or no agreement to 1, perfect agreement. We calculated a Kappa of 0.83, $p < 0.0001$ (Miller 2005), indicating “almost perfect” agreement between the Feature Analyst classification and imagery (Landis & Koch 1977).

Forested Buffer Width

We measured forested buffer width using the USGS 2003 high-resolution, true color, digital orthoimagery of the Raleigh-Durham area and the ArcGIS measure tool. The total buffer width was measured three times, once at each 10-m segment, and averaged for each reach.

Data Analysis

We used the square-root transformation of larval *E. cirrigera* abundance, averaged over April, May, and November as the response variable. The square-root transformation improved the normality of the data. The data analysis for our research was generated using SAS software, Version 9.1 (SAS Institute 2003). Stepwise and Mallow’s C_p selection methods were used to select significant explanatory variables and develop a linear regression model for the 43 streams. Points of inflection were estimated for quadratic parameters, using the formula:
$-(\beta_1/2\beta_2)$.

Upon examining the results of our initial analysis, we identified 13 sites that had few or no salamanders despite what appeared to be high-quality habitat. This is a common occurrence in urban and suburban areas of Wake County (A. Braswell, personal communication). These sites were not outliers; however, we felt they could be better described than with the original model. We conducted an additional analysis to investigate these relationships. During June sampling, many streams were noted as being intermittent or having very low surface flow. Streams observed to be flowing during all four field visits were identified as perennial, and streams not flowing in June were identified as intermittent. We included the interaction between this class variable and all other measured variables. Using stepwise and Mallow's C_p selection methods, a second linear regression model was selected.

Results

Stepwise and Mallow's C_p methods selected impervious surface cover, detritus, pebble substrate, and water conductivity as significant variables with an R^2 of 0.59 (Fig. 2). Impervious surface cover and detritus had the best fit in a quadratic form (Table 1). Larval *E. cirrigera* abundance declined with increasing impervious surface cover from 0 – 26.6% and increased with increasing impervious surface cover greater than 26.6%. Abundance increased with more detritus to 11.4% and then decreased with increasing detritus greater than 11.4%. Abundance increased with pebble substrate and decreased with increasing water conductivity. Forested riparian buffer width had little effect on larval *E. cirrigera* abundance ($p = 0.21$).

In the additional analysis, we included the variable of intermittent or perennial flow. A similar model was selected; however, impervious surface cover was significant as a linear, not quadratic, relationship, and water conductivity was no longer significant (Table 2). The interaction of the variables pebble substrate and perennial was significant. We kept the not-significant variables of pebble substrate and perennial in the model to allow the interaction variable to have different intercepts as well as different slopes for each value of the class variable. In perennial streams, larval *E. cirrigera* abundance increased with pebble substrate (Fig. 3a). In intermittent streams, pebble substrate had no effect on larval *E. cirrigera* abundance (Fig. 3b). The additional analysis demonstrated good overall predictability with an R^2 of 0.73 (Fig. 4).

Discussion

Impervious surface cover, but not forested riparian buffer width, correlates with larval *E. cirrigera* abundance. In our first analysis, increased impervious surface cover was associated with decreased larval *E. cirrigera* abundance from 0 – 26.6% impervious surface cover. Our threshold of 26.6% is remarkably close to the value of 26% impervious surface cover commonly used to classify catchments as degraded (Schueler 1994; Arnold & Gibbons 1996). Larval *E. cirrigera* abundance increased with impervious surface cover values greater than 26.6%. In our additional analysis, larval *E. cirrigera* abundance decreased linearly with increased impervious surface cover. We believe abundance actually declines from 0 to 26.6% impervious surface cover and then reaches a threshold, flattening out. To fully define this relationship, more catchments with greater than 26% impervious surface cover, and especially greater than 35% cover, should be sampled.

Other researchers have observed a decline in stream salamander abundance with increasing impervious surface cover (Minton 1968, Orser & Shure 1972; Wilson & Dorcas 2003). This trend also has been observed in other aquatic taxa. Mussels experience a 73% loss of species with high impervious surface cover (Gillies 2003), and impervious surface cover negatively affects fish communities (Paul & Meyer 2001, Wang 2001, Wang, et al. 2003, Weber & Bannerman 2004). Environmental Protection Agency data in Ohio revealed a loss of sensitive fish species at 5% impervious surface cover, with remaining species experiencing toxicity at 15% impervious surface cover (Paul & Meyer 2001).

Although the width of the forested riparian buffer adjacent to our sample streams did not influence larval *E. cirrigera* abundance, we do not conclude that buffers are ineffective. Buffers protect stream water quality by slowing runoff traveling to the stream, allowing it to percolate into the soil, and intercepting sediment and chemical pollutants (Muscott et al. 1993; Tomer et al. 2003). In our study, we measured the buffer width adjacent to our sample reaches. Our results indicate that the width of a buffer immediately adjacent to a stream will not predict stream water quality for that given point. We suggest that, to be effective, buffers must be implemented catchment-wide, including small headwater streams. Furthermore, culverts, piping, and ditches, common in urban and suburban areas, bypass the buffers. This prevents the slowing of runoff and allowing potentially contaminated water to flow directly into the stream, as demonstrated in agricultural settings (Muscott et al. 1993). Although the buffers along our 50-m reaches were not bypassed, there certainly were breaches upstream. To develop an improved predictive variable, buffers should be quantified catchment-wide, accounting for culverts and other breaches.

Local habitat is also important to larval *E. cirrigera* abundance. Larval *E. cirrigera* abundance increased to 11.8% detritus cover, above which larval *E. cirrigera* abundance declined. Some detritus provides shelter and food for salamanders and their prey, such as aquatic invertebrates, but high levels of detritus might lead to high bacterial decomposition rates and anoxic conditions detrimental to salamanders. Larval *E. cirrigera* abundance increased with increasing pebble substrate, which supports Orser and Shure's (1972) finding that salamander densities increase with available cover. Pebble substrate provides foraging habitat, breeding sites, and cover from predators.

We noted that several streams with what appeared to be good habitat contained few or no larval *E. cirrigera*. We determined that this was caused by an interaction between low stream flow and substrate composition. In intermittent streams, during dry periods, salamanders will migrate down with the water column into the hyporheic zone, or the area below the streambed where water percolates down through the spaces between rocks. If these interstices become filled with sediment , salamanders are unable to migrate down with the water column during dry periods. Low larval *E. cirrigera* abundance occurred in intermittent streams with sediment-filled interstices. Our measure of pebble substrate did not describe this effect because it only measured the percent cover on the surface layer of substrate. A three-dimensional description of substrate including the hyporheic zone is needed. Subsurface characterization of substrate is less important in perennial streams because salamanders do not need to migrate down into the hyporheic zone.

Time since disturbance (e.g. building a housing subdivision) may be another important variable influencing larval *E. cirrigera* abundance. Some of our sites had high impervious surface constructed predominately in the 1950s and 1960s. These sites had relatively high larval *E. cirrigera* abundance, whereas sites with lower impervious surface cover but more recent disturbance had lower larval *E. cirrigera* abundance. The effects of impervious surface cover are most commonly documented by percent area; however, the temporal and spatial distribution of impervious surface cover rarely is addressed. We conducted an exploratory analysis using 2005 Wake County tax parcel data (Wake County 2005) in which we calculated the percent of the catchment build-up for five-year periods, 2000-2004, 1995-1999, 1990-1994, etc. Larval *E. cirrigera* abundance decreased with increased disturbance in a catchment between 2000 and 2004 ($p = 0.06$), suggesting that temporal pattern of disturbance should be considered in future research.

Salamanders are slowly being integrated into water quality management. Our results support the use of stream salamanders as bio-indicators of water quality. Examining age class structure may provide additional insight to water quality: the loss of an age class may indicate a pulse event from which the population can recover, whereas the absence of all larvae may indicate an unsustainable population. As water quality managers search for indicators of intermittent stream flow, salamanders may be one to consider. In our study, intermittent streams had good surface habitat, but no salamander larvae. Our findings also have implications for stream restoration design. Restoration often begins with a hard-packed, clay bottom. Without a hyporheic zone of unsedimented substrate, restored streams experiencing low flow events are unlikely to provide suitable salamander habitat.

Ecological relationships within a stream are also important. Fish predation was not significant in previous research (Wilson & Dorcas 2003) and was not measured for our research. For most streams, the effects of fish are believed to be similar. Three of our sites were located near larger streams or ponds. These sites had lower than expected abundances. It is possible that during high flow events, fish and other predators are introduced into these small streams, reducing salamander abundance. Crayfish interactions should also be considered in future research, as crayfish are a predator of salamander larvae but also excavate tunnels through sediment, improving low quality habitat. Anecdotal observations of crayfish suggest that abundances will vary differently than salamander abundances. The effect of macroinvertebrates on salamander abundance is also unclear. Orser and Shure (1972) did not consider macroinvertebrate abundance and diversity to be a limiting factor for salamanders. However, Wilson and Dorcas found macroinvertebrate diversity to decline with increased disturbance (2003). The role of macroinvertebrates, the major prey of stream salamanders, needs to be better understood.

Conclusions

Our data support the growing body of evidence that increasing impervious surface cover negatively affects stream ecosystems. Larval *E. cirrigera* abundance decreased with increasing impervious surface cover. Previous research has suggested the scouring effects of high flow events to be the cause of reduced salamander abundance (Orser & Shure 1972; Wilson & Dorcas 2003). In our study, low flow, rather than high flow, events were associated with decreased salamander abundance. More attention needs to be given to hydrologic changes resulting in reduced base flow.

Quantifications of buffers through measuring width at the point of sampling is not sufficient to predict abundance, and thus not an effective strategy for mitigating the effects of impervious surface. Rather, buffer systems free of culverts, piping, and ditches should be maintained catchment-wide. Consideration of the temporal and spatial distribution of disturbance may also be important when determining the buffer necessary to protect water quality, as a stream might be able to recover, to some degree, with time. However, it is important to note four common salamander species have already been lost in our study area of Wake County streams. We suspect this is due to the loss of rocky bank habitat needed by these more sensitive species; research targeting these species might provide more insight.

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Table 1. Parameter estimates for linear regression model with larval *E. cirrigera* abundance as the dependent variable ($R^2 = 0.59$). Points of inflection are shown for variables with quadratic terms.

Variable (Data Range)	Parameter Estimate	p	Inflection Point
Intercept	2.69	0.010	
Impervious Surface Cover (0-40%)	-21.74	0.025	
Squared Impervious Surface Cover (0-16%)	40.83	0.007	26.6%
Detritus (0-25%)	23.11	0.035	
Squared Detritus (0-6%)	-149.97	0.019	11.4%
Pebble Substrate (0-83%)	3.93	0.007	
Water Conductivity (49-384 µS)	-0.01	<0.0001	

Table 2. Parameter estimates for additional linear regression model with larval *E. cirrigera* as the dependent variable (R^2 = 0.73). Points of inflection are shown for variables with quadratic terms.

Variable (Data Range)	Parameter Estimate	*p*	Inflection Point
Intercept	-0.17	0.891	
Impervious Surface Cover (0-40%)	-3.78	0.043	
Detritus (0-25%)	36.76	0.003	
Squared Detritus (0-6%)	-154.72	0.001	11.8%
Pebble Substrate (0-83%)	1.52	0.283	
Perennial (0=no, 1=yes)	-0.34	0.675	
Pebble x Perennial Interaction (0-0.83)	5.12	0.003	

Figure 1. Distribution of percent impervious surface cover and forested riparian buffer width for 39 non-reference sites sampled.

Figure 2. Observed values of larval *E. cirrigera* abundance versus values predicted from the original linear regression model.

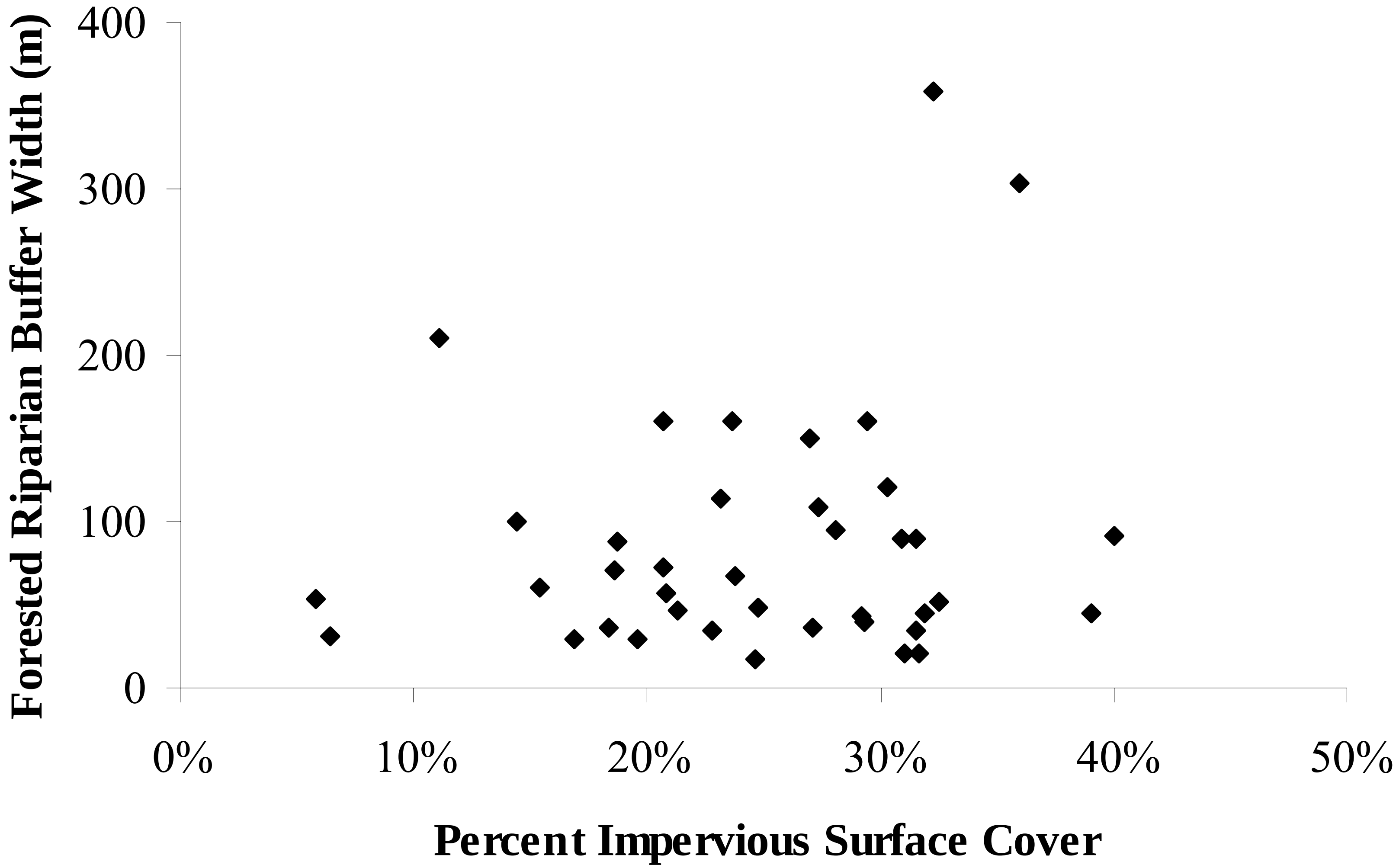
Figure 3. Relationship between the square root of larval *E. cirrigera* abundance and percent pebble substrate in (a) perennial and (b) intermittent streams.

Figure 4. Observed values of larval *E. cirrigera* abundance versus values predicted by the additional linear regression model with the intermittent or perennial class variable.

Figure 5. Images of *E. cirrigera*: (a) adult, (b) egg mass under rock, (c) 2 year-old and hatch-year larvae, and (d) salamanders captured from most abundant 10-m reach in bucket.

Figure 6. Images of streams: (a) good quality habitat, (b) moderate quality habitat, (c) moderate quality habitat, (d) poor quality, highly sedimented habitat, (e) eroded bank (approximate height 2 m), (f) litter accumulation, (g) zoom-in of image a demonstrating open pebble interstices, and (h) zoom-in of image b demonstrating sedimented pebble interstices.

Figure 1.



Forested Riparian Buffer Width (m)
400
300
200
100
0
0%
10%
20%
30%
40%
50%
Percent Impervious Surface Cover

Figure 2.

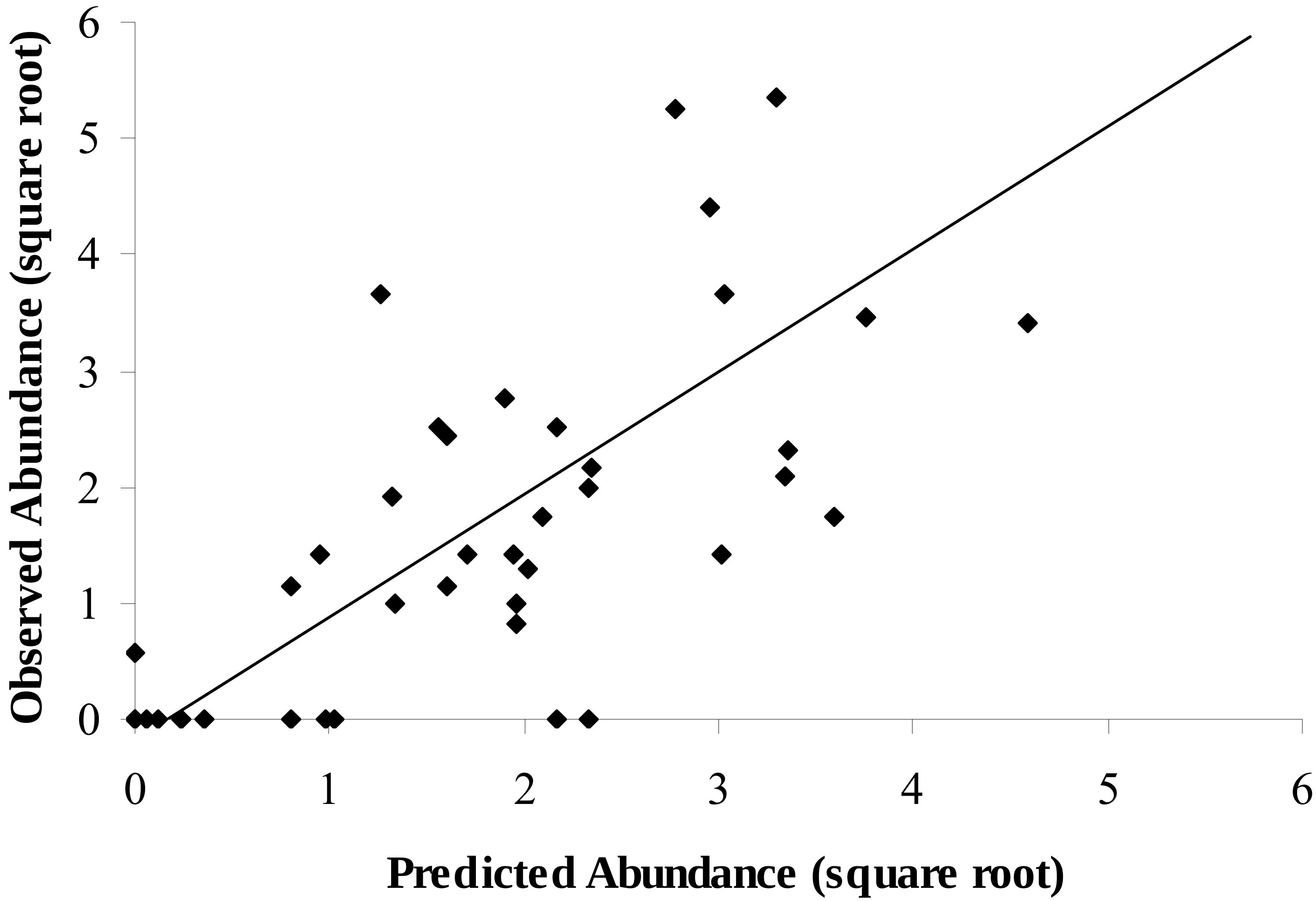
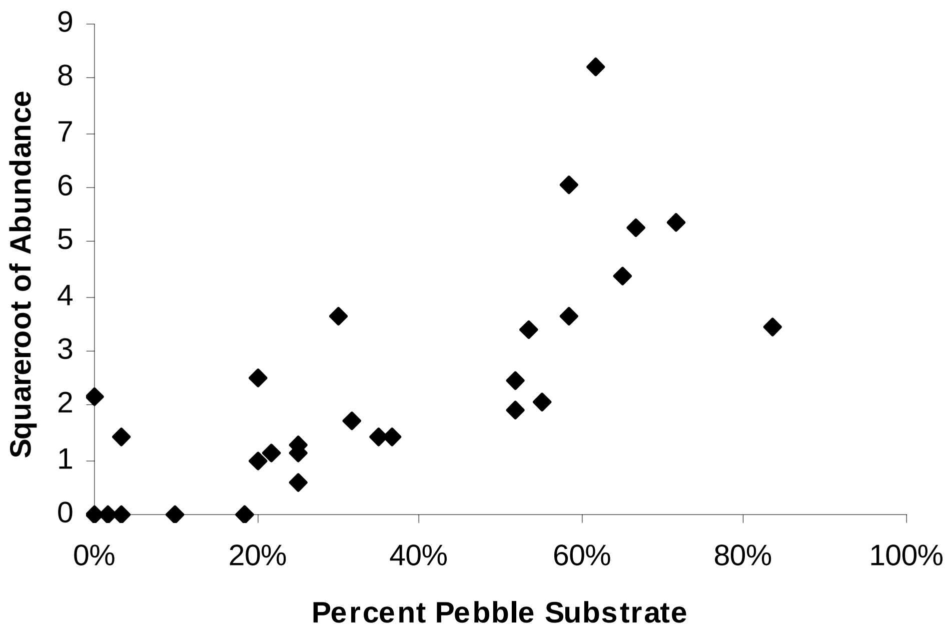

Observed Abundance (square root)
Predicted Abundance (square root)
0
1
2
3
4
5
6

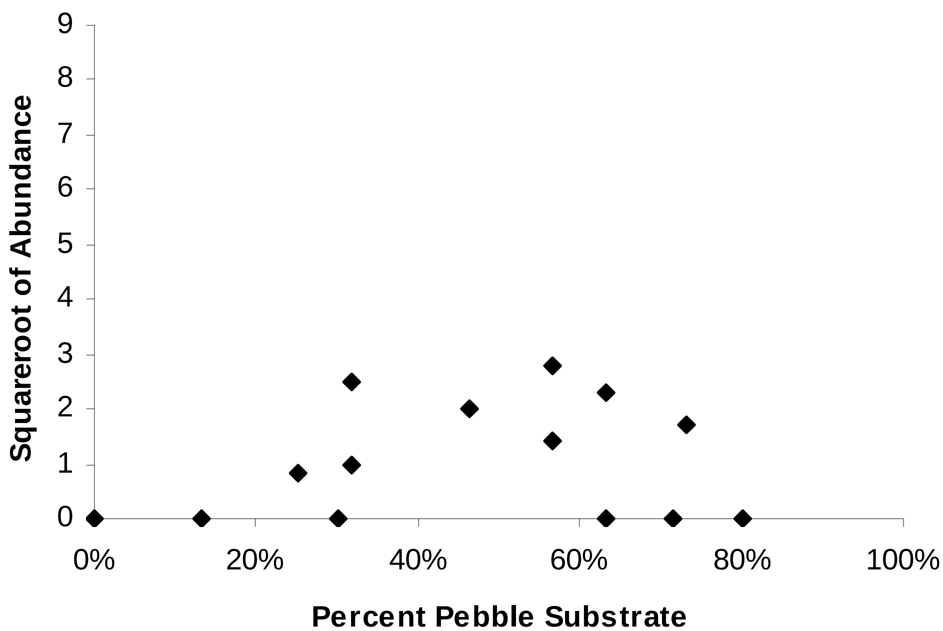
Figure 3.

a.



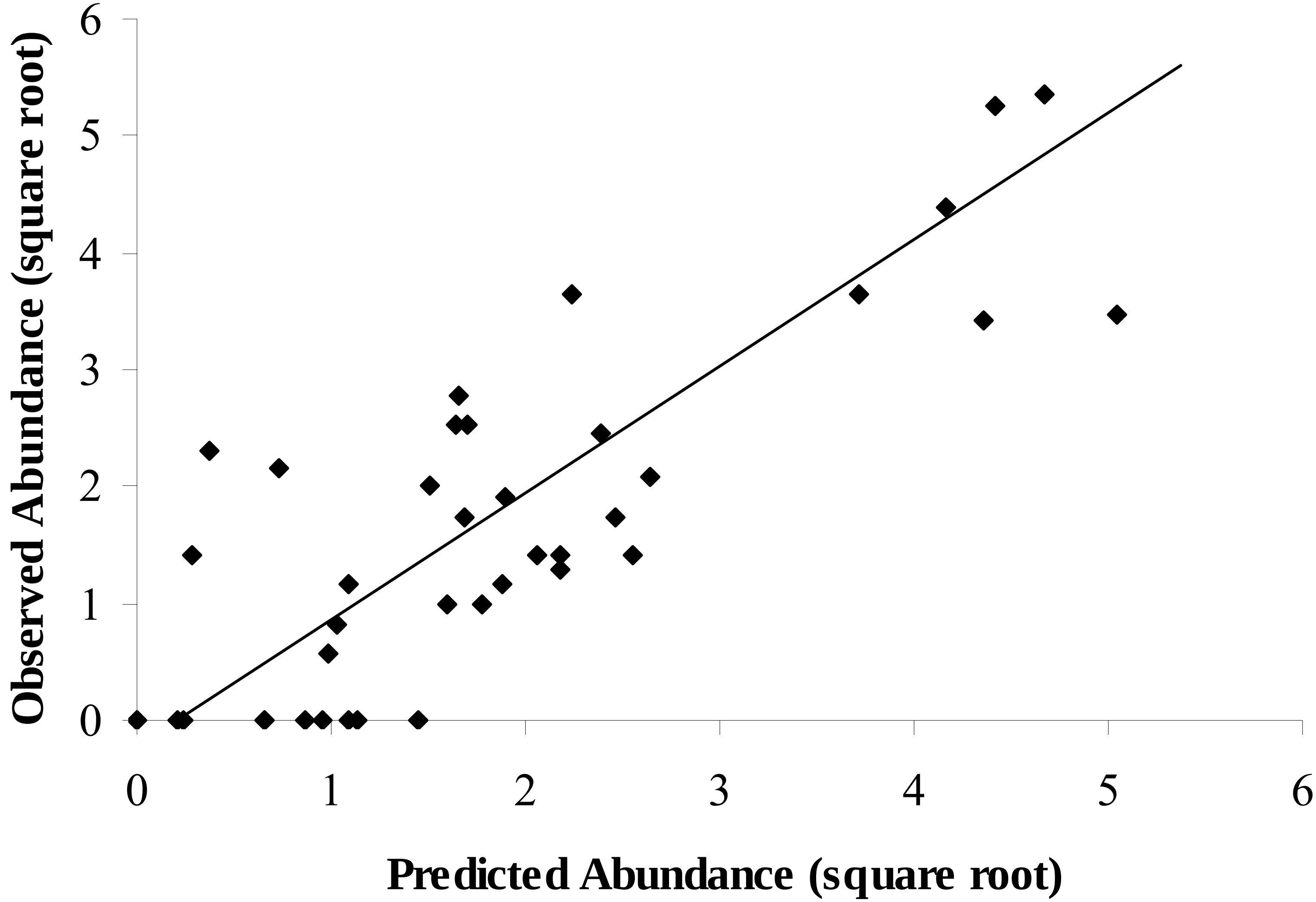
9
8
7
6
5
4
3
2
1
0
Squareroot of Abundance
0%
20%
40%
60%
80%
100%
Percent Pebble Substrate

b.



9
8
7
6
5
4
3
2
1
0
Squareroot of Abundance
0%
20%
40%
60%
80%
100%
Percent Pebble Substrate

Figure 4.



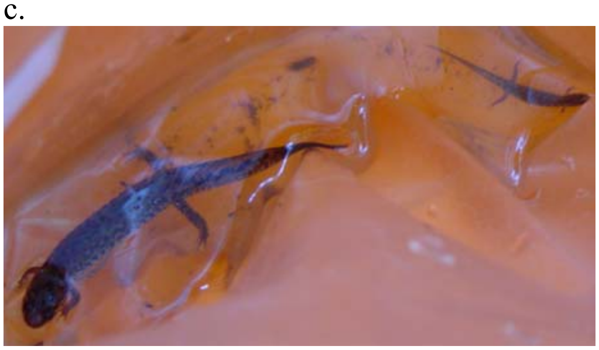
6
5
4
3
2
1
0
Observed Abundance (square root)
0
1
2
3
4
5
6
Predicted Abundance (square root)

Figure 5.

a.

b.

c.



d.

Figure 6.

Chapter 2

A New Object-Oriented Method of Impervious Surface Classification Using Feature Analyst

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ABSTRACT / Urbanization causes many changes in the landscape, including increased impervious surface cover. To minimize these effects, environmental, economic, and resource management research and decision-making requires current and accurate spatial information. Mapping with aerial imagery can play an important role in providing such information, if it can be done in a cost effective and accurate manner. Recent advances in spatial resolution have improved the identification of features within a landscape, but require more complex algorithms for automated classification. New procedures strive to compromise between high-accuracy classifications and the intense user input, steep learning curves, and processing time common with complex algorithms. For our research, we needed an efficient technique for identifying impervious surfaces in urbanizing Wake County, North Carolina, USA. The objectives of our study were to develop an accurate classification of impervious surface using high-resolution aerial imagery and to provide insight into the practical application of Feature Analyst, an object-oriented classification extension within ArcGIS. Feature Analyst utilizes advanced, object-oriented classification algorithms that incorporate spatial context with color and tone to classify high-resolution imagery. We trained Feature Analyst to differentiate pervious and impervious surfaces and classified 111 United States Geological Survey images with a spatial resolution of 33-cm. Our classification results yielded an overall accuracy of 92%, with a user's accuracy of 95.2% for the impervious surface class. These results show improvement over historical accuracies of 85% or less. Feature Analyst is most beneficial when spectral value alone will not distinguish classes, object-oriented output is desired, and the time or knowledge for developing complex, customized algorithms is unavailable. We recommend Feature Analyst for classification of high-resolution imagery when object-oriented output is desired and hand-digitizing is impractical.

Introduction

Mapping impervious surface cover is important for the management and planning of many municipal services (Jensen and Cowen 1999). Impervious surfaces, such as roof-tops, roads, and parking lots, prevent water from penetrating the soil. This may contribute to hydrologic, chemical, and biological changes in receiving waters. Increased impervious surface cover changes stream flow patterns and channel morphology through more rapid peaking of floods, greater peak discharge, reduced groundwater recharge, reduced base-flow, and channel modifications (Paul and Meyer 2001, Wang and others 2001, Jennings and Jarnagin 2002). Chemical changes in waterways, including increased suspended solids, increased concentrations of heavy metals, and decreased dissolved oxygen levels, also occur (Paul and Meyer 2001, Gray 2004). Relatively small changes in the amount of impervious surface cover can cause major changes in aquatic biota. These changes are often apparent before detection of physical or chemical changes in the water (Wang and others 2001, Wang and others 2003). The responses of aquatic macroinvertebrate communities are best studied, where increased impervious surface cover results in decreased abundance and a rapid loss of species sensitive to pollution (Paul and Meyer 2001, Gray 2004).

Environmental, economic, and resource management activities require current and accurate spatial information (Herold and others 2005). This especially is true in urban environments, where mapping with aerial imagery has become a critical component of urban analysis and planning (Donnay and others 2001). Aerial imagery provides an improved vantage point and a permanent record of conditions. In the urban environment, aerial imagery and spatial data assist in population estimates, housing studies, traffic and parking studies, transportation routes, infrastructure and utility planning, and urban change detection. Aerial imagery can be classified through hand-delineation procedures. This approach is very time-consuming and prone to human errors (Lillesand and others 2004).

In the 1970s and 1980s, spectral data became more available with the launching of satellite platforms, the two most common being Landsat and System Pour l'Observation de la Terre (SPOT). Imagery from these satellites is considered efficient and economical because each image covers a large area and can be classified using automated spectral pattern recognition algorithms (Lillesand and others 2004). However, classifications are typically limited to a broad level of classification, and have little detail within urban and built-up areas. Land cover and land use maps derived from satellite data often fail to meet two of the United States Geological Survey (USGS) land use/land cover quality criteria (Anderson and others 1976): 1) a minimum accuracy of 85% for each class and 2) equal accuracies among all categories classified. This is especially true in heterogeneous urban environments where one pixel's reflectance value incorporates multiple natural and artificial land covers (Donnay and others 2001, Lillesand and others 2004).

In the late 1990's, sensors such as IKONOS and Quickbird, increased the availability of spectral data and improved the available spatial resolution of satellite data. Higher spatial resolution improves the ability to differentiate features within dense, heterogeneous environments, such as buildings and roads in urban areas (Donnay and others 2001). However, spectral classification algorithms poorly differentiate complex land cover environments, such as urban areas (Donnay and others 2001, Herold and others 2003, Thomas and others 2003). Different classes in complex environments can have identical spectral reflectance, such as cement and bare soil, and the same class can have different spectral reflectance values, such as a black roof and a brown roof. To improve classifications, size, shape, texture, context, and pattern can be incorporated into classification methods. New algorithms, such as nearest neighbor analysis, neural networks, decision trees, and the mixing of spectral and textural data, can be applied (Donnay and others 2001, Herold and others 2003, Thomas and others 2003). This improves results, but further increases the level of skill required for use (Herold and others 2003, Thomas and others 2003).

New procedures strive to compromise between high-accuracy classifications and the intense user input, steep learning curves, and processing time needed. Object-oriented approaches classify objects rather than individual pixels (Geneletti and Gorte 2003). Pixel-based classification methods frequently group dissimilar pixels with the larger, surrounding class. Object-oriented classification allows relevant objects to be any size. For example, a backyard shed, can be classified separately from the surrounding lawn. The object-oriented technique identifies a meaningful object, such as a building, and can be linked to attribute data within a spatial database (Geneletti and Gorte 2003). Object-oriented classification is not without limitations. Classifications are difficult in urban areas, where complex buildings and shadows often lead to classification errors. Additionally, advanced user knowledge of processing techniques is frequently needed to develop classification algorithms (Mitri and Gitas 2004, Pen and Liu 2005).

In 2001, Visual Learning Systems released Feature Analyst as a software extension to automate object-oriented classification. Feature Analyst incorporates spatial context with color and tone to classify high-resolution imagery and iteratively applies advanced algorithms, such as nearest neighbor, neural networks, decision trees, genetic ensemble feature selection (VLS 2005). However, integration with a graphical user interface, such as ESRI's ArcGIS and ERDAS Imagine, increases accessibility throughout the geographic information systems (GIS) and remote sensing community. For our research, we needed an efficient, accurate technique for identifying impervious surfaces in urbanizing Wake County, North Carolina. Our objectives were to develop an accurate classification of impervious surface using high-resolution aerial imagery and provide insight to the practical application of using the object-oriented classifier, Feature Analyst, within ArcGIS.

Methods

Study Area

Wake County is located in the piedmont of North Carolina and contains the metropolitan area of the state capital, Raleigh. With an area of 2,225 km^2, Wake County is experiencing rapid population growth, reaching 750,000 people in the year 2005 and expected to exceed one million people by 2016 (Wake County 2005). Forty-three watersheds, each approximately 1.3 km^2 in size, were selected throughout the county to represent the range of impervious surface cover (Miller 2005). Land cover in the county included industrial, commercial, residential, agriculture, open grass, coniferous forest, deciduous forest, mixed forest, and open water.

Imagery

We used USGS 2003 high-resolution, true color, digital orthoimagery of the Raleigh-Durham area, North Carolina for the analysis (USGS 2005). Images were un-compressed, georectified, tagged image file format (tiff) images that represented 1,500-m^2 on the ground with 0.33-m spatial resolution. Each tiff file required a hard-drive storage space of 73-megabytes and a 1-kilobyte world file as a format table (.tab) file to reference its location to known geographic coordinates. A total of 111 images were necessary to provide complete coverage of the spatial extent of interest. The images comprised a total area of 250 km^2 and hard-drive storage space of 8.1-gigabytes. Visual inspection of the images revealed no atmospheric anomalies and minimal scene to scene color variations, thus color balancing was not applied. The acquired imagery was pre-processed by USGS to provide a seamless mosaic. However, not all images of interest were contiguous, leaving gaps within the seamless image mosaic (Figure 1). As a result we chose to classify independent images. We used Visual Learning Systems' Feature Analyst 3.5.01 in ArcGIS 8.3 to classify impervious and pervious surface area from the imagery.

Training Procedure

Our classification technique was adapted from the Feature Analyst tutorial (VLS 2004). We developed two training files by hand-digitizing examples of impervious surface and examples of pervious surface (Table 1) on a randomly selected image. Sixteen impervious examples and seven pervious examples incorporated the diversity of categories throughout the image (Figure 2).

Our classification algorithm was created using the following settings: (1) all three input bands from the imagery, (2) a pre-defined input representation, (3) aggregation of areas less than 100 pixels, (4) inclusion of rotated instances, and (4) a wall-to-wall classification. The input bands determine the number spectral bands used in the classification when imagery has multiple bands. Our imagery had three available bands, and all of them were used. The input representation describes the pattern of pixels considered around a target pixel to classify the target pixel. We used the representation called "Bullseye2'7'" (Figure 3). Aggregation determines the minimum number of pixels needed to be considered an object. Objects less than 100 pixels are automatically aggregated with the most appropriate neighboring object. Inclusion of rotated instances allows classification of similar objects oriented differently; for example classifying two roads, one oriented north-south and one east-west, would be a rotated instance. A wall-to-wall classification assigns every pixel in the image into a category. Without this option, portions of the image remain unclassified.

Classification

We classified the first image based on the hand-digitized examples and algorithm settings described above. This resulted in an output ArcGIS shapefile of the classified image and associated classification algorithm which was saved as a learnfile. The learnfile contains the algorithms used for the classification. We iteratively improved the learnfile using the following three steps (Figure 4):

(1) improving the initial classification of an image through selecting a range of correctly classified and incorrectly classified examples, incorporating pattern, shape, color, and texture;

(2) updating the learnfile classification algorithm through re-classifying the image to produce a new output shapefile and updated classification algorithm learnfile; and

(3) classifying a new, randomly selected image, by applying the updated learnfile.

To complete step one, the "remove clutter" tool within Feature Analyst was used. This tool allowed selection of correctly classified and omission of incorrectly classified areas. "Remove clutter" was more useful than the alternative "add missed polygons" tool. This procedure was repeated for three images selected randomly from the 111 to produce the final learnfile. We visually assessed the classification of the third image and were satisfied with the classification results. We classified two additional randomly-selected images using the final learnfile and conducted a final visual assessment of the completeness of the final learnfile's classification algorithm. We were still satisfied with the final learnfile and thus classified all 111 images with the final learnfile, producing the final classification of all imagery needed.

Accuracy Assessment

We conducted an accuracy assessment of the final classification. We followed Congalton's (1991) recommendation to use at least 250 points with a minimum of 50 points per class to ensure each class is within five percent of the total estimated error. For this assessment, a total of 252 points were generated randomly across the 111 images with 126 points per class. To determine the accuracy, the known cover type for each point was obtained from the original imagery. The classification cover type for each point was obtained from the Feature Analyst classification output. These were compared at each point to produce a classification error matrix, from which we calculated overall accuracy and user's accuracy as well as the Kappa Statistic. The overall accuracy is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels. The user's accuracy measures accuracy by category, giving the probability a classified pixel from a given category actually represents that category on the ground. User's accuracy is calculated by dividing the number of correctly classified pixels by the total number of pixels classified in that category. The Kappa statistic indicates the extent to which the accuracy agreement is true agreement instead of agreement due to chance alone. Kappa ranges from 0 to 1, where 0 is no agreement and 1 is perfect agreement (Lillesand and others 2004).

Results and Discussion

Accuracy

The final object-oriented classification produced a vector layer of imagery classified as impervious or pervious surface for the entire study area. Impervious surface represented 21.1% of the 250-km^2 area. The classification had an overall accuracy of 91.7% (Table 2). The user's accuracy was 95.2% for the impervious class and 88.1% for the pervious class. Our accuracy assessment produced a Kappa coefficient of 0.8333. The Kappa test was found to be highly significant at $Z = 13.2626$ ($p < 0.0001$) and is considered "almost perfect" on Landis and Koch's (1977) strength of agreement scale.

Discussion

Feature Analyst met our needs as an efficient and accurate object-oriented classification method. The classification procedure resulted in a highly detailed classification which identified even small differences between the impervious and pervious categories (Figure 5), and the vector layer output was easy to manipulate within ArcGIS. It took JEM approximately two days to become familiar with Feature Analyst, a process facilitated by the effective graphic user interface and helpful tutorial. Feature Analyst training necessary to classify the 250km^2 study area was then completed in less than one hour. The run-time to batch-classify the 111 images was less than eight hours using a modestly equipped computer with a 2.19 gigahertz processor, 1.0 gigabytes of RAM, and 186 gigabytes of hard drive space. Unlike our experience with many other GIS extensions, Feature Analyst produced results consistently, and never caused computer crashes.

Other researchers using object-oriented classification have obtained slightly lower accuracies. Giada and others (2003) obtained accuracies between 85% and 90% using another object-oriented software, eCognition by Definiens Imaging, to extract tents as objects from IKONOS imagery with spectral resolution of 1-m panchromatic, 4-m multispectral. Using IKONOS imagery, Wang and others (2004), integrated spectral and object-oriented classification methods to classify seven land use/land cover types in coastal Panama. They performed three classifications of the same imagery. Their pixel level spectral classification had an overall classification accuracy of 88.9%. Their nearest neighbor object-oriented classification had an overall classification accuracy of 80.4%. When spectral and object-oriented classifications were integrated, they achieved an overall classification accuracy of 91.4% (Wang and others 2004).

Recommendations Specific to Feature Analyst

Initial Training

An accurate and precise initial training set representing the range of objects found within a scene is essential. Incorporating color transitions and patterns, such has how a house connects to a sidewalk that connects to a driveway and a road, and including features partially covered in shadow, greatly improves classification. If a component of a class was obviously missed after the first classification, it is more effective to add examples to the initial training class than to use either of the two improvement tools provided within the software: "remove clutter" and "add missed polygons." All Feature Analyst work should be done using the Feature Analyst tools. Introducing files manipulated outside Feature Analyst, such as geoprocessing in ArcGIS, back into the Feature Analyst environment frequently caused errors or corruption. -

Most of the settings used in our analysis were recommended in the Feature Analyst tutorial. In the final training and classification, we used all three available input bands without smoothing or masking. For the spatial resolution of our imagery, smoothing created incorrect borders and notably increased the run-time. Masking was effectively applied in earlier training attempts, but not needed for the final classification. However, an alternative masking option "area of interest" did not perform well. This option classifies a target area, rather than omitting a masked area. Using "area of interest" typically resulted in failure to classify.

The input representation defines the surrounding pixels used to help classify the target pixel. For our analysis, we changed the input representation from the "Manhattan ‘5’” recommended by the tutorial to "Bullseye2 ‘7’” (Figure 3). In Feature Analyst, there are many pre-defined input representations, as well as the option to define your own. We found "Bullseye2 '7’” produced the most refined output for our imagery. Pixel aggregation is another user-definable option. Selecting the number of pixels to be aggregated was challenging in the urban setting. Increasing the number of pixels aggregated reduced misclassification of the spaces between leaf-off trees as impervious surface, but omitted some correctly-classified, small impervious surfaces, such as backyard sheds. We found the recommended 100-pixel aggregation balanced the omission and commission errors for our spatial-resolution.

Iterative Improvement

Two tools are provided to help users improve initial training sets: “remove clutter” and “add missed polygons” tools. Th"remove clutter” tool was useful in reducing incorrect classifications, with two caveats. Applying the "remove clutter” tool more than once on an individual image greatly improved the classification of that image, but led to reduced accuracy when the training algorithm was applied to multiple images. Second, carefully choosing the correct and incorrect example areas is important. We recommend using the "cut out shapes" option to select a portion of the polygon that is correct, rather than the selecting the entire polygon that may have some incorrect pixels. The "add missed polygons" tool was not used in our classification, because, in earlier experimentation, we found that it increased run time without improving the classification. If objects were misclassified, it was more effective to use the "remove clutter" tool or manually add new polygons to the initial training set.

We tried many approaches to developing a suitable learnfile including: classifying with a learnfile developed from a single image and classifying with a learnfile developed using ten percent of the images. The classification using the learnfile developed from one image was accurate when applied to adjacent images, but classification quality degraded with distance from the training image. This was especially apparent at a radius of about 30 km. A previous attempt to develop a final learnfile in the iterative method described in this paper used 10%, or 11, of the images. This technique worked well for the first few images. Classification of additional images resulted in alternating errors between commission of spaces between leaf-off trees in the impervious surface class and omission of orange-brown rooftops from the impervious surface class. Continuing to classify more images to improve the learnfile did not resolve this alternation and resulted in a notable increase of processing time from eight hours to eight days for 111 images. In our study, developing the training set across three images with verification on two additional images balanced the alternation as well as possible without increasing run time, and consequently, we used that method the final classification described in this paper.

Applications and Limitations

Feature Analyst is a useful tool for impervious-pervious classification. Other applications of Feature Analyst, including locating downed, woody debris and hurricane damage, are currently being studied and appear promising. Feature Analyst is most beneficial when spectral value alone will not distinguish classes, object-oriented output is desired, and the time or knowledge for developing complex, customized algorithms is unavailable. Our application only required a USGS land use/land cover classification Level I (Anderson 1976) and basic GIS skills; however, Feature Analyst is capable of performing more detailed classifications. Incorporating advanced GIS and remote sensing knowledge may further improve Feature Analyst's classification abilities. Image post-processing, such as color balancing, or other more complex training techniques were not needed for our classification, but may be useful in more complex classifications or at different scales. Further research is needed do determine Feature Analyst's applicability to larger geographic areas, more detailed classifications, and areas outside the mid-Atlantic United States. However, because of its ease of use, low expense, and availability within a range of software, including ArcView 3.x, ArcGIS, and ERDAS IMAGINE, classification using Feature Analyst may prove valuable to local and regional governments, educational and research institutions, private industry, and other users when hand-digitization becomes impractical but high-resolution, object-oriented output is desired.

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Table 1. Examples of objects classified in impervious and pervious categories in Wake County, North Carolina, USA (2003).

Impervious	Pervious
Buildings	Trees
Roads	Forest Floor
Parking Lots	Field
Sidewalks	Lawn
Cars	Open Water
Railroad Tracks	Bare Soil

Table 2. Classification error matrix, accuracy, and Kappa statistics for the 111 batch-classified images.

	Imagery			Users
Feature Analyst	Impervious	Pervious	Total	Accuracy
Impervious	120	6	126	95.24%
Pervious	15	111	126	88.10%
Total			252	91.67%

Kappa = 0.833 (0.765, 0.901), Z = 13.263, p<.0001

Figure 1. Watersheds and associated imagery of interest within Wake County, North Carolina, USA.

Figure 2. Hand-digitized pervious (green) and impervious (orange) input shapes from a randomly selected USGS image.

Figure 3. The Feature Analyst Bullseye 2'7 input representation used for classification, where the central blue pixel (boxed in red) is the pixel of interest, blue pixels are considered when classifying the pixel of interest, and white pixels are ignored while classifying the pixel of interest.

Figure 4. Methods for creating, iteratively improving, and applying classification algorithm.

Figure 5. Example classification for one USGS 2003 high-resolution, true color, digital orthoimagery image of the Raleigh area, North Carolina, USA: input image (A), classified image (B), and impervious surface class overlaid on input image (C).

Figure 1.

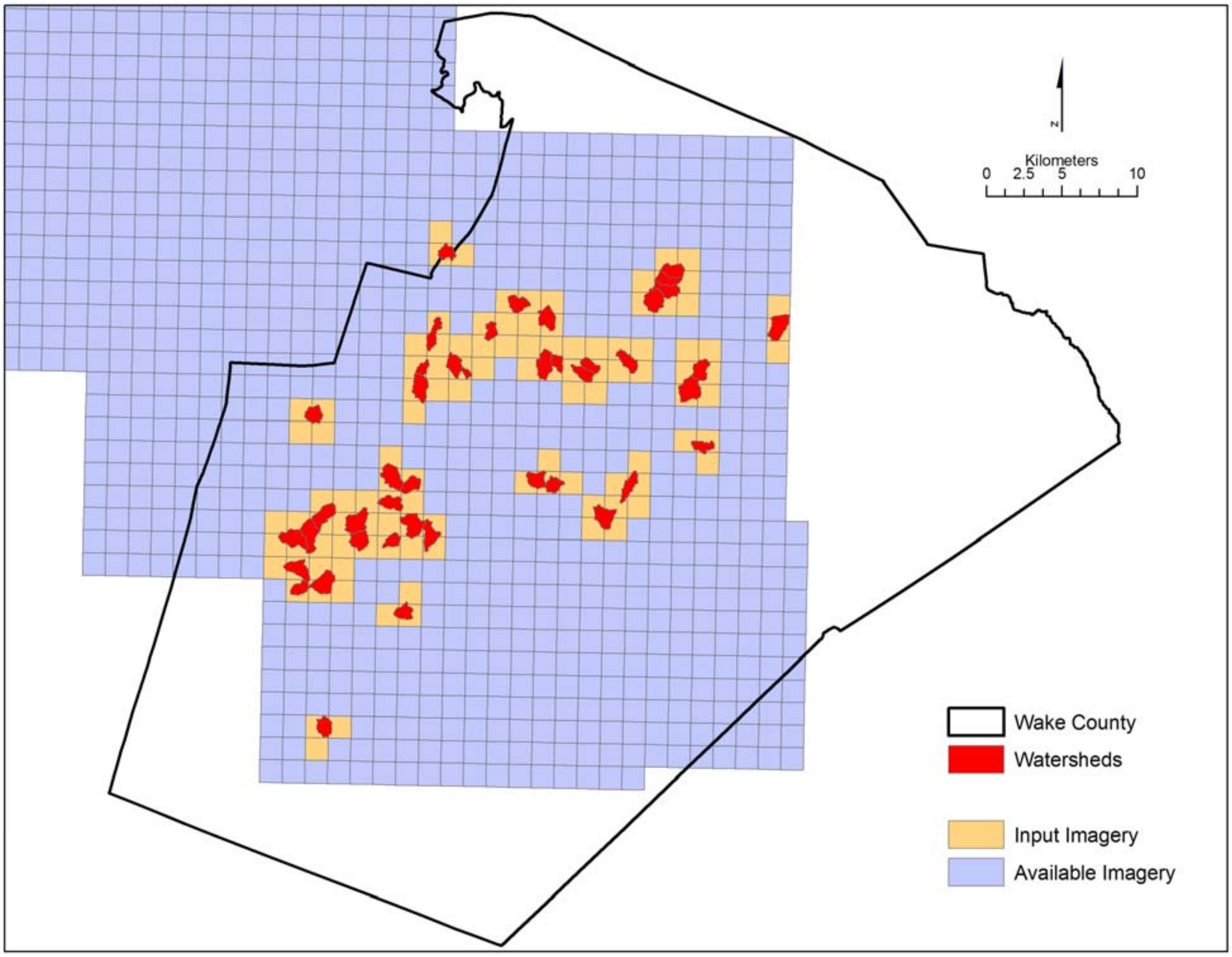

N
Kilometers
0 2.5 5 10
Wake County
Watersheds
Input Imagery
Available Imagery

Figure 2.

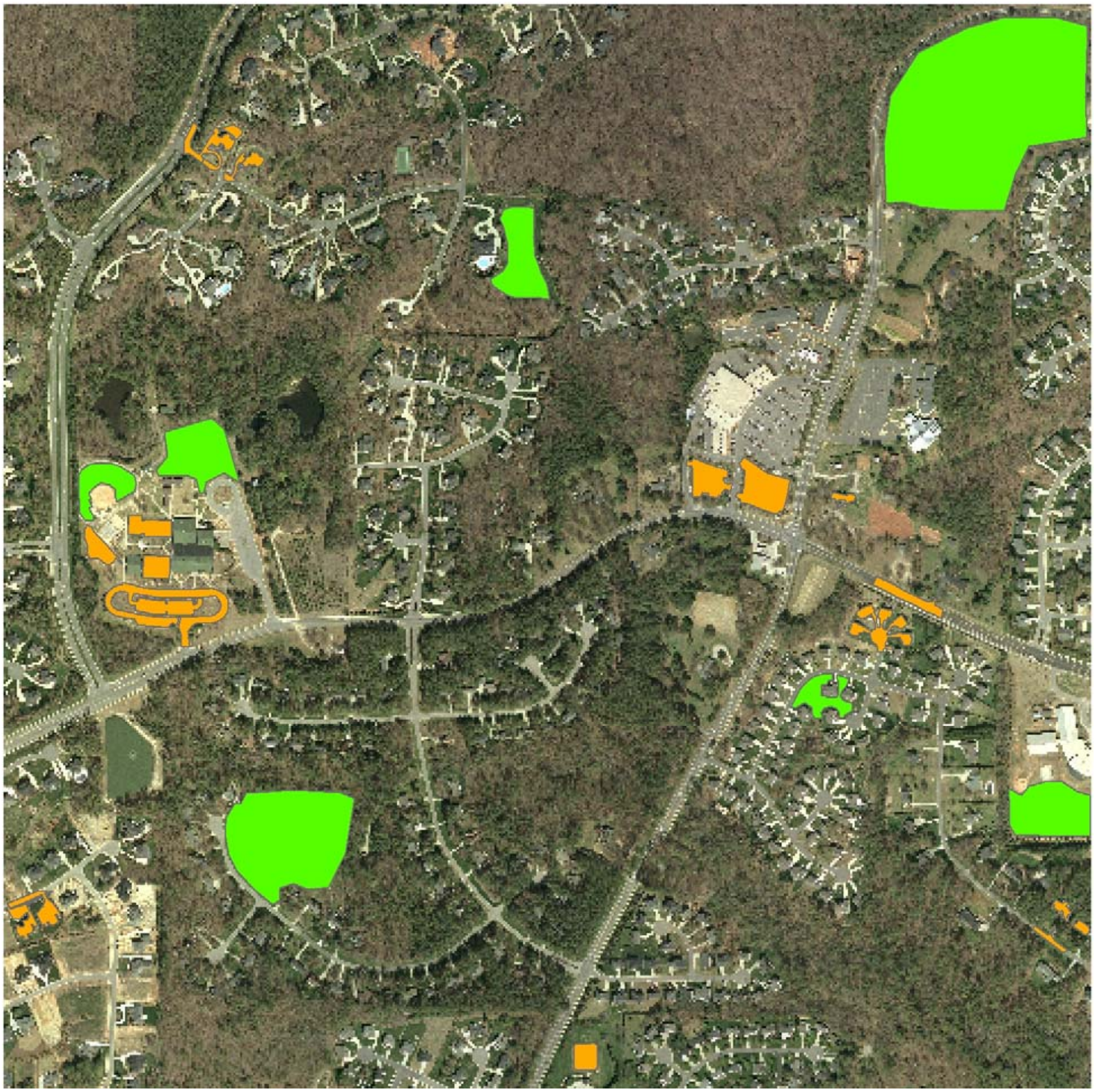


Figure 3.

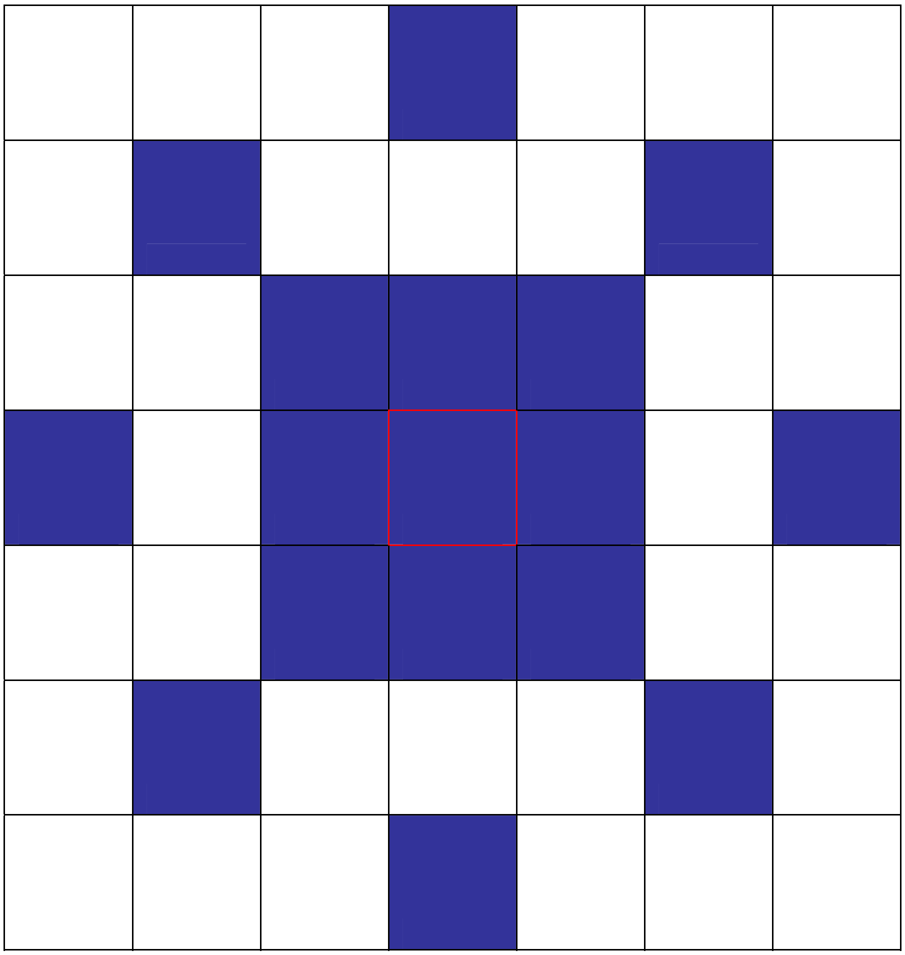
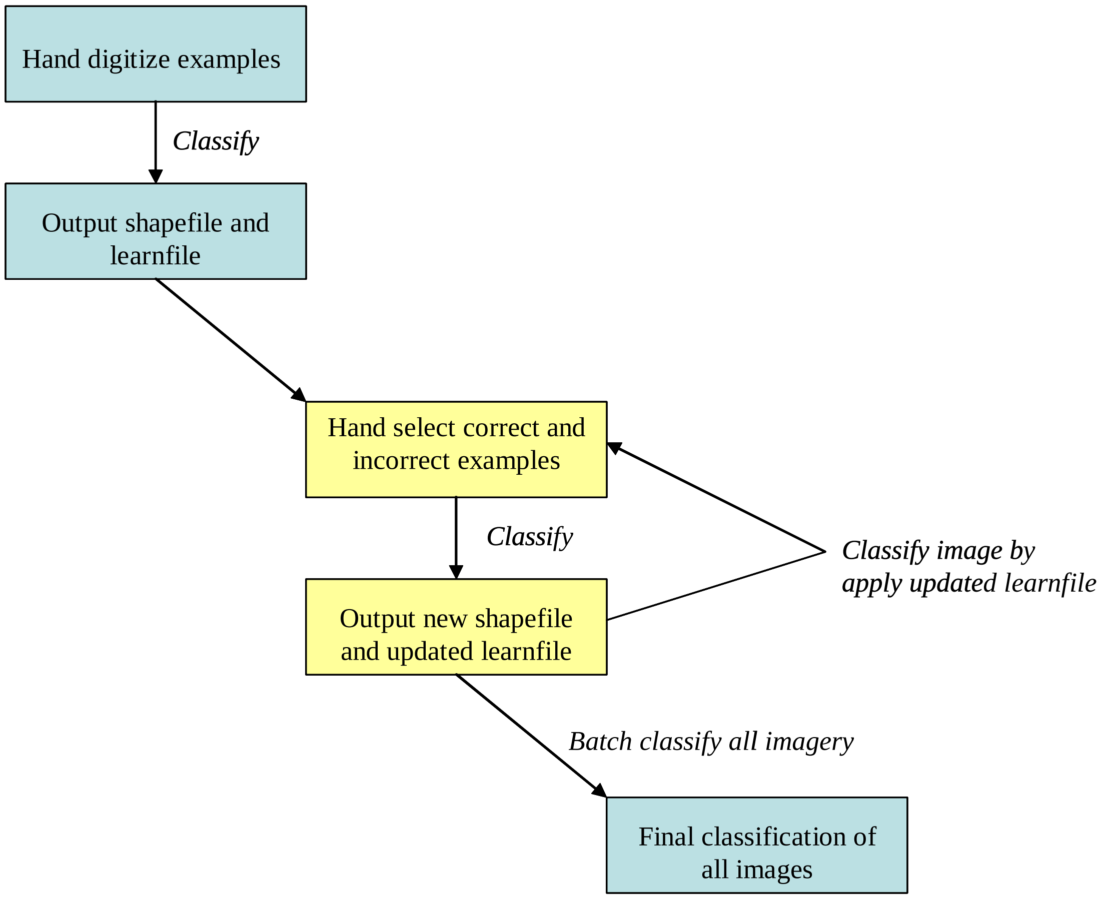


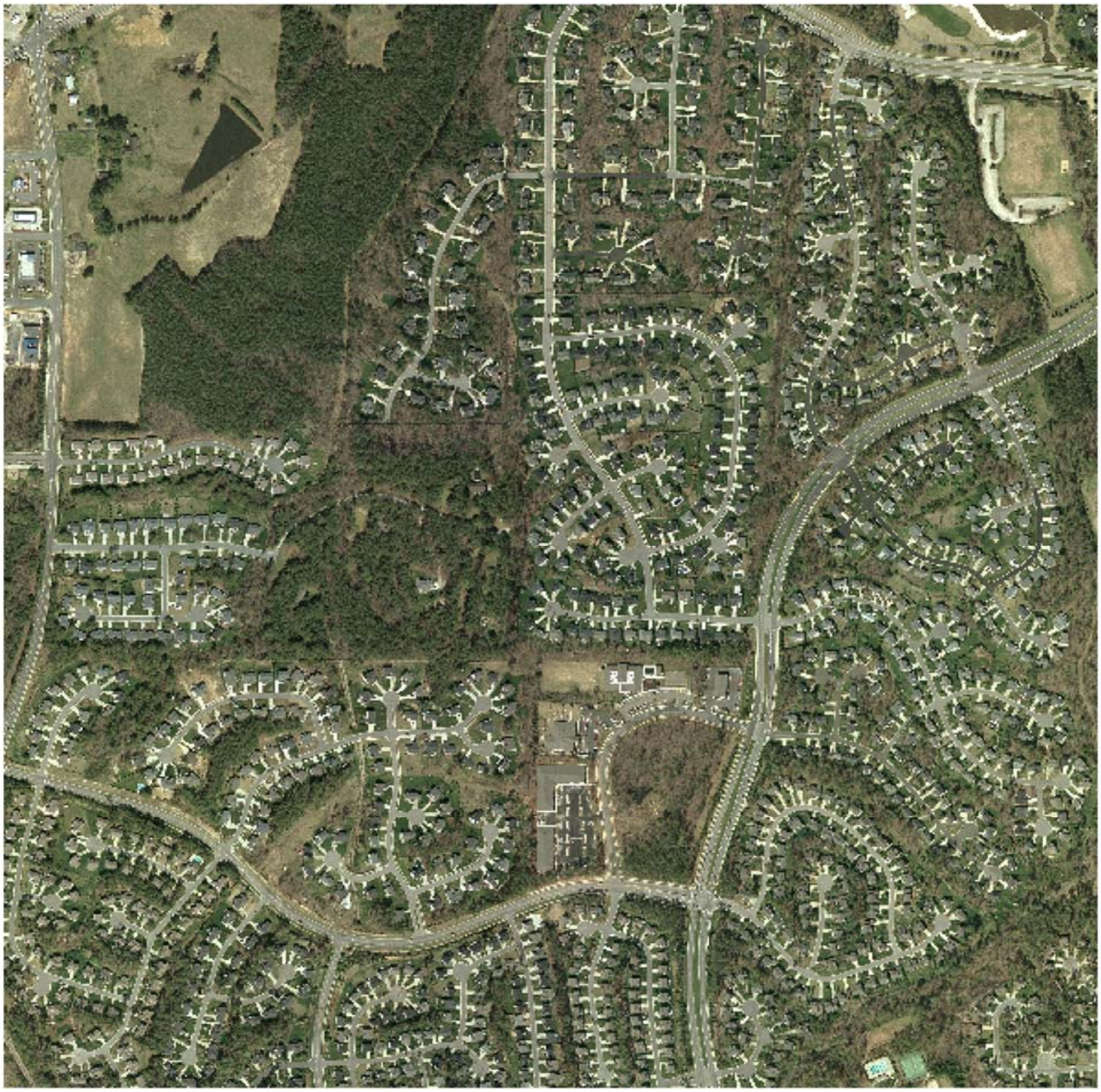
Figure 4.



Hand digitize examples
Classify
Output shapefile and learnfile
Hand select correct and incorrect examples
Classify
Output new shapefile and updated learnfile
Classify image by apply updated learnfile
Batch classify all imagery
Final classification of all images

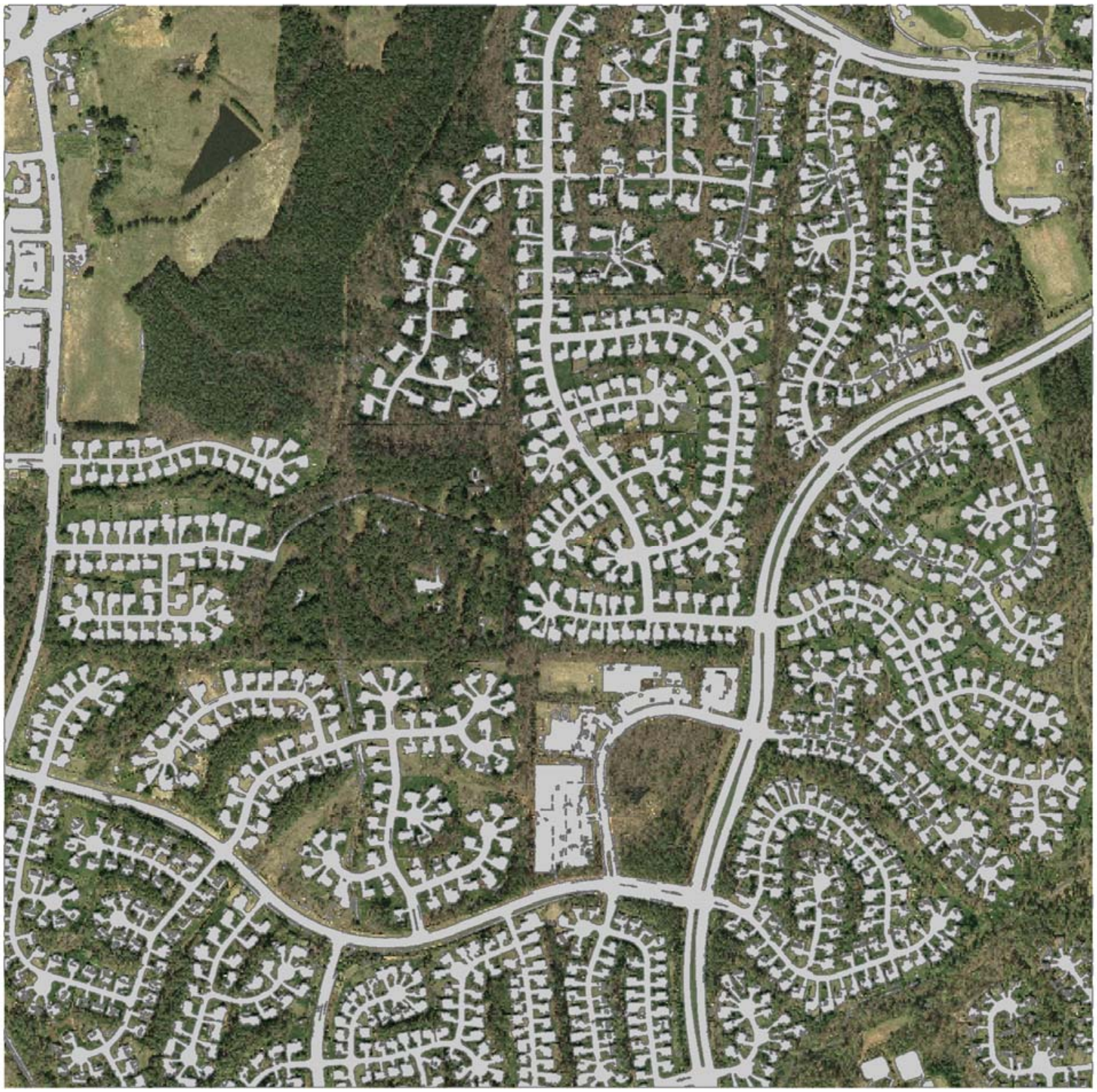
Figure 5.

A.



B.

C.



Chapter 3

Eurycea cirrigera (Southern Two-Lined Salamander). COLORATION.

Jennifer E. Miller and Alvin L. Braswell

Submitted to Herpetological Review August 2005

***Eurycea cirrigera* (Southern Two-Lined Salamander). COLORATION.**

We are reporting a leucistic larval *Eurycea cirrigera* (24 mm SVL) collected on 27 May 2004. The individual was found in northern Raleigh, North Carolina, USA (35.8599°N, 78.6733°W (WGS84/NAD83) USGSRaleigh West Quad) and is believed to be the second observation of a leucistic *Eurycea cirrigera*. Normal larvae are gold in color with extensive dark mottling. The leucistic individual lacked most pigmentation, exhibiting a transparent, cream coloration with faint orange and light brown speckling (Figure 1). The individual was classified as leucistic because of the presence of brassy eyes with dark pupils, instead of the unpigmented eyes of a true albino. The light coloration contrasted markedly from other, normal individuals; however, similar size, development, and behavior were observed.

We believe this is the second report of a leucistic *E. cirrigera* in North Carolina or elsewhere. Review of files and reexamination of an adult female considered albinistic by Palmer and Braswell supports calling it leucistic using current terminology (Bechtel). Although the frequency of leucism is unknown, repeated sampling of 45 sites in Wake County, NC produced 866 observations of *E. cirrigera* larvae, including 58 observations at the site of this specimen's collection. No other leucistic individuals were observed. In addition, only one like specimen or record of this color variant is present in the North Carolina State Museum of Natural Sciences (NCSM) collection, which documents over 9,000 specimens of *E. bislineata* complex from throughout the state. The larva was believed to be one-year old at the time of collection and was lab reared through October of 2004 without metamorphosing. The individual is now specimen #NCSM 66443 in the herpetological collection at the NCSM.

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Figure 1. Photograph of leucistic *Eurycea cirrigera* captured May 27, 2004 in Raleigh, North Carolina, USA.