ABSTRACT

HUX, SHARON JOYCE. Quantifiable Long-term Monitoring on Parks and Nature Preserves. (Under the direction of Dr. Chris Moorman.)

Herpetofauna have declined globally, and monitoring is a useful approach to document local and long-term changes. However, monitoring efforts often fail to account for detectability or follow standardized protocols. We performed a case study at Hemlock Bluffs Nature Preserve (HBNP) in Cary, North Carolina to model occupancy of focal species and demonstrate a replicable long-term protocol applicable to parks and nature preserves. From March 2010 to 2011, we documented occupancy of *Ambystoma opacum* Gravenhorst (Marbled Salamander), *Plethodon cinereus* Green (Red-backed Salamander), *Carphophis amoenus* Say (Eastern Worm Snake), and *Diadophis punctatus* Linnaeus (Ringneck Snake) at coverboard sites and estimated breeding female *Ambystoma maculatum* Shaw (Spotted Salamander) abundance via dependent double-observer egg mass counts in ephemeral pools. Precipitation was an influential predictor variable for detection of all four species and temperature influenced detection of both salamander species. Based on egg mass data, we estimated salamander abundance to be between 22 and 44 breeding females. We detected 43 of 53 previously documented herpetofauna species. Our approach demonstrates an example of a monitoring protocol that accounts for factors that influence species detection and that can be replicated by parks or nature preserves with limited resources.

Quantifiable Long-term Monitoring on Parks and Nature Preserves

by
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BIOGRAPHY

Sharon Becker-Hux was born and raised in Sciota, Pennsylvania. She completed her B.S. in Zoology at North Carolina State University and graduated magna cum laude. During her graduate career, she received the “Best Student Presentation” award for her poster at the North Carolina Chapter of The Wildlife Society Annual Meeting in 2011 and was nominated for NCSU’s Outstanding Teaching Assistant Award in 2012 after five semesters as a teaching assistant for the Department of Biology. She currently is pursuing certifications as an associate wildlife biologist and environmental educator and hopes to garner a job as a wildlife biologist with emphasis in outreach and education.

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INTRODUCTION

Reptile and amphibian species have declined globally with more species declining than either birds or mammals (Gibbons et. al 2000; Gardner et al. 2007; Heyer et al. 1994; Wake 1991; Pechman et al. 1991). Declines have been attributed to climate change, disease, invasive species, and habitat loss and degradation (Gamble 2009; Alford and Richards 1999; Stuart et al. 2004). Additionally, reptiles and amphibians are important bio-indicators of ecosystem health, so understanding the drivers of population change is critical (Bury and Corn 1988; Wake 1991; Dunson et al. 1992; Gibbons et al. 2000; Hanlin et al. 2000).

Documenting species distribution and abundance is essential to comprehending changes in global biodiversity. Some reptiles and amphibians are wide ranging and could serve as global indicators of biodiversity change; other species are endemic to smaller areas and could indicate local conservation threats (Heyer et al. 1994). However, knowledge of the distribution and status of most herpetofauna species is lacking, even on public lands (Smith et al. 2006). Therefore, long-term monitoring of local sites is particularly critical to describing larger scale changes in biodiversity (Gooch et al. 2006).

Repeatable and affordable methods for monitoring herpetofaunal populations are needed by parks and nature preserves to document long-term trends and make well-informed management decisions. Standardized monitoring is necessary to assess changes in local species diversity and species-specific response to management (Yoccoz et. al 2001). Using data from monitoring programs, inferences can be made about species occurrence, conservation status, and metapopulation dynamics (Williams and Berkson 2004, Nichols et al. 2007, Heyer et al. 1994). However, standardized sampling techniques are necessary to limit biased results that may not accurately portray changes in species diversity (Feest 2006) or be comparable to data from other surveys (Heyer et al. 1994, Feest 2006). Often, inferences about system dynamics are made based on monitoring programs that only consider static glimpses of spatial relationships at single points in time. Conversely, multi-season occupancy modeling is a modern technique that incorporates spatial and temporal relationships and influential covariates and can be used by parks and natural preserves to monitor populations using few resources (MacKenzie et al. 2006).

Perfect detection through a survey is rare and an absence may not be a true absence but rather an undetection. Without accounting for the chance of non-detections, occupancy would be underestimated (MacKenzie et al. 2002) and would represent the researchers' ability to detect the species rather than providing an unbiased occupancy estimate (MacKenzie 2005). Occupancy modeling provides a method to estimate the probability of imperfectly detecting a species while providing accurate occupancy estimates.

We used a 1-year monitoring program at Hemlock Bluffs Nature Preserve (HBNP), Cary, North Carolina as a case study to demonstrate a quantifiable approach that could be used by other nature preserves, parks, and land trusts over longer time spans. We monitored the presence of herpetofauna within the preserve to develop a preliminary inventory and implemented standardized and replicable survey methods. Our study determined baseline occupancy and detection probability estimates of *Ambystoma opacum* Gravenhorst (Marbled Salamander), *Plethodon cinereus* Green (Red-backed Salamander), *Carphophis amoenus* Say (Eastern Worm Snake), and *Diadophis punctatus* Linnaeus (Ringneck Snake), which will provide the opportunity to model long-term changes in the future. Also, we determined a baseline abundance estimate of breeding female *Ambystoma maculatum* Shaw (Spotted Salamander) via egg mass counts, which can be expanded to more pool-breeding amphibians and provides the opportunity to model long-term changes in reproductive efforts.

FIELD-SITE DESCRIPTION

Hemlock Bluffs Nature Preserve is 64 ha and located in southwestern Cary, North Carolina. The property is co-owned by the State of North Carolina and the Town of Cary and has high patron visitation (annual visitation estimate for 2010 was 100,000 patrons [J. Logan, Hemlock Bluffs Nature Preserve Customer Service Representative, Cary, North Carolina, pers. comm.]). Several boardwalks, overlooks, and approximately 4.8 km of trails occur within the preserve. A natural area owned by the State of North Carolina includes a system of north-facing bluffs featuring a disjunct population of *Tsuga canadensis* Carr (Eastern Hemlock). This bluff system is adjacent to Swift Creek, which runs through the preserve and along a portion of the property boundary. Also, several small tributaries of Swift Creek intersect the property. The bluffs create a division between upland ridges and flats and the floodplain forest habitat, which is primarily at the east end of the preserve. Upland areas are mainly a pine-hardwood mix. The floodplain forest lies in the northeastern part of the property and contains several ephemeral pools which provide essential breeding areas for many amphibian species such as Marbled Salamander, Spotted Salamander, *Pseudacris feriarum* Baird (Upland Chorus Frog), and *Pseudacris crucifer* Wied-Neuwied (Spring Peeper).

Areas of urban development encompass three sides of the preserve with a four-lane road on the southeastern boundary. The loss of forest cover adjacent to the preserve has increased water discharge of Swift Creek (Fig. 1) (USGS 2011), which is a primary variable affecting transport of sediment and channel morphology in alluvial streams (Doyle et al. 2005).The increase of water discharge could lead to increased flooding, bank erosion, stream sedimentation, and overall changes in hydrology of the floodplain forest, affecting key amphibian breeding sites.

Historically, HBNP has not conducted standardized and quantifiable herpetofauna monitoring, thus preventing replication of previous inventory efforts. Therefore, a standardized monitoring program is needed to track possible changes in occupancy related to urban development and other long-term conservation threats.

METHODS

During fall 2009, we established coverboards (0.6 m X 0.6 m plywood boards) at 55 sites throughout HBNP. Coverboard sites were selected to effectively sample each major habitat type, surround ephemeral pools, and prevent visibility from walking trails (Fig. 2). Coverboard sites were at least 10 m apart. We numbered each coverboard and recorded GPS locations. We conducted coverboard surveys from March 2010 through March 2011, but seven coverboard sites around an additional ephemeral pool were added on October 23, 2010. We checked coverboards every two weeks and recorded each species detected. We conducted 28 coverboard surveys from 2010 through 2011 with 7 surveys in each of the 4 sampling seasons. We designated samplings seasons as spring (March – May 2010), summer

(June – August 2010), fall (September – December 2010), and winter (January – March 2011).

At HBNP, we recorded covariates that could influence herpetofauna occupancy and detection probabilities, including habitat type (upland or bottomland habitat), ambient temperature, precipitation, and sampling season. Precipitation was recorded as a categorical variable, denoting if a rain event occurred during the survey, and ambient temperature was measured at the beginning of each survey.

We conducted Spotted Salamander egg mass surveys in three ephemeral pools within HBNP. We used a dependent double-observer approach, where observer 1 pointed out and counted egg masses to observer 2, who then recorded the observations and noted any egg masses missed by observer 1 (Grant et al. 2005). Halfway through each survey at individual pools, observer 1 and 2 switched responsibilities (Grant et al. 2005). Egg masses were counted by viewing from the shore, and surveys were conducted twice by the same observers in each pool to ensure the maximum number of egg masses was counted. Surveys were conducted during March, which is prime oviposition time for Spotted Salamanders (Egan and Paton 2004). Spotted Salamander breeding females lay between 2 and 4 egg masses each year (Petranka 1998); we used this range to estimate the number of breeding female salamanders in the three pools.

Using program PRESENCE, detection probabilities and site occupancy were estimated for Marbled Salamander, Red-backed Salamander, Eastern Worm Snake, and Ringneck Snake through multiple sampling seasons. These 4 species were selected as focal species because they were the only species detected >5 times over the entire year. Occupancy modeling makes allowances for missing or adding sites during surveys, so adding coverboard sites to the survey did not affect the accuracy of the estimates calculated (Mackenzie et al. 2006). By conducting multiple surveys within each sampling season, we were able to model changes in occupancy and detection probabilities across the seasons (MacKenzie et al. 2002, 2003, 2006). We developed multi-season models with different combinations of the covariates precipitation, temperature, and habitat type for each focal species. We reported only top models with a ΔAIC_c score of less than 2. We used program DOBSERVE software to estimate detection probabilities and abundance of egg masses. From our egg mass abundance estimate we then calculated abundance of breeding Spotted Salamander females (Nichols et al. 2000). We used 2 models, the first held variation of detection due to observer effect constant and the second allowed for variation of detection based on observer.

We recorded opportunistic encounters by HBNP staff to supplement the species inventory. This species list was compared with historical records of species within HBNP from personal field notes of A. Braswell (North Carolina Museum of Natural Sciences (NCMNS), Raleigh, NC, 2010 unpubl. data) and a species list developed by M. Johns (Hemlock Bluffs Nature Preserve (HBNP), Cary, NC, 2010 unpubl. data).

RESULTS

OCCUPANCY ESTIMATION

Sampling season influenced detection for all focal species (Table 1). Detection of Ringneck Snake was highest in summer and individuals were not detected during spring or winter (Table 2). Ringneck Snake had the lowest number of detections of the four focal species. Eastern Worm Snake was detected the most during spring and was not detected during fall. Marbled Salamander and Red-backed Salamander had the highest detection during fall and winter respectively, and were not detected during the summer. Detection of all focal species increased with precipitation events (Table 1). Temperature was an important predictor of detection for the 2 salamander species, with higher detection probabilities during the cooler months of the year.

Site occupancy estimates for Eastern Worm Snake and Ringneck Snake were constant across all seasons (Table 2). Marbled Salamander occupancy estimates were highest in fall and winter. Increased site occupancy and detection during fall and winter seasons correlated with the timing of breeding season migrations and favorable temperature and precipitation conditions for Marbled Salamander (Table 1). Site occupancy estimates for Red-backed Salamander was highest in spring and lowest in winter correlating with breeding season and favorable temperature conditions (Table 2). Habitat type influenced site occupancy for both Red-backed Salamander and Ringneck Snake (Table 1). Ringneck Snake had greater site occupancy in the floodplain habitat type and Red-backed Salamander had greater site occupancy in the upland habitat type.

EGG MASS DETECTION AND SALAMANDER ABUNDANCE

The first survey produced a higher count of egg masses and was used for analysis in the DOBSERV software. Detection of egg masses differed only by 0.0002 between the 2 models and the top model did not include the observer covariate (Table 3). The estimation of egg mass abundance was 86.7. Therefore, estimates of breeding female Spotted Salamander abundance were between 21.7 and 43.3 across the three pools surveyed.

SPECIES RICHNESS INVENTORY

We documented 22 of the 25 amphibian species previously known to occur within HBNP (Table 4). Two caudate and 2 anuran species were recorded in historical surveys but not detected in recent surveys. Three anuran species were detected in recent surveys (both Historic 2 and Present surveys) but went undetected in Historic 1 (Table 4). Also, we documented 21 of the 28 reptilian species reported in historical accounts (Table 5). Six squamate species and 1 testudinate species not detected in present surveys had been previously detected (Table 5). Thirteen reptilian species were detected in recent surveys (both Historic 2 and Present surveys) that had not been detected in Historic survey 1. Overall, we documented 43 of the 53 reptile and amphibian species previously known to occur within HBNP.

DISCUSSION

Occupancy modeling offers an approach for parks and nature preserves to monitor the presence of species more accurately than historically. Common approaches to monitoring herpetofauna involve non-standardized and non-quantifiable inventories, which cannot provide verifiable conclusions, as was demonstrated with our inventory comparisons. We detected species not detected historically at HBNP, possibly due to site colonization or improved standardization of sampling methods, which provided more spatially complete sampling. *Anaxyrus fowleri* Hinckley (Fowler's Toad), *Lithobates sphenocephalus* Cope (Southern Leopard Frog), and 13 historically undetected reptilian species have wide ranges across North Carolina and were likely present but not detected during Historic 1 surveys (Beane et al. 2010). Conversely, the *Hyla cinerea* Schneider (Green Treefrog) range in North Carolina has expanded westward from the Coastal Plain indicating it may have been absent from HBNP during Historic 1 (Beane et al. 2010).

Site extinction and the short time frame of our sampling may indicate why we did not detect 7 reptilian and 2 anuran species historically detected at HBNP. Generally, herpetofauna have low detection probabilities and detection can be highly variable, depending on changes in environmental covariates (Dodd 2010). Most of the species we did not detect are nocturnal, secretive, and/or rare (Beane et al. 2010). These characteristics and our short sampling time frame reduced the probability of detection. Also, changing habitat conditions leading to site extinctions may explain why 2 caudate (*Pseudotriton montanus* Baird (Mud Salamander) and *Pseudotriton ruber* Sonni de Manoncourt and Latreille [Red Salamander]) and 2 squamate (*Thamnophis sauritus* Linnaeus (Eastern Ribbon Snake) and *Nerodia erythrogaster erythrogaster* Forster [Red-bellied Water Snake]) species were not detected. Due to forest succession and increasing water discharge, the spring-fed seeps within the lowlands of HBNP have filled in with vegetation and the stream morphology of Swift Creek is less suitable than historical habitats for these 4 species (M. Johns, Hemlock Bluffs Nature Preserve Naturalist, Cary, North Carolina, pers. comm., Beane et al. 2010).

Although our comparisons across inventories imply site extinction or colonization, there is no quantifiable data from historical methods to help explain non-detections. Conversely, estimating occupancy and detection probabilities allowed park staff to account for external influences and design a replicable protocol for long-term monitoring. Hemlock Bluffs Nature Preserve had historical records of herpetofauna of special concern to North Carolina, including *Tantilla coronata* Baird and Girard (Southeastern Crowned Snake) and *Hemidactylium scutatum* Temminck and Schlegel (Four-toed Salamander) (Mark Johns, Hemlock Bluffs Nature Preserve Naturalist, Cary, North Carolina, and Alvin Braswell, North Carolina Museum of Natural Sciences, Raleigh, North Carolina, pers. comm.). However, without accounting for the probability of detection, these historical records cannot be used as a baseline for current and future assessments of change in species occurrence.

The approach we used allowed staff to model the potential environmental covariates that influence changes in detection while working with constrained time and budgets. Sampling season influenced detection probability for all four focal species, indicating sampling efforts could be focused on seasons with the highest detection probabilities. Also, precipitation was influential for all focal species demonstrating that efforts could be more focused during rain events. Ambient temperature influenced detection of both focal salamander species indicating monitoring programs could account for the influence of annual climatic variation on salamander detection. Detection of both focal salamander species was low from April to October, when temperatures were above monthly averages (Southeast Regional Climate Center 2011). Occupancy estimates for both Red-backed Salamander and Ringneck Snake species were influenced by habitat type, which demonstrates the importance of sampling locations when surveys are focused on a single or few species.

Though modeling occupancy and detection probability provides a more reasonable alternative to compiling species inventories, there are limitations to this approach. Rare species often are the focus of monitoring programs and present the challenge of low detection or highly variable detection leading to biased estimates (Royle and Nichols 2003). However, occupancy bias can be reduced by including covariates influential to detection (e.g., weather conditions, seasonal behavior patterns, and differences between observers) (MacKenzie et al. 2006). Additionally, occupancy modeling estimates only species occurrence and not population abundance. Therefore, tracking changes in population size directly is not possible with this approach alone.

Using combinations of multiple survey techniques provides a more accurate depiction of the herpetofauna community (Heyer et al. 1994, Hutchens et al. 2009). The similarity in egg mass detection probabilities between models indicates there was no observer effect on our detection and an accurate abundance estimate was calculated for female breeding Spotted Salamanders. The dependent double-observer egg mass survey protocol can be implemented to record abundance and reproductive effort of several other pool-breeding amphibian species such as the Upland Chorus Frog, *Lithobates clamitans* Latreille (Green Frog), Southern Leopard Frog, and Spring Peeper.

Time and resource constraints on park staff often determine which sampling protocols can be implemented. Staff available to conduct surveys can be limited and conducting surveys on a standardized basis may be difficult to accomplish. Also, the amount of time required to complete each survey takes time away from other park responsibilities. Survey methods need to be practical to persist long-term through changes in leadership and personnel. More time intensive but less frequent survey events make sampling more efficient for park staff by allowing staff to conduct multiple sampling methods over less occasions. Also, selecting sampling sites based on appropriate habitat type for focal species in conjunction with seasons of high detection and precipitation events would reduce the time required for individual surveys.

Other sampling methods not implemented in this survey may be used to increase detection probabilities of focal species (Heyer et al. 1994, Hutchens et al. 2009). Repeated visual encounter surveys in selected plots would provide more sampling events that could be included in occupancy estimation, which would improve estimate accuracy (MacKenzie et al. 2006). Drift fence arrays provide a passive capture method that is especially effective with nocturnal and secretive species; however, effort required to install, maintain, and monitor drift fence arrays could be more than park staff can contribute and may not be appropriate in most cases (Heyer et al. 1994). Calling amphibian surveys can account for anuran species that otherwise have low detection probabilities and require no equipment and can be used to cover large sampling areas (Dodd 2010).

Using statistical software such as PRESENCE and DOBSERV may present an additional challenge for park staff not trained in statistical analysis. We recommend parks and nature preserves work with local universities or hire system-wide personnel that have skills to use statistical software; this will be a more cost and time efficient option. Park staff would still need to be trained in appropriate data collection and ways to compile data for analysis, but this training would not be costly or as time consuming.

Randomization of site locations helps reduce estimate bias (Heyer et al. 1994); however, randomization may be difficult to accomplish at parks and nature preserves. We were unable to randomly establish site locations at HBNP because patrons would be more likely to venture off trails to visible site locations. Also, patron visits to site locations could have biased our detection probabilities. Parks with high visitation such as HBNP prioritize preservation of wildlife habitat and patron safety. Sampling locations should be selected in a way to effectively sample each habitat type and reduce visibility of site locations from trails.

Our standard approach used multi-season occupancy modeling as the basis for a long-term monitoring program that accounts for detection bias and environmental covariates, and is applicable to parks and nature preserves with limited resources. Historic approaches only provided inventory lists of species encountered and did not account for the probability of detection. Parks and nature preserves should consider the natural history of focal species to help determine the most efficient sampling techniques and seasons for their monitoring protocol. Rare and hard to detect species should be sampled over a longer time frame to account for detection bias. Additionally, parks and nature preserves should consider working with local university staff or hire appropriately trained personnel to use statistical software to conduct data analysis and assist in implementation of suitable monitoring protocol. Implementing occupancy modeling into park and nature preserve monitoring protocol generates quantifiable results that can be compared across long time frames and provide reliable insight for management decisions.

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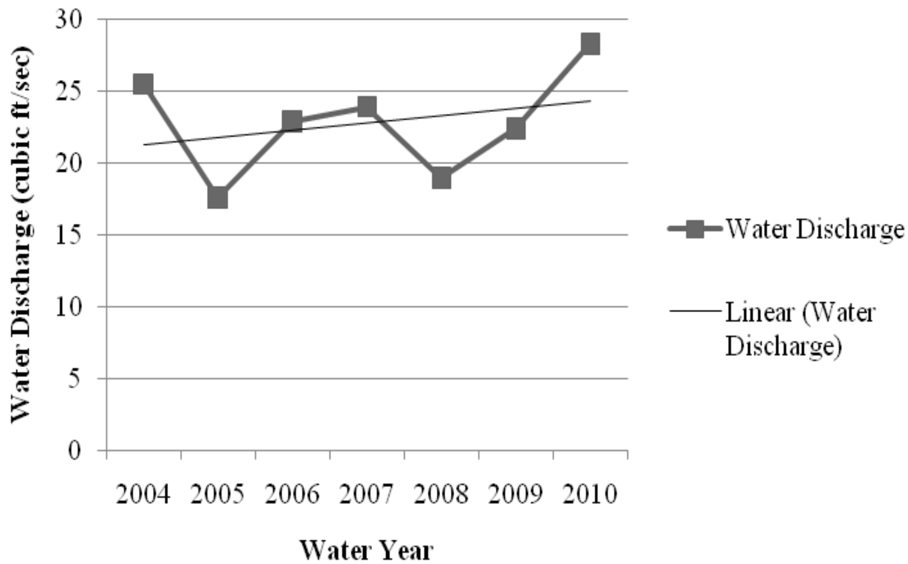

Figure 1 - Annual water discharge for Swift Creek near Apex, North Carolina from 2004-2010. Water volume in Swift Creek has increased gradually from 2004 - 2010.

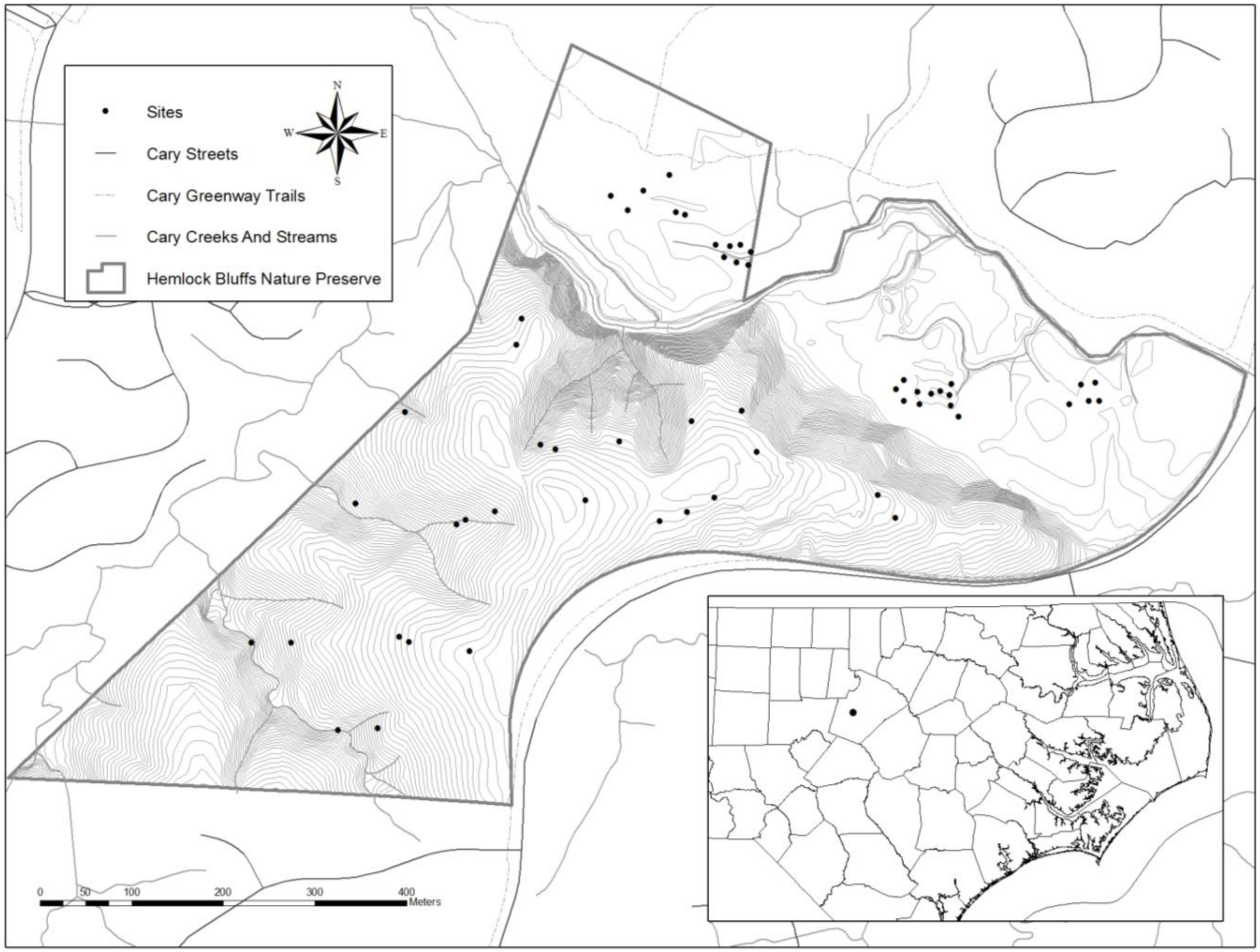

Figure 2 - Coverboard sites at Hemlock Bluffs Nature Preserve, Cary, North Carolina. Sampling was conducted from March 2010 - March 2011.

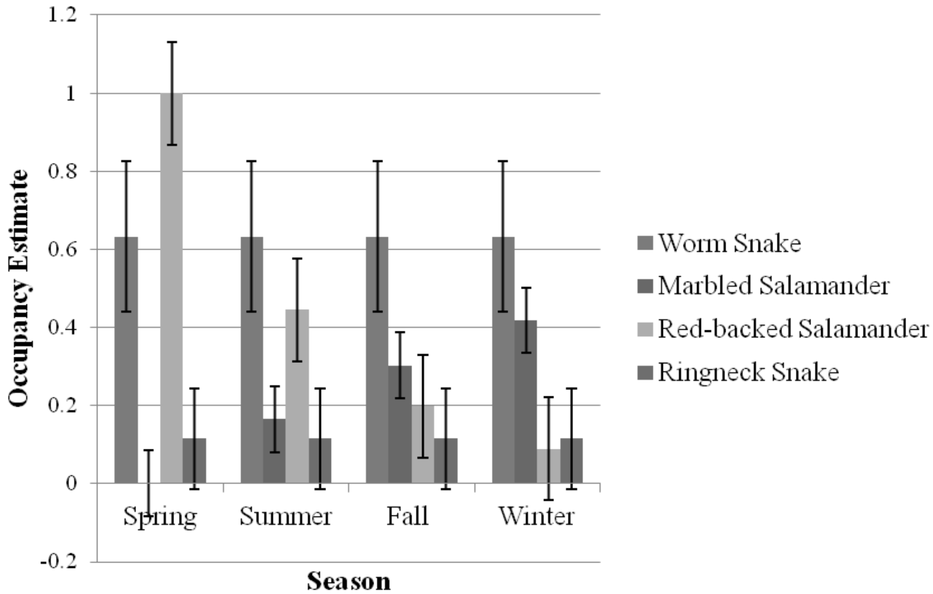

Figure 3 - Occupancy estimates across the four sampling seasons for the four focal species monitored at Hemlock Bluffs Nature Preserve March 2010 - March 2011.

Table 1- Multi-season occupancy models for each focal species from program PRESENCE. ΔAICc scores of less than 2 designate appropriate top models for each species. Habitat type influenced site occupancy (Ψ), whereas ambient temperature and precipitation events influenced detection probability (P).

Species	Top Occupancy Models	AICc	Δ AICc
Worm Snake			
	Ψγεp(seasons)	147.57	0
	Ψγεp(seasons)(precip)	148.37	0.80
Marbled Salamander			
	Ψγεp(seasons)(precip)(temp)	206.65	0
Red-backed Salamander			
	Ψγεp(seasons)(temp)	138.33	0
	Ψγεp(seasons)(precip)(temp)	140.32	1.99
	Ψ(habitat)γεp(seasons)(temp)	140.32	1.99
Ringneck Snake			
	Ψγεp(seasons)(precip)	58.16	0
	Ψ(habitat)γεp(seasons)(precip)	59.64	1.48
	Ψγεp(seasons)(precip)(temp)	60.15	1.99

Table 2- Occupancy (Ψ), standard error (SE), and detection probability (P) estimates from the top model for each focal species across the seasons. Seasons were designated as spring = March-May, summer = June-August, fall = September-December, winter = January-March.

Species	Season	Ψ	SE	P
Worm Snake	Spring	0.6324	0.4059	0.0427
	Summer	0.6324	0.4059	0.0047
	Fall	0.6324	0.4059	0.0000
	Winter	0.6324	0.4059	0.0123
Marbled Salamander	Spring	0.0000	0.0000	0.0983
	Summer	0.1651	0.0409	0.0000
	Fall	0.3030	0.0682	0.2947
	Winter	0.4181	0.0854	0.0374
Red-backed Salamander	Spring	1.0000	102.235	0.0060
	Summer	0.4456	0.0736	0.0000
	Fall	0.1986	0.0656	0.0374
	Winter	0.0885	0.0438	0.0542
Ringneck Snake	Spring	0.1151	0.0972	0.0000
	Summer	0.1151	0.0972	0.0453
	Fall	0.1151	0.0972	0.0131
	Winter	0.1151	0.0972	0.0000

Table 3- Models for Spotted Salamander egg mass abundance estimates from program DOBSERV.

Model	AICc	ΔAICc	P	N (egg masses)	N (adult females)
p (.,.)	8.178	0.000	0.9921	86.68	21.67 - 43.34
p (.,observer)	10.23	2.052	0.9923	86.67	21.67 – 43.34

Table 4- Comprehensive list of amphibian species detected within Hemlock Bluffs Nature Preserve, Cary, North Carolina. Species from current survey (March 2010 through March 2011) were compared against historical inventory data collected from March 1973 through February 1984 (Historic 1) and inventory data collected from 1990 through 2009 (Historic 2).

Species	Historic 1	Historic 2	Present
Anurans			
Acris crepitans (Northern Cricket Frog)	X	X	X
Anaxyrus americanus (American Toad)	X	X	X
Anaxyrus fowleri (Fowler's Toad)		X	X
Gastrophryne carolinensis (Eastern Narrowmouth Toad)	X	X	X
Hyla chrysoscelis (Cope's Gray Treefrog)	X	X	X
Hyla cinerea (Green Treefrog)		X	X
Hyla squirella (Squirrel Treefrog)		X	
Lithobates catesbeianus (American Bullfrog)	X	X	
Lithobates clamitans (Green Frog)	X	X	X
Lithobates sphenocephalus (Southern Leopard Frog)		X	X
Pseudacris crucifer (Spring Peeper)	X	X	X
Pseudacris feriarum (Upland Chorus Frog)	X	X	X
Scaphiopus holbrookii (Eastern Spadefoot)		X	
Caudates			
Ambystoma maculatum (Spotted Salamander)	X	X	X
Ambystoma opacum (Marbled Salamander)	X	X	X
Desmognathus fuscus (Northern Dusky Salamander)	X	X	X
Eurycea cirrigera (Southern Two-lined Salamander)	X	X	X
Eurycea guttolineata (Three-lined Salamander)	X	X	X
Eurycea quadridigitata (Dwarf Salamander)	X	X	X
Hemidactylium scutatum (Four-toed Salamander)	X	X	X
Notophthalmus viridescens viridescens (Red-spotted Newt)	X	X	X
Plethodon cinereus (Red-backed Salamander)	X	X	X
Plethodon cylindraceus (White-spotted slimy Salamander)	X	X	X
Pseudotriton montanus (Mud Salamander)	X	X	
Pseudotriton ruber (Red Salamander)		X	

Table 5- Comprehensive list of reptilian species detected within Hemlock Bluffs Nature Preserve, Cary, North Carolina. Species from current survey (March 2010 through March 2011) were compared against historical inventory data collected from March 1973 through February 1984 (Historic 1) and inventory data collected from 1990 through 2009 (Historic 2).

Species	Historic 1	Historic 2	Present
Squamates			
Agkistrodon contortrix (Copperhead)		X	X
Anolis carolinensis (Green Anole)		X	X
Carphophis amoenus (Eastern Worm Snake)		X	X
Coluber constrictor (Black Racer)		X	X
Diadophis punctatus (Ringneck Snake)	X	X	X
Elaphe guttata guttata (Corn Snake)		X	
Elaphe obsolete obsoleta (Black Rat Snake)	X	X	X
Eumeces fasciatus (Five-lined Skink)	X	X	X
Eumeces laticeps (Broadhead Skink)		X	X
Heterodon platirhinos (Eastern Hog-nosed Snake)		X	X
Lampropeltis calligaster rhombommaculata (Mole Kingsnake)		X	
Lampropeltis getula getula (Eastern Kingsnake)		X	
Nerodia erythrogaster erythrogaster (Redbelly Water Snake)		X	
Nerodia sipedon (Northern Water Snake)	X	X	X
Opheodrys aestivus (Rough Green Snake)		X	X
Sceloporus undulatus (Eastern Fence Lizard)		X	X
Scincella lateralis (Ground Skink)		X	X
Storeria dekayi (Brown Snake)	X	X	X
Tantilla coronata (Southeastern Crowned Snake)	X		
Thamnophis sauritus (Eastern Ribbon Snake)		X	X
Thamnophis sirtalis (Common Garter Snake)		X	X
Virginia striatula (Rough Earth Snake)		X	
Testudinates			
Chelydra serpentine (Common Snapping Turtle)		X	X
Clemmys guttata (Spotted Turtle)	X	X	X
Kinosternon subrubrum (Eastern Mud Turtle)	X	X	X
Sternotherus odoratus (Common Musk Turtle)	X	X	X
Terrapene carolina (Eastern Box Turtle)		X	X
Tracemys scripta scripta (Yellow-bellied Slider)		X	

APPENDIX

The following is a list of herpetofaunal species found in Hemlock Bluffs Nature Preserve, Cary, North Carolina (1973 – 2011). Nomenclature follows the Integrated Taxonomic Information System (ITIS 2011).

Amphibia

Anura

Anaxyridae

Anaxyrus americanus Holbrook (American Toad)

Anaxyrus fowleri Hinckley (Fowler's Toad)

Hylidae

Acris crepitans Baird (Northern Cricket Frog)

Hyla chrysoscelis Cope (Cope's Gray Treefrog)

Hyla cinerea Schneider (Green Treefrog)

Hyla squirella Bosc (Squirrel Treefrog)

Pseudacris crucifer Wied-Neuwied (Spring Peeper)

Pseudacris feriarum Baird (Upland Chorus Frog)

Lithobatidae

Lithobates catesbeianus Shaw (American Bullfrog)

Lithobates clamitans Latreille (Green Frog)

Lithobates sphenocephalus Cope (Southern Leopard Frog)

Microhylidae

Gastrophryne carolinensis Holbrook (Eastern Narrowmouth Toad)

Pelobatidae

Scaphiopus holbrookii Harlan (Eastern Spadefoot)

Caudates

Ambystomatidae

Ambystoma maculatum Shaw (Spotted Salamander)

Ambystoma opacum Gravenhorst (Marbled Salamander)

Plethodontidae

Desmognathus fuscus Rafinesque (Northern Dusky Salamander)

Eurycea cirrigera Green (Southern Two-lined Salamander)

Eurycea guttolineata Holbrook (Three-lined Salamander)

Eurycea quadridigitata Holbrook (Dwarf Salamander)

Hemidactylium scutatum Temminck & Schlegel (Four-toed Salamander)

Plethodon cinereus Green (Red-backed Salamander)

Plethodon cylindraceus Harlan (White-spotted slimy Salamander)

Pseudotriton montanus Baird (Mud Salamander)

Pseudotriton ruber Sonnini de Manoncourt and Latreille (Red Salamander)

Salamandridae

Notophthalmus viridescens viridescens Rafinesque (Red-spotted Newt)

Reptilia

Squamata

Sauria

Phrynosomatidae

Sceloporus undulatus Bosc & Daudin (Eastern Fence Lizard)

Polychrotidae

Anolis carolinensis Voigt (Green Anole)

Scincidae

Eumeces fasciatus Linnaeus (Five-lined Skink)

Eumeces laticeps Schneider (Broadhead Skink)

Scincella lateralis Say (Ground Skink)

Serpentes

Colubridae

Carphophis amoenus Say (Eastern Worm Snake)

Coluber constrictor Linnaeus (Black Racer)

Diadophis punctatus Linnaeus (Ringneck Snake)

Elaphe guttata guttata Linnaeus (Corn Snake)

Elaphe obsolete obsoleta Say (Black Rat Snake)

Heterodon platirhinos Latreille (Eastern Hog-nosed Snake)

Lampropeltis calligaster rhombommaculata Holbrook (Mole Kingsnake)

Lampropeltis getula getula Linnaeus (Eastern Kingsnake)

Nerodia erythrogaster erythrogaster Forster (Redbelly Water Snake)

Nerodia sipedon Linnaeus (Northern Water Snake)

Opheodrys aestivus Linnaeus (Rough Green Snake)

Storeria dekayi Holbrook (Brown Snake)

Tantilla coronata Baird & Girard (Southeastern Crowned Snake)

Thamnophis sauritus Linnaeus (Eastern Ribbon Snake)

Thamnophis sirtalis Linnaeus (Common Garter Snake)

Virginia striatula Linnaeus (Rough Earth Snake)

Viperidae

Agkistrodon contortrix Linnaeus (Copperhead)

Chelonia

Testudines

Chelydridae

Chelydra serpentina Linnaeus (Common Snapping Turtle)

Emydidae

Clemmys guttata Schneider (Spotted Turtle)

Terrapene carolina Linnaeus (Eastern Box Turtle)

Tracemys scripta scripta Schoepff (Yellow-bellied Slider)

Kinosternidae

Kinosternon subrubrum Lacepede (Eastern Mud Turtle)

Sternotherus odoratus Latreille (Common Musk Turtle)