



Summary of Amphibian Community Monitoring at Cape Hatteras National Seashore, 2010

Natural Resource Report NPS/SECN/NRDS—2011/153



ON THE COVER

Hyla cinerea (green treefrog)

Photograph by SECN staff.

Summary of Amphibian Community Monitoring at Cape Hatteras National Seashore, 2010

Natural Resource Data Series NPS/SECN/NRDS—2011/153

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data were collected and analyzed using established methods based on peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Executive Summary

This report summarizes data collected with the Draft SECN Amphibian Community Monitoring Protocol (Byrne et al., *in preparation*) at Cape Hatteras National Seashore in 2010.

1. Data were collected at 30 spatially-balanced random locations at the Seashore with two techniques: automated recording devices and visual-encounter surveys.
2. Sampling activities occurred at the Seashore from 5/12/2010 to 5/29/2010, and again from 8/15/2010 to 9/1/2010.
3. We detected 106 amphibians in six species and 39 reptiles and reptile signs in 15 species, genera, or order.
4. No non-native amphibians or reptiles were detected.
5. Observed amphibian-species richness was six and the sample adequately characterized species richness.
6. Green treefrog and squirrel treefrog were the most widely distributed amphibians.
7. Six-lined racerunner was the most widely distributed reptile.
8. This monitoring protocol will be implemented again at the Seashore in 2013.
9. The full dataset, and associated metadata, can be acquired from the data store at <http://science.nature.nps.gov/nrdata/>

Introduction

Overview

Amphibian populations have exhibited declines in North America and many other areas around the world. Several factors are attributable to population declines and localized extinctions. Among these factors are disease and anthropogenic stressors such as habitat loss and degradation, non-native predators, acid precipitation, altered hydrology and hydroperiod, ultraviolet radiation, and chemical contaminants (Collins and Storfer 2003). Although diseases and parasites naturally occur in amphibian populations, the effects of these influences can be exacerbated when combined with other anthropogenic stressors.

Amphibians have complex life cycles, where the immature phase often consists of an aquatic larval stage, followed by a post-metamorphic adult terrestrial stage. Slight alterations in the aquatic or terrestrial communities upon which amphibians are dependent can have substantial impacts on the survival, reproduction, and persistence of a species. Given their habitat requirements, anatomy, and physiology, amphibians are considered good indicators of ecological condition.

The southeastern U.S. is host to one of the most diverse amphibian communities in the world. With an estimated 140 amphibian species, more than half of which are salamanders, the Southeast accounts for about half of the total number of amphibians in the U.S (Echternacht & Harris 1993, Petranka 1998). The Southeast Coast Network (SECN) has 61 known amphibian species; 26 in Caudata (salamanders, newts, amphiumas, sirens), and 35 in Anura (frogs and toads; Appendix A).

Given their known population declines, sensitivity to anthropogenic stressors, and the diversity of amphibians in the southeastern U.S., amphibian communities are a priority for SECN monitoring efforts.

The National Park Service Omnibus Management Act of 1998, and other reinforcing policies and regulations, require park managers “to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources” (Title II, Sec. 204). The amphibian-community monitoring data summarized herein is a tool to assist park managers in fulfilling this mandate.

This report summarizes data collected under the draft SECN Amphibian Community Monitoring Protocol (Byrne et al., *in preparation*).

Objective

- Determine trends in amphibian-species occupancy, distribution, diversity, and community composition in SECN parks.

Methods

Study Area

Cape Hatteras National Seashore (CAHA) is part of the Outer Banks Group of parks, which includes Fort Raleigh National Historic Site and Wright Brothers National Memorial; however, only CAHA was included in this monitoring effort.

The Outer Banks Group of National Parks is part of the Atlantic coast barrier-island system of the U.S (Figure 1) which is a 12,663-ha (31,292 ac) seashore extending approximately 119 km (74 miles) along the east-central coast of North Carolina. Pea Island National Wildlife Refuge, located within the Seashore's administrative boundary, is managed by the U.S. Fish and Wildlife Service. The Seashore occurs on three islands: Bodie Island, Hatteras Island, and Ocracoke Island.

The Seashore is year-round host to a wide variety of plants and wildlife, including several state- and federally-listed species. The Seashore is considered a Globally Important Bird Area by the American Bird Conservancy because of the importance of the Seashore's habitats to avian breeding, migration, and wintering.

Vegetation communities at the Seashore include sea oats (*Uniola paniculata*) dominated dune communities, wax myrtle (*Morella cerifera*) shrub communities, and coastal maritime hammock commonly characterized by Virginia live oak (*Quercus virginiana*). Small remnant slash pine (*Pinus elliotii*) plantations also occur in the Seashore. The southern interior of Hatteras Island contains Buxton Woods, a unique and complex freshwater wetland system very uncommon in barrier islands. Approximately one-third of this wetland complex occurs within the Seashore's boundary. Despite its complexity, sweetbay (*Magnolia virginiana*) and loblolly pine (*Pinus taeda*) generally occur throughout this system. The bayside of the Seashore generally consists of salt marsh cordgrass (*Spartina alterniflora* and *Spartina patens*) communities.

Given the location of the Seashore, it is subject to a high frequency of naturally occurring wind-, tide-, and wave-driven processes of erosion, accretion, and overwash that result in a very dynamic environment. Much of the land immediately outside of the Seashore boundary is developed, as it serves as a vacation and recreation area for many people. Consequently, this intense recreational pressure at the Seashore results in a complex management challenge in order to ensure natural resources are protected while allowing recreational access.

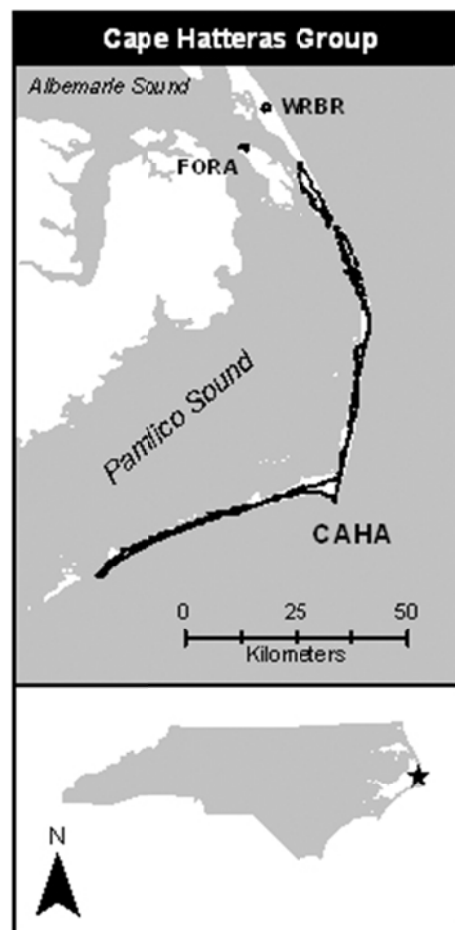


Figure 1. Location of Cape Hatteras National Seashore.

CAHA has 12 known amphibian species and 36 known reptiles (Appendix A). The amphibians consist of nine species in Anura (frogs and toads) and three species in Caudata (e.g. salamanders, newts, amphiumas, sirens). The reptiles consist of 23 species in Squamata (e.g. lizards, snakes, geckos, and skinks) and 13 species in Testudines (turtles and tortoises).

Sampling Design

A detailed explanation of the sampling design and site selection can be found in the SECN Draft Amphibian Monitoring Protocol (Byrne et al., *in preparation*) and sample site selection SOP (Byrne 2009). In summary, to allow for park-wide inference, the Seashore's administrative boundary was used as the sampling frame. The sampling frame was divided into a systematic 0.5-ha grid; the center point of each grid cell served as the potential sampling site. A spatially-balanced sample was drawn from this grid using the Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm (Theobald et al. 2007). Alternate points were used when selection criteria (i.e., including safety and access issues) were not met. Areas not considered amphibian habitat (e.g., saline tidal marshes) were also excluded from the suite of sampling locations. A sample size of 30 was chosen after consideration of the Seashore's size, hypothesized variability, and logistical issues regarding travel time and conducting monitoring activities in five to six park units per year. Sampling locations are presented in Figure 2a and Figure 2b.

Sampling Methodology

Two sampling techniques are used as part of SECN amphibian monitoring; a combination of active and passive sampling techniques. The active technique is a time- and area-constrained medium-intensity visual encounter survey (VES) that incorporates dip-net techniques in sampling locations with aquatic communities. All species or species sign detected by sight or sound are recorded as part of the VESs. The passive technique is an automated-recording device (ARD) programmed to record one minute every ten minutes from dusk to dawn once every three days. Use of multiple techniques, as a "toolbox" approach (Olson et al. 1997), is generally agreed to be the most effective means to monitor amphibian communities (Hutchens and DePerno 2009). These sampling techniques are described in detail in Byrne (2007a) and Byrne (2007b).

ARD's were deployed from 5/12/2010 to 5/29/2010. A total of 9,408 minutes were recorded by all of the devices deployed the Seashore. VESs were conducted from 8/15/2010 to 9/1/2010. Due to Hurricane Earl, VESs were not conducted at six sampling locations (4, 6, 14, 23, 25, Alt2). The ARD malfunctioned and did not record data at two sampling locations (15, 16).

Data Analysis

Because this is the first year of this protocol's implementation at the Seashore, only the status of the elements presented in the aforementioned monitoring objective are presented with the exception of occupancy. The data in this report are summarized and presented in three general categories: diversity, composition, and distribution. Sampling locations are presented in Figure 2a and Figure 2b, labeled locations are presented in Appendix B, and species detected at each location are presented in Appendix C.

Despite a well-trained and dedicated field crew, complete identification of all individuals encountered was not always possible due to the quick and evasive nature of many species. Species were, however identified to the most refined taxonomic level possible. For example,

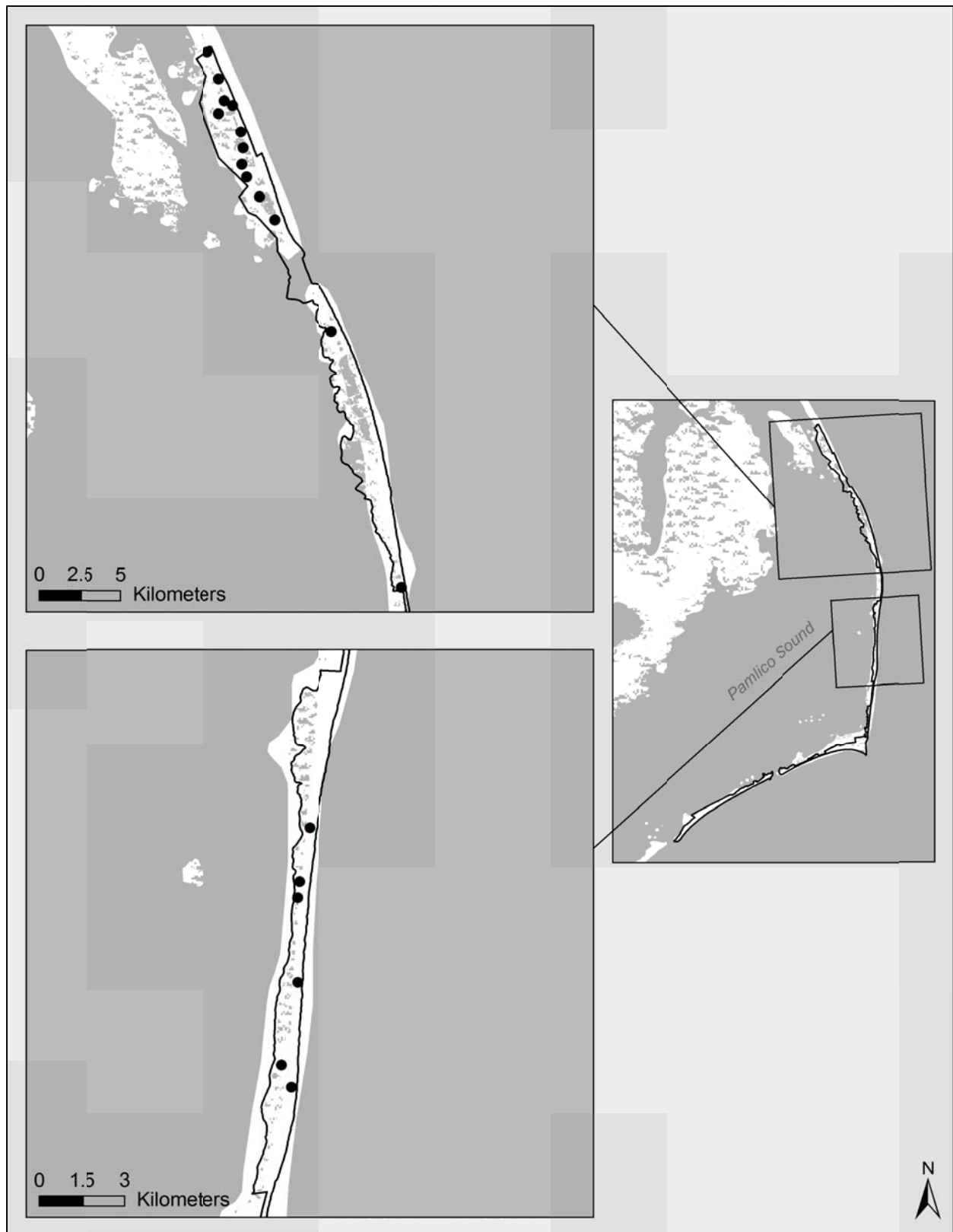


Figure 1a. Spatially-balanced random sampling locations at the northern end of CAHA, 2010.

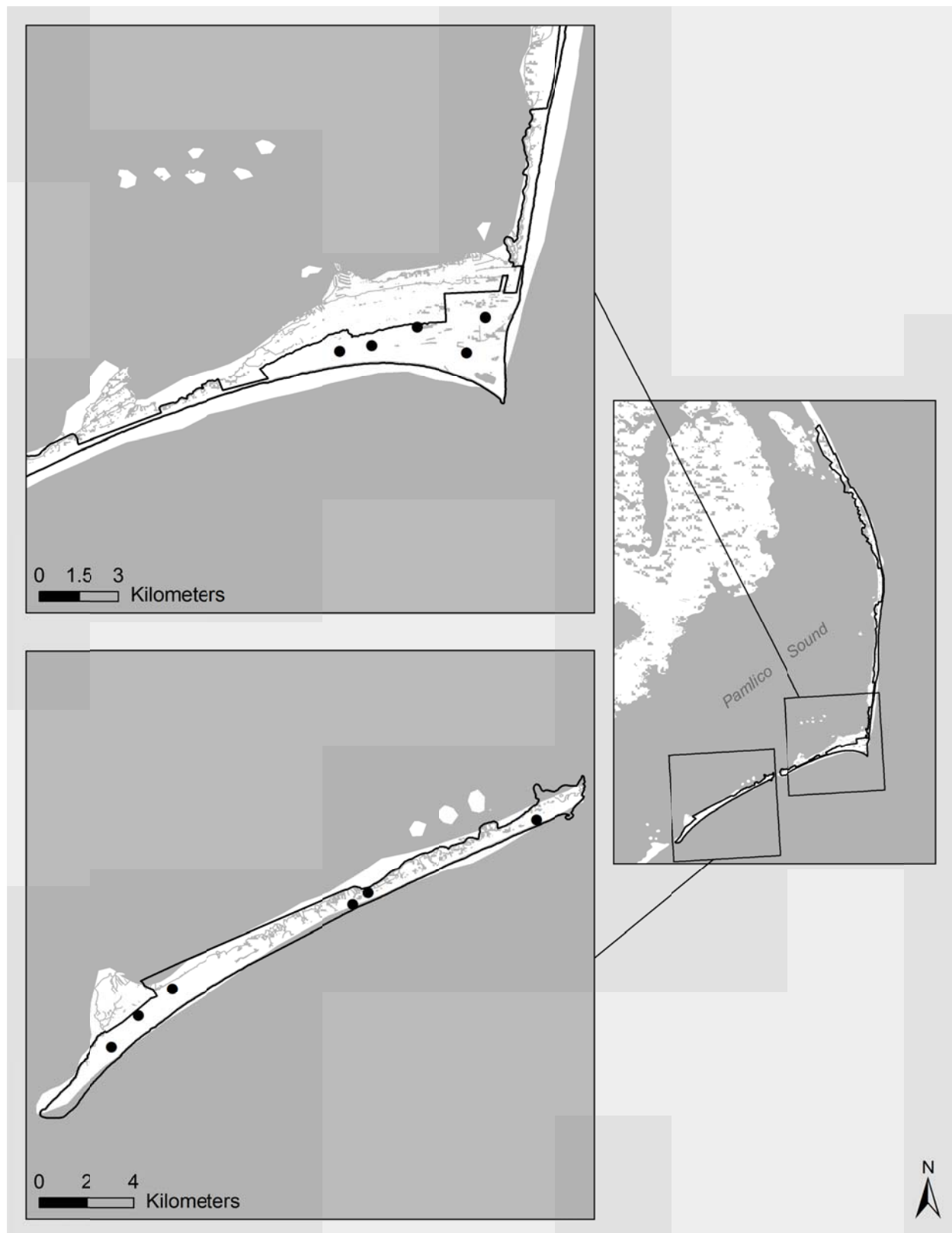


Figure 2b. Spatially-balanced random sampling locations at the southern end of CAHA, 2010.

while the surveyors are approaching a small pool surrounded by dense vegetation, they catch brief glimpses of and hear several frogs dive into the pool prior to completing a full visual inspection of the individuals necessary for identification. Although the majority of these species could most likely be identified to the genus or family level (i.e., Unknown *Rana* or Ranidae in this instance) based upon knowledge of the site and the local fauna, a conservative estimation is used and these species are identified to Order as “Unknown Anuran”.

Although the primary purpose for implementing the aforementioned monitoring techniques as part of SECN monitoring efforts was to detect amphibians, reptiles were also encountered. It is important to note that VESs and ARDs are not effective tools to survey for many reptile species, nor was the intent of VES implementation to target reptiles, but all reptile, and reptile sign detections are presented.

Diversity

Diversity is defined as “the variety and abundance of species in a defined unit of study” (Magurran 2004, p. 8). Diversity is a community property that is related to trophic structure, productivity, stability (McIntosh 1967, McNaughton 1977), immigration / emigration (Colwell and Lees 2000), and ecological condition (i.e., ecological integrity as defined by Karr and Chu [1995]). Species diversity consists of two components: the number of species (species richness) and the relative abundance of those species (species evenness / dominance) within a defined community (Margalef 1958, Lloyd and Ghelardi 1964, Pielou 1966). Species diversity is often communicated in the form of diversity indices. The term community refers to the assemblage of species populations that occur together in space and time (Begon et al. 1986), and we consider the Seashore as a whole community as per the conceptual ecological models presented in our monitoring plan (see Chapter 2 in DeVivo et al. 2008).

Because diversity indices respond differently to various mechanisms that influence community change, several indices must be used to adequately characterize diversity in SECN parks (Haedrick 1975, Boyle et al. 1984). After careful appraisal of advantages and disadvantages of the many diversity indices, a suite of alpha diversity indices were selected to summarize these data (Table 1), where alpha diversity is the diversity of species within a defined area, community, or ecosystem (Whittaker 1972).

Species diversity estimates are based only on amphibian observations identified to the species level, as they were the primary target of this monitoring effort. Non-native amphibians were not included in diversity estimates. As previously mentioned, the methodologies used for amphibians are inadequate for the reptile community; therefore, diversity indices generated for reptiles would be biased and were not calculated.

Composition

Measures of community composition are often good indicators of abiotic variability, disturbance, or other stressors. For all species detected, a naïve estimate of occupancy is calculated as the proportion of sites where the species was detected at least once and unadjusted for probability of detection. All non-native species detections were pooled to calculate the proportion of sites where at least one non-native species was detected. Future data analyses will include estimates of occupancy adjusted for probability of detection (MacKenzie et al. 2002) and taking into account

environmental covariates known to influence the probability of detection of amphibians (e.g., rainfall and temperature).

Distribution

The distribution of species on park lands is integral to informed management. Further, changes in species distributions over time provides useful information regarding possible unseen influences that alter wildlife-habitat use and may be indicative of other issues. This section presents maps of all sampling locations where each amphibian, reptile, and reptile sign was detected.

Table 1. Diversity indices used, corresponding symbol, community attribute the index reflects, the range of index values, and notes on each index.

Index	Symbol	Community Attribute	Index Citation	Notes
Native Spp. Richness	S_{obs}	Richness	n/a	Value is a positive integer that indicates the number of native species in the sample. Intuitive. Good discriminant ability if sampling effort is comparable; sensitive to sample size, the occurrence of rare species, or those with low detectability; does not account for relative abundances.
Chao 1	Chao1	Richness	Chao (1984) Chao (1987)	Values indicate an estimate of species richness; abundance-based estimate; works well with dataset containing several infrequent observations ^a .
Chao 2	Chao2	Richness	Chao (1984) Chao (1987)	Values indicate an estimate of total species richness (including species not present in the sample); incidence-based estimate; works well with dataset containing several infrequent observations ^a .
Abundance-based Coverage	ACE	Richness	Chao and Lee (1992) Chazdon et al. (1998)	Values indicate an estimate of species richness; abundance-based estimate.
Incidence-based Coverage	ICE	Richness	Lee and Chao (1994) Chazdon et al. (1998)	Values indicate an estimate of total species richness (including species not present in the sample); incidence-based estimate.
Jackknife 1	Jack1	Richness	Burnham and Overton (1978) Burnham and Overton (1979) Heltsh and Forrester (1983)	Values indicate an estimate of total species richness (including species not present in the sample); incidence-based estimate; The higher the value the higher the species richness. This procedure requires no assumptions regarding the data distribution.
Jackknife 2	Jack2	Richness	Smith and van Belle (1984)	Values indicate an estimate of species richness; incidence-based estimate.
Bootstrap	Boot	Richness	Smith and van Belle (1984)	Values indicate an estimate of species richness; incidence-based estimate.

Table 1. (Continued)

Index	Symbol	Community Attribute	Index Citation	Notes
Fisher's α	α	Richness	Fisher et al. (1943)	Value is a positive integer and indicates a relative estimate of species richness; good discriminant ability, low sensitivity to sample size, and robust to deviations in the assumed distribution ^{b, c, d, e} ; abundance-based estimate.
Q Statistic	Q	Richness	Kempton and Taylor (1976) Kempton and Taylor (1978)	Value is a positive integer and indicates a relative estimate of species richness. Good discriminant ability and low bias with small samples ^f , model fit is irrelevant to index performance ^g ; value is not weighted towards abundant or rare species; abundance-based estimate.
Smith and Wilson	E_{var}	Evenness	Smith and Wilson (1996)	Values range from 0 (no evenness) to 1 (perfectly even and all species exists in relatively equal abundance); weighs common species more heavily than rare species (desirable in certain cases).
Smith and Wilson 1/D	E_{1/D}	Evenness	Smith and Wilson (1996) Simpson (1949)	Values range from 0 (no evenness) to 1 (perfectly even and all species exists in relatively equal abundance); weighs rare and abundant species equally (desirable in certain cases).
Camargo	E'	Evenness	Camargo (1992)	Values range from 0 (no evenness) to 1 (perfectly even and all species exists in relatively equal abundance); performs well estimating intermediate values of evenness than the other indices; weighs rare and abundant species equally (desirable in certain cases).
Gini	E_G	Evenness	Gini (1912)	Values range from 0 (no evenness) to 1 (perfectly even and all species exists in relatively equal abundance); Good discriminant ability and low sensitivity to sample size ^h .
Berger-Parker	D_{BP}	Dominance	Berger and Parker (1970)	Values range from 0 (no single-species dominance) to 1 (sample is strongly dominated by a single species); describes the proportional dominance of the single most abundant species; low sensitivity to sample size but poor discriminant ability ⁱ – not used for across year or site comparisons.

^a(Chao 1984), ^b(Kempton 2002), ^c(Kempton and Taylor 1974), ^d(Hayek and Buzas 1997), ^e(Wolda 1983), ^f(Kempton and Wedderburn 1978),

^g(Magurran 1988), ^h(Lexerød and Eid 2006), ⁱ(Magurran 2004)

Results

Diversity

Diversity indices calculated for these data were selected to reflect community composition (i.e., number of species) and structure (i.e., number of individuals), which include species richness and evenness estimates (Table 2). Confidence intervals for each diversity index were estimated with a bootstrap procedure. A brief explanation of interpreting the value is presented in Table 2.

Rank-abundance plots, frequency distributions, and other descriptive approaches were used to explore the abundance distributions and patterns in the dataset, and evaluate the utility of select indices and abundance equitability among species. The data are best fit by a geometric abundance model; $\chi^2=6.9164$, $df=5$, $p=0.227$. While geometric abundance models are often associated with uneven, species-depauperate, or disturbed communities where one species dominates the community, this is likely not the case at CAHA. Rather, this is an artifact of the patchy distribution of freshwater communities capable of hosting amphibians at the Seashore (i.e., because it is a barrier island, much of the Seashore is saline) where amphibians were locally common but widely less common. The dispersion (i.e., the variance / mean) also suggests that those species are aggregated and do not occur randomly at the Seashore.

The species accumulation curve generated from the data asymptotes at approximately 21 samples (i.e., less than the total number of samples collected), validating the sample size as effective in characterizing amphibian diversity at the Seashore.

Estimates of amphibian species richness across indices are very consistent with one another (i.e., 6 – 8) with all richness indices closely approximating observed species richness (i.e., S_{obs}); suggesting adequate sampling effort. Species-diversity estimates are low ($\alpha=1.38$, $Q=1.11$) (Table 2), however, given the preponderance of saline communities (i.e., those not suitable as amphibian habitat) at the Seashore, these are expected and acceptable values. Although calculations suggest the sample was not dominated by one species (see E_{var} , $E_{1/D}$, E_G , D_{BP} ; Table 2), it was dominated by two species (*Hyla cinerea* and *Hyla squirrellea*). These species accounted for 74% of all individuals detected. Because 2010 monitoring efforts were the first for this vital sign, these values will serve as a baseline to which to compare when the Seashore is sampled again.

Table 2. Amphibian alpha-diversity estimates at CAHA, 2010.

Index	Symbol	Value	Lower 95% CI	Upper 95% CI	Value Interpretation
Native Spp. Richness	S_{obs}	6.00	4.69	7.31	Number of native species detected
Chao 1	Chao1	6.50	6.03	14.44	Estimated true species richness
Chao 2	Chao2	6.50	3.51	9.09	Estimated true species richness
Abundance-based Coverage	ACE	7.11	5.39	8.83	Estimated true species richness
Incidence-based Coverage	ICE	6.68	5.84	7.52	Estimated true species richness
Jackknife 1	Jack1	6.97	5.05	8.89	Estimated true species richness
Jackknife 2	Jack2	7.06	5.28	8.72	Estimated true species richness
Bootstrap	Boot	6.49	6.08	6.90	Estimated true species richness
Fisher's α	α	1.38	0.81	1.95	Baseline value, suggests low diversity
Q Statistic	Q	1.11	0.95	1.25	Baseline value, suggests low diversity
Smith and Wilson	E_{var}	0.30	0.25	0.72	Species occur in a variety of relative abundances – medium evenness (high CI)
Smith and Wilson 1/D	E_{1/D}	0.54	0.47	0.74	Species occur in a few different relative abundances – medium evenness (high CI)
Camargo	E'	NA			Poor index performance given dataset
Gini	E_G	0.48	0.39	0.58	Species occur in a variety of relative abundances – medium evenness
Berger-Parker	D_{BP}	0.45	0.37	0.55	Sample is not dominated by a single species

Composition

Amphibians

We detected 106 amphibians in six species. Approximately 45% of the sample was composed of squirrel treefrog, followed by green treefrog and southern leopard frog at 28% and 16%, respectively (Figure 3). Naïve occupancy rates for amphibians detected during 2010 sampling effort are presented in Table 3. Occupancy provides insight into the distribution of species across the park and whether a species is commonly or uncommonly encountered; however, this is strongly influenced by a species' detectability (which will be accounted for in future analyses) as more-easily detected species may be more frequently encountered (and vice versa). Green treefrog and squirrel treefrog were the most frequently encountered species (0.50), followed by southern leopard frog (0.30) and Fowler's toad (0.27; Table 3). Eastern narrow-mouthed toad (*Gastrophryne carolinensis*) and bullfrog (*Rana catesbeiana*) were the least frequently encountered species (Table 3). No non-native species were detected.

Reptiles

We detected 39 reptiles and reptile signs in 15 species, genera, or order. The majority of the sample was composed of six-lined racerunner (*Cnemidophorus sexlineatus*). All other species composed a much lower proportion of the sample (Figure 4). Naïve occupancy rates for reptiles detected during 2009 sampling effort are presented in Table 4. Six-lined racerunner was the most frequently encountered species, while the other species detected only occurred in one or two sampling locations. No non-native species were detected.

CAHA - Amphibians, 2010

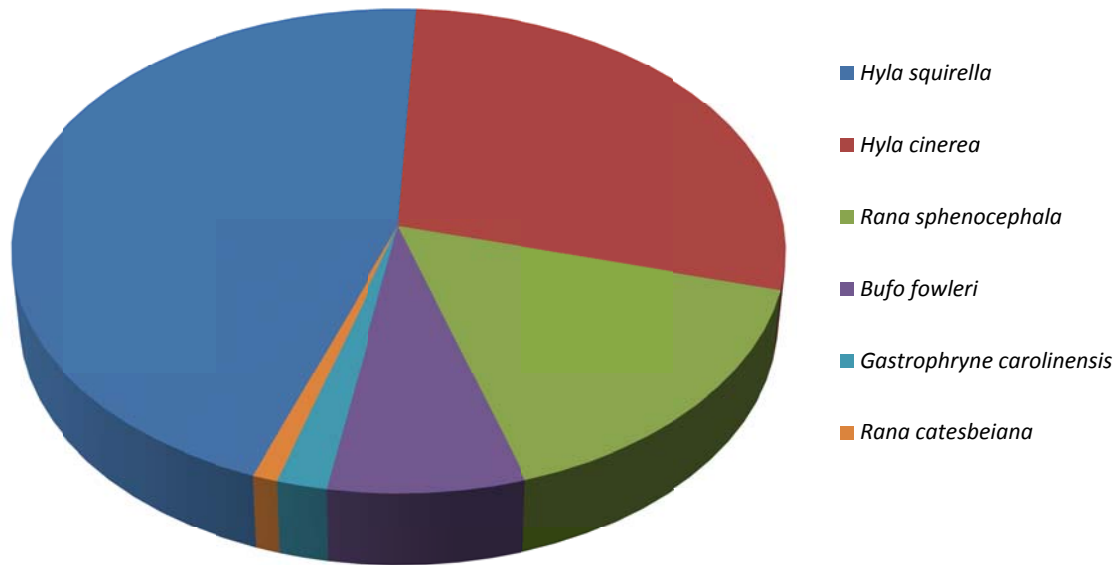


Figure 3. Proportions of amphibian species at CAHA, 2010.

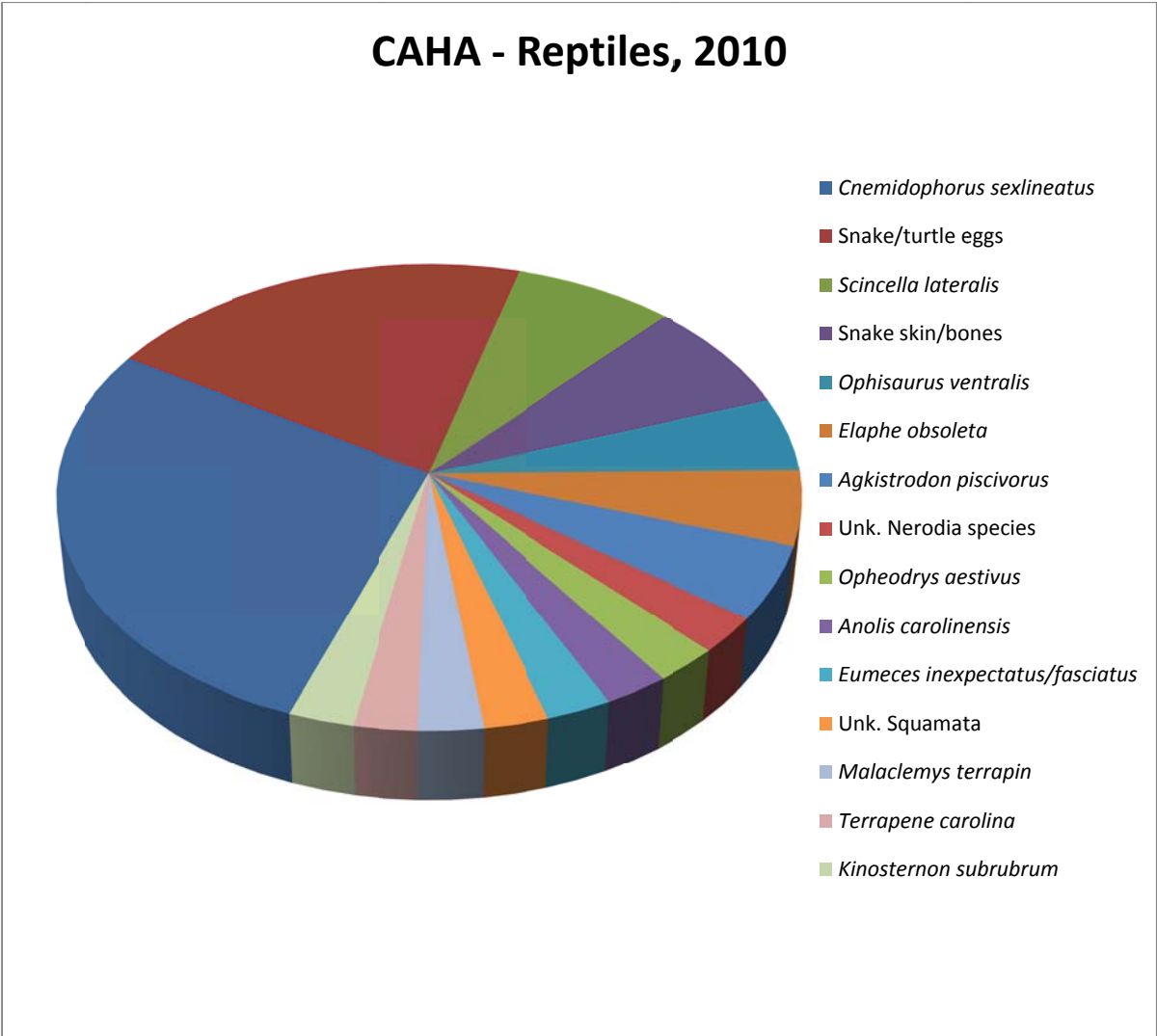


Figure 4. Proportion of reptile species and reptile signs at CAHA, 2010.

Table 2. Naïve occupancy estimates (proportion of sites where the species was detected) for amphibians at CAHA, 2010.

Scientific Name	Common Name	Frequency of Occurrence
<i>Hyla cinerea</i>	Green treefrog	0.50
<i>Hyla squirella</i>	Squirrel treefrog	0.50
<i>Rana sphenoccephala</i>	Southern leopard frog	0.30
<i>Bufo fowleri</i>	Fowler's toad	0.27
<i>Gastrophryne carolinensis</i>	Eastern narrow-mouthed toad	0.07
<i>Rana catesbeiana</i>	Bullfrog	0.03

Table 3. Naïve occupancy estimates (proportion of sites where the species was detected) for reptiles and reptile sign at CAHA, 2010.

Scientific Name	Common Name	Frequency of Occurrence
<i>Cnemidophorus sexlineatus</i>	Six-lined racerunner	0.20
<i>Elaphe obsoleta</i>	Common rat snake	0.07
<i>Scincella lateralis</i>	Ground skink	0.07
<i>Agkistrodon piscivorus</i>	Cottonmouth	0.07
Snake skin/bones		0.07
<i>Ophisaurus ventralis</i>	Eastern glass lizard	0.03
Unk. <i>Nerodia</i> species		0.03
<i>Opheodryx aestivus</i>	Rough green snake	0.03
<i>Anolis carolinensis</i>	Green anole	0.03
<i>Eumeces inexpectatus/fasciatus</i>	Five-lined skink	0.03
Unk. Squamata		0.03
Snake/turtle eggs		0.03
<i>Malaclemys terrapin</i>	Diamondback terrapin	0.03
<i>Terrapene carolina</i>	Eastern box turtle	0.03
<i>Kinosternon subrubrum</i>	Common mud turtle	0.03

Distribution

Amphibians

Green treefrog (Figure 5a, Figure 5b) and squirrel treefrog (Figure 6a, Figure 6b) were the most widely distributed species at the Seashore, followed by southern leopard frog (*Rana sphenoccephala*; Figure 7a, Figure 7b) and Fowler's toad (*Bufo fowleri*; Figure 8a, Figure 8b). All of these species occurred on all islands, except the southern leopard frog was not detected on Ocracoke Island.

Reptiles

The six-lined racerunner was the most widely distributed species (Figure 11a, Figure 11b). All other reptiles detected occurred at only a few locations.

Distribution Maps



Figure 5a. Sampling locations where green treefrog (*Hyla cinerea*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 5b. Sampling locations where green treefrog (*Hyla cinerea*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 6a. Sampling locations where squirrel treefrog (*Hyla squirella*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 6b. Sampling locations where squirrel treefrog (*Hyla squirella*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 7a. Sampling locations where southern leopard frog (*Rana sphenocephala*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 7b. Sampling locations where southern leopard frog (*Rana sphenocephala*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 8a. Sampling locations where Fowler's toad (*Bufo fowleri*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.

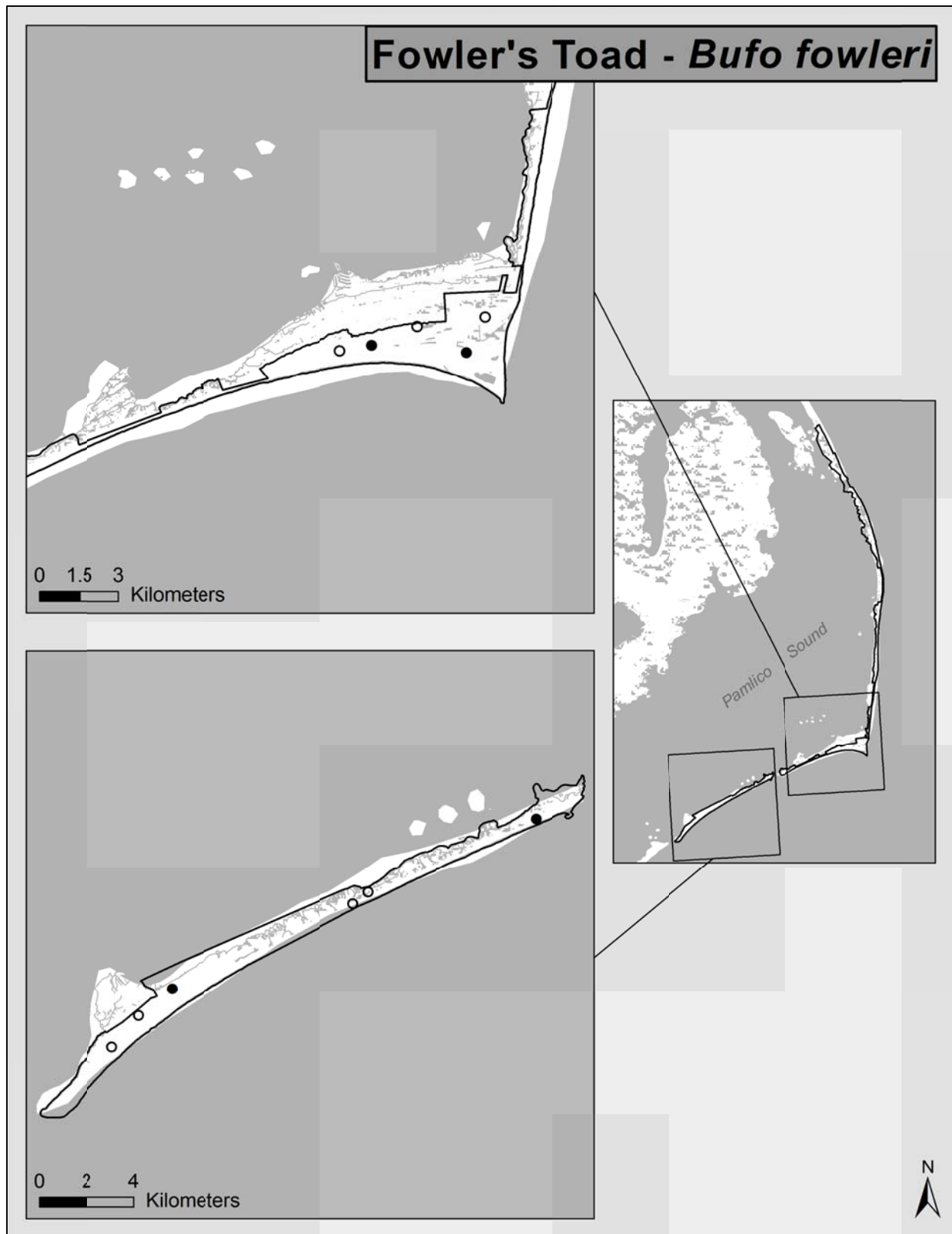


Figure 8b. Sampling locations where Fowler's toad (*Bufo fowleri*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 9a. Sampling locations where eastern narrow-mouthed toad (*Gastrophryne carolinensis*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.

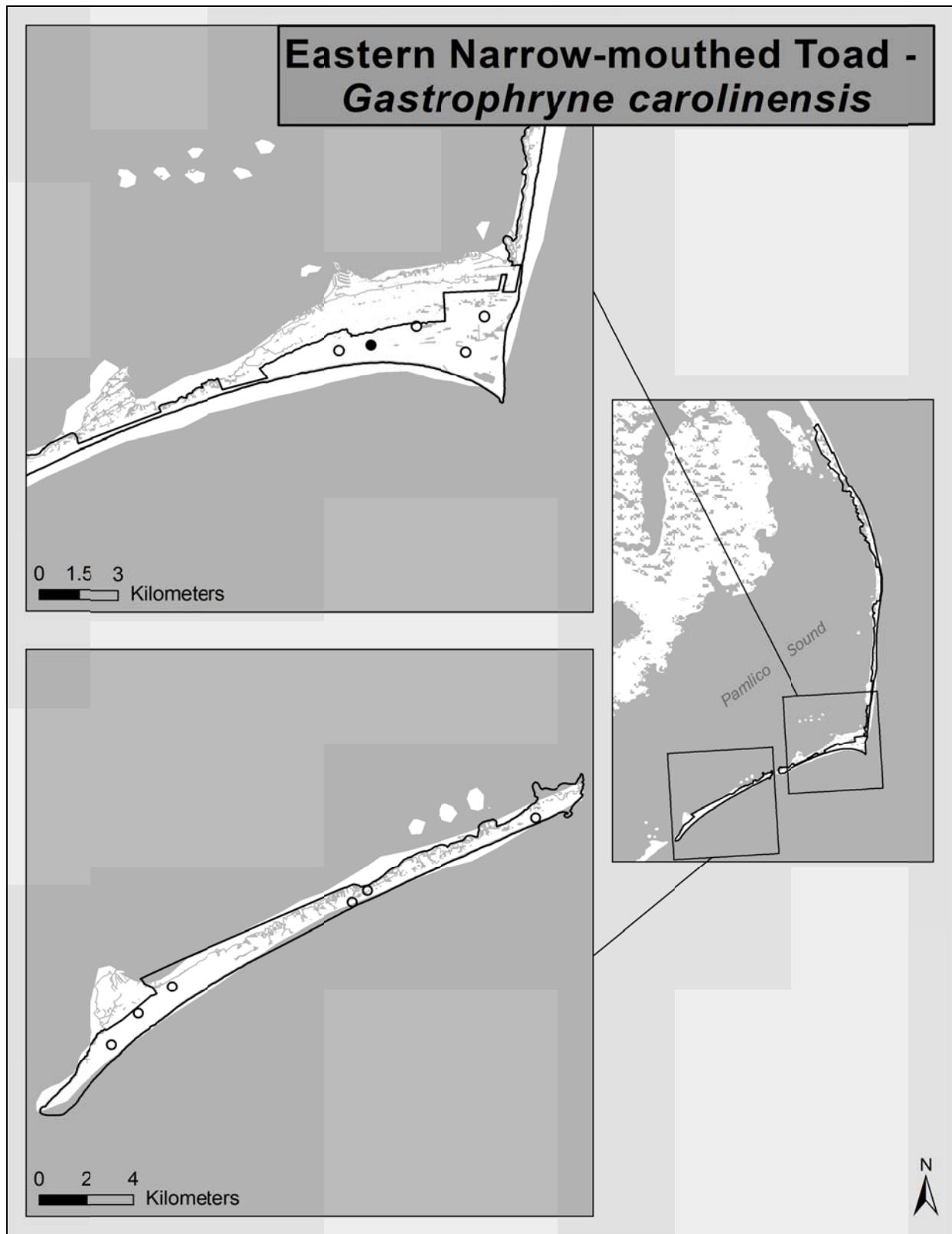


Figure 9b. Sampling locations where eastern narrow-mouthed toad (*Gastrophryne carolinensis*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 10a. Sampling locations where bullfrog (*Bufo catesbeiana*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 10b. Sampling locations where bullfrog (*Bufo catesbeiana*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 11a. Sampling locations where six-lined racerunner (*Cnemidophorus sexlineatus*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 11b. Sampling locations where six-lined racerunner (*Cnemidophorus sexlineatus*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 12a. Sampling locations where common rat snake (*Elaphe obsoleta*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 12b. Sampling locations where common rat snake (*Elaphe obsoleta*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 13a. Sampling locations where ground skink (*Scincella lateralis*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 13b. Sampling locations where ground skink (*Scincella lateralis*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 14a. Sampling locations where cottonmouth (*Agkistrodon piscivorus*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.

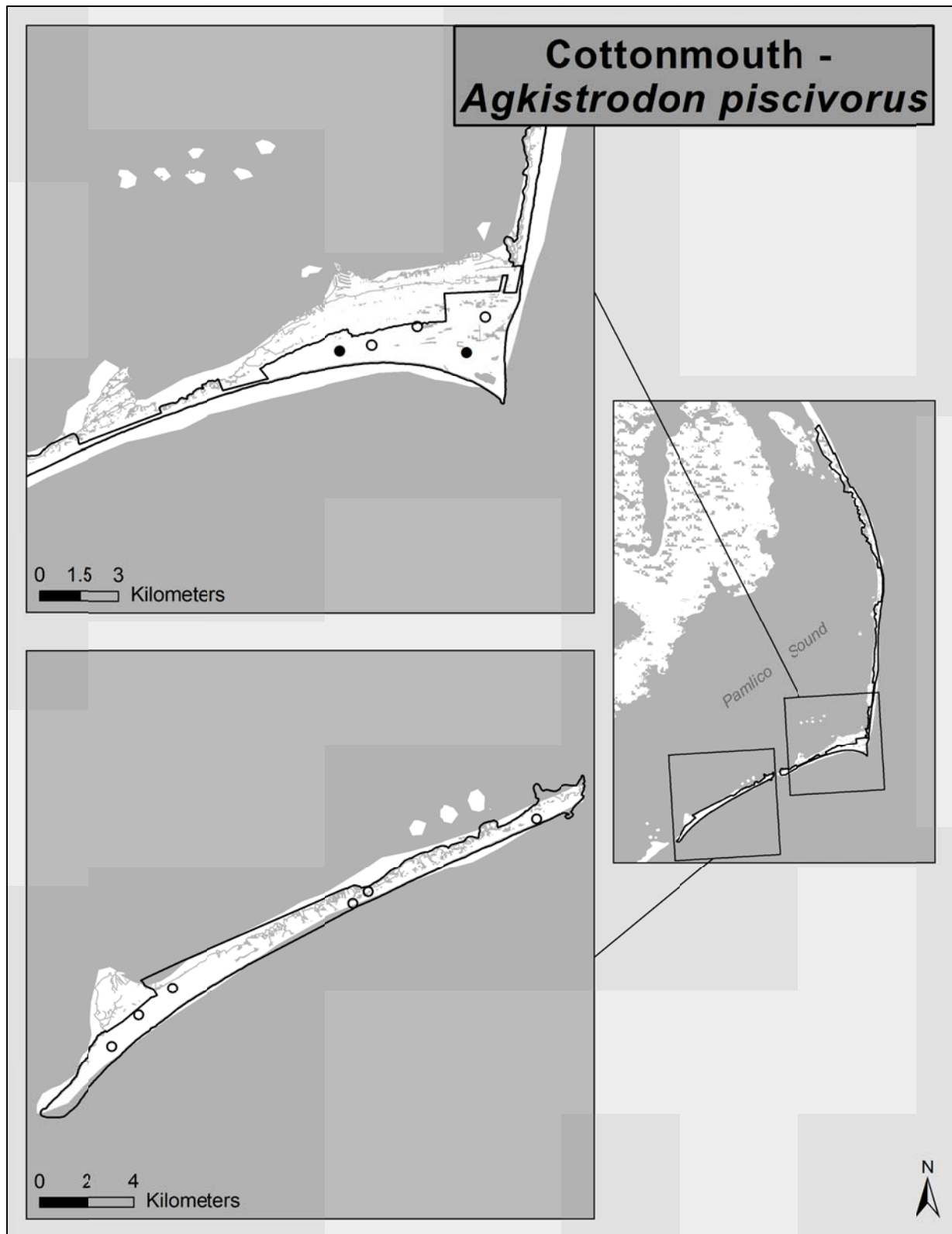


Figure 14b. Sampling locations where cottonmouth (*Agkistrodon piscivorus*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 15a. Sampling locations where eastern glass lizard (*Ophisaurus ventralis*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 15b. Sampling locations where eastern glass lizard (*Ophisaurus ventralis*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 16a. Sampling locations where rough green snake (*Opheodrys aestivus*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 16b. Sampling locations where rough green snake (*Opheodrys aestivus*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 17a. Sampling locations where green anole (*Anolis carolinensis*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 17b. Sampling locations where green anole (*Anolis carolinensis*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 18a. Sampling locations where five-lined skink (*Eumeces fasciatus/inexpectatus*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 18b. Sampling locations where five-lined skink (*Eumeces fasciatus/inexpectatus*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 19a. Sampling locations where diamondback terrapin (*Malaclemys terrapin*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 19b. Sampling locations where diamondback terrapin (*Malaclemys terrapin*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 20a. Sampling locations where eastern box turtle (*Terrapene carolina*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.

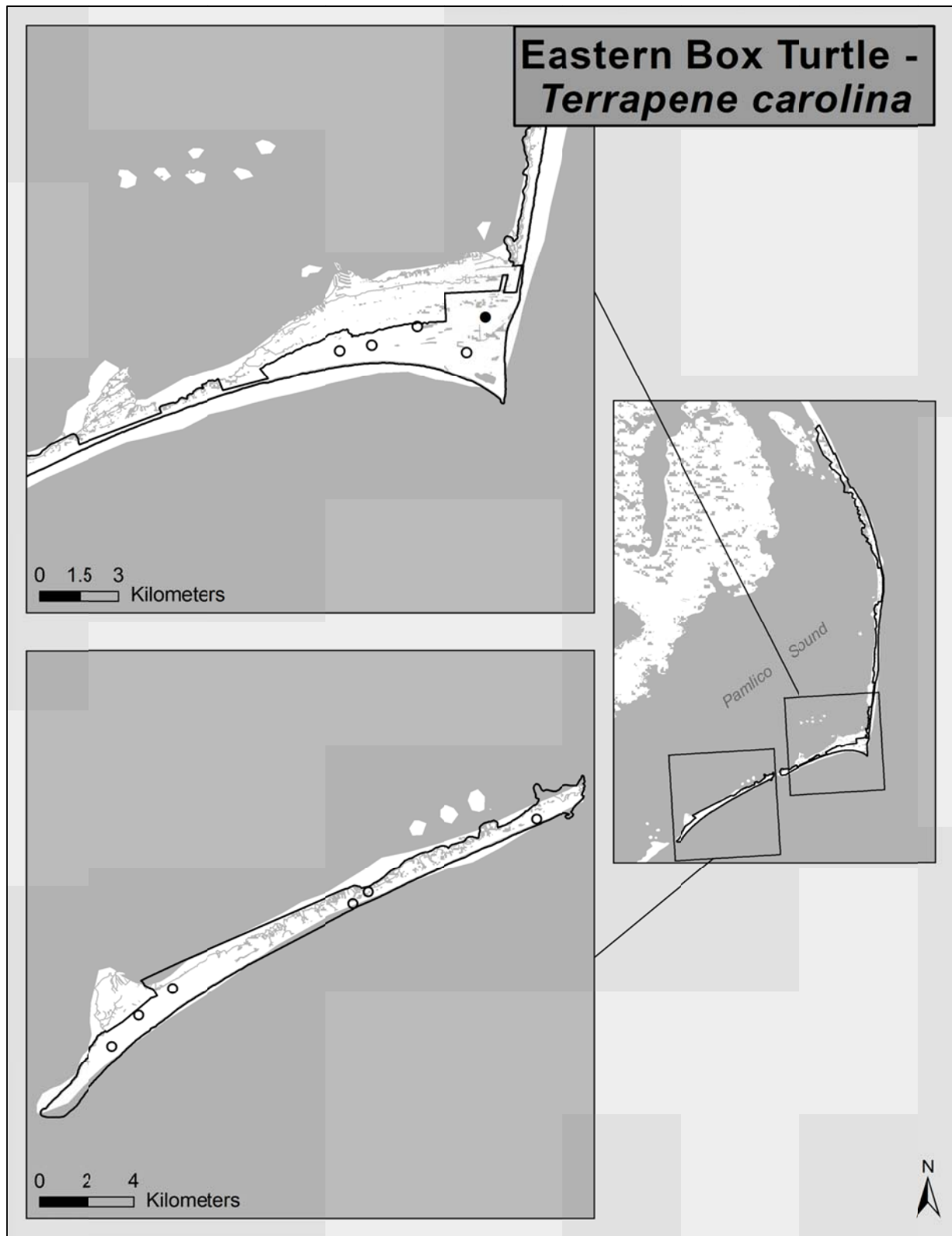


Figure 20b. Sampling locations where eastern box turtle (*Terrapene carolina*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 21a. Sampling locations where common mud turtle (*Kinosternon subrubrum*) was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 21b. Sampling locations where common mud turtle (*Kinosternon subrubrum*) was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 22a. Sampling locations where unknown *Nerodia* sp. was detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 22b. Sampling locations where unknown *Nerodia* sp. was detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 23a. Sampling locations where snake skin/bones were detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 23b. Sampling locations where snake skin/bones were detected at the southern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 24a. Sampling locations where snake/turtle eggs were detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.



Figure 24b. Sampling locations where snake/turtle eggs were detected at the northern end of CAHA, 2010. ● = detected, ○ = not detected.

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Appendix A. Amphibians and reptiles known to occur at CAHA.

Table A-1. Amphibians and reptiles known to occur at CAHA based upon records in NPSpecies (2011) or from current monitoring efforts presented herein.

Order	Family	Scientific Name	Common Name	NPSpecies	ARD	VES
Anura	Bufonidae	<i>Bufo fowleri</i>	Fowler's toad	X	X	
Anura	Hylidae	<i>Hyla chrysoscelis</i>	Cope's gray treefrog	X		
Anura	Hylidae	<i>Hyla cinerea</i>	Green treefrog	X	X	X
Anura	Hylidae	<i>Hyla squirella</i>	Squirrel treefrog	X	X	X
Anura	Hylidae	<i>Hyla versicolor</i>	Gray treefrog	X		
Anura	Hylidae	<i>Pseudacris ocularis</i>	Little grass frog	X		
Anura	Microhylidae	<i>Gastrophryne carolinensis</i>	Eastern narrow-mouthed toad	X	X	
Anura	Ranidae	<i>Rana catesbeiana</i>	Bullfrog	X	X	
Anura	Ranidae	<i>Rana sphenoccephala</i>	Southern leopard frog	X	X	X
Caudata	Amphiumidae	<i>Amphiuma means</i>	Two-toed amphiuma	X		
Caudata	Plethodontidae	<i>Plethodon chlorobryonis</i>	Atlantic coast slimy salamander	X		
Caudata	Plethodontidae	<i>Plethodon cinereus</i>	Eastern red-backed salamander	X		
Squamata	Anguidae	<i>Ophisaurus ventralis</i>	Eastern glass lizard	X		X
Squamata	Colubridae	<i>Coluber constrictor</i>	Racer	X		
Squamata	Colubridae	<i>Diadophis punctatus</i>	Ring-necked snake	X		
Squamata	Colubridae	<i>Elaphe guttata</i>	Corn snake, red rat snake	X		
Squamata	Colubridae	<i>Elaphe obsoleta</i>	Common rat snake	X		X
Squamata	Colubridae	<i>Heterodon platirhinos</i>	Eastern hog-nosed snake	X		
Squamata	Colubridae	<i>Lampropeltis getula</i>	Common kingsnake	X		
Squamata	Colubridae	<i>Lampropeltis getula sticticeps</i>	Outer banks kingsnake	X		
Squamata	Colubridae	<i>Nerodia fasciata</i>	Southern water snake	X		
Squamata	Colubridae	<i>Nerodia sipedon</i>	Northern water snake	X		
Squamata	Colubridae	<i>Nerodia sipedon williamengelsi</i>	Carolina water snake	X		
Squamata	Colubridae	<i>Nerodia taxispilota</i>	Brown water snake	X		
Squamata	Colubridae	<i>Opheodrys aestivus</i>	Rough green snake	X		X
Squamata	Colubridae	<i>Storeria dekayi</i>	Dekay's brown snake	X		
Squamata	Colubridae	<i>Thamnophis sauritus</i>	Eastern ribbon snake	X		

Table A-1. (Continued).

Order	Family	Scientific Name	Common Name	NPSpecies	ARD	VES
Squamata	Colubridae	Thamnophis sauritus sauritus	Eastern ribbon snake	X		
Squamata	Polychrotidae	Anolis carolinensis	Green anole	X		X
Squamata	Scincidae	Eumeces inexpectatus	Southeastern five-lined skink	X		X
Squamata	Scincidae	Scincella lateralis	Ground skink	X		X
Squamata	Teiidae	Cnemidophorus sexlineatus	Six-lined racerunner	X		X
Squamata	Teiidae	Cnemidophorus sexlineatus sexlineatus	Eastern six-lined sacerunner	X		
Squamata	Viperidae	Agkistrodon piscivorus	Cottonmouth	X		X
Squamata	Viperidae	Crotalus horridus	Timber rattlesnake	X		
Testudines	Cheloniidae	Caretta caretta	Loggerhead sea turtle	X		
Testudines	Cheloniidae	Chelonia mydas	Green sea turtle	X		
Testudines	Cheloniidae	Eretmochelys imbricata	Hawksbill sea turtle	X		
Testudines	Cheloniidae	Lepidochelys kempii	Kemp's Ridley sea turtle	X		
Testudines	Chelydridae	Chelydra serpentina	Common snapping turtle	X		
Testudines	Dermochelyidae	Dermochelys coriacea	Leatherback sea turtle	X		
Testudines	Emydidae	Clemmys guttata	Spotted turtle	X		
Testudines	Emydidae	Malaclemys terrapin	Diamondback terrapin	X		X
Testudines	Emydidae	Pseudemys rubriventris	American red-bellied turtle	X		
Testudines	Emydidae	Terrapene carolina	Eastern box turtle	X		X
Testudines	Emydidae	Trachemys scripta	Common slider	X		
Testudines	Emydidae	Trachemys scripta elegans	Red-eared slider	X		
Testudines	Kinosternidae	Kinosternon subrubrum	Common mud turtle	X		X

Appendix B. Map of sampling locations with point labels.

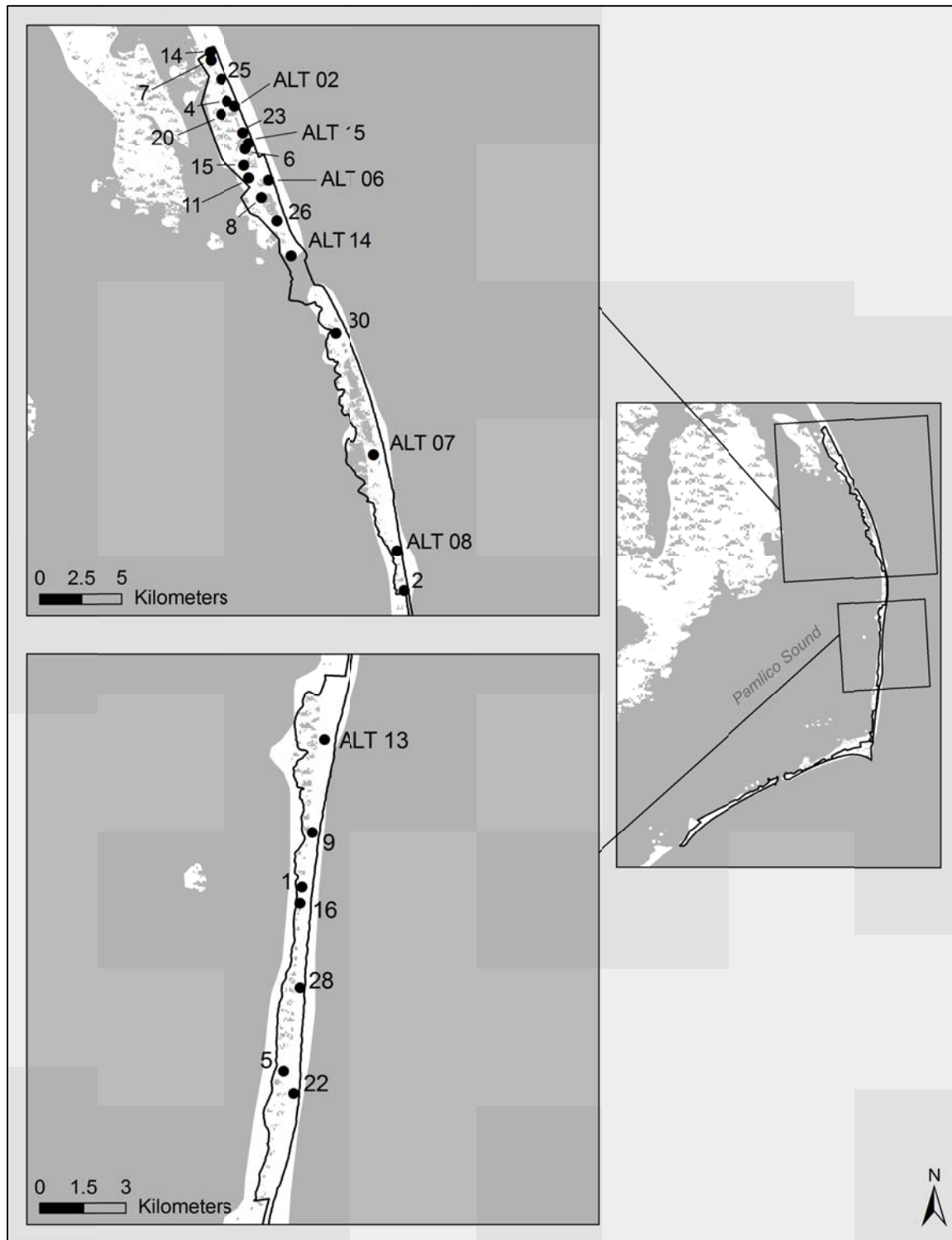


Figure B-1a. Spatially-balanced random sampling locations at the northern end of CAHA with labels, 2010.

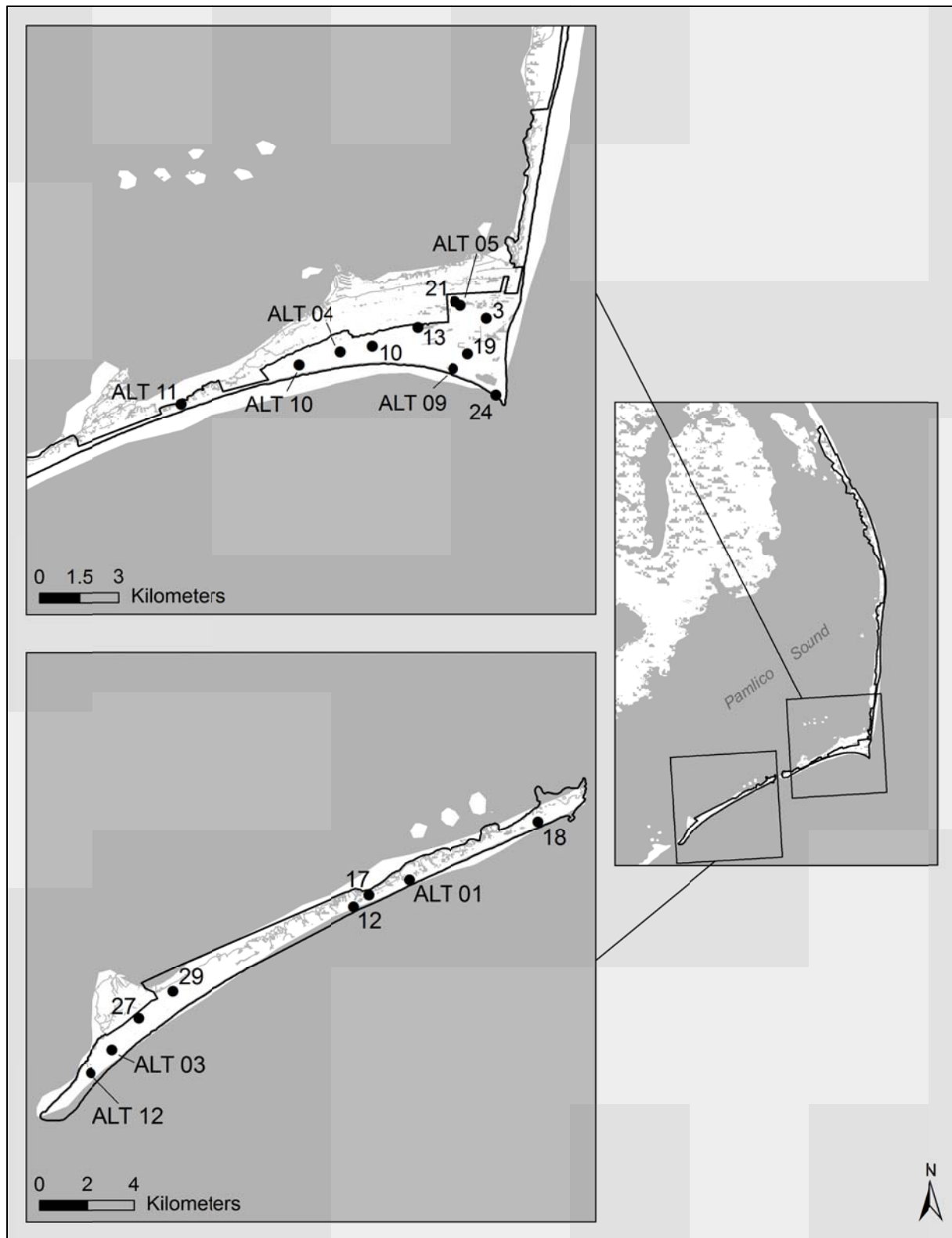


Figure B-1b. Spatially-balanced random sampling locations at the southern end of CAHA with labels, 2010.

Appendix C. Species detections by sampling location.

Table C-1. Species or species sign detected at each sampling location at CAHA, 2010. Refer to Appendix B for labeled sampling-locations. Gray-shaded cells indicate that visual-encounter surveys were not conducted at these locations, while patterned cells indicate ARDs were not conducted at these locations.

Scientific Name	Sampling Location																															
	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	17	18	19	20	22	23	25	26	27	28	29	30	A2	A3	A4		
<i>Bufo fowleri</i>							X		X	X							X	X			X		X			X						
<i>Gastrophryne carolinensis</i>						X			X																							
<i>Hyla cinerea</i>			X	X		X	X		X	X	X	X		X	X		X	X	X			X	X									
<i>Hyla squirella</i>	X		X	X	X		X		X	X	X	X					X	X					X	X				X		X		
<i>Rana catesbeiana</i>																		X														
<i>Rana sphenoccephala</i>			X	X		X			X			X						X	X		X		X									
<i>Opphisaurus ventralis</i>								X																								
<i>Elaphe obsoleta</i>														X				X														
Unk. <i>Nerodia</i> species																			X													
<i>Opheodrys aestivus</i>															X																	
<i>Anolis carolinensis</i>			X																													
<i>Eumeces inexpectatus/fasciatus</i>												X																				
<i>Scincella lateralis</i>			X				X																									
<i>Cnemidophorus sexlineatus</i>		X								X	X				X										X					X		
<i>Agkistrodon piscivorus</i>																		X												X		
Unk. Squamata												X																				
<i>Malaclemys terrapin</i>																	X															
<i>Terrapene carolina</i>			X																													
<i>Kinosternon subrubrum</i>																									X							
Snake skin/bones			X																				X									
Snake/turtle eggs																														X		