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Measuring species diversity to determine land-use effects on reptile and amphibian assemblages

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Abstract. Populations of herpetofauna are declining globally primarily due to land-use practices (e.g., silviculture or conversion to agriculture) and declines require monitoring of all herpetofauna communities. Therefore, forest management plans for Bull Neck Swamp, a pocosin wetland in North Carolina, USA, initiated an inventory of the herpetofauna community. Our objectives were to: (1) derive diversity measures for four designated habitat preserves (i.e., Atlantic white-cedar [*Chamaecyparis thyoides*], Pond pine [*Pinus serotina*], Non-riverine Swamp, and Shoreline/Islands) and a Forest manageable area, (2) determine if there were benefits to habitat preserves for the herpetofauna community, and (3) provide recommendations for future monitoring. We employed 11 different sampling techniques across the four habitat preserves and Forest manageable area. Species richness estimates and similarity indices were derived using EstimateS 8.0. For post hoc comparisons, we derived species distributions with the Nestedness Temperature Calculator Program. Observed species richness ranged from 7 to 32 species ($S = 13$ to 44) and abundances ranged from 99 to 873 individuals. Similarity indices suggested species compositions were similar among habitats. Further, nestedness temperature ($T = 12.6°C$) indicated an even species distribution among assemblages. Comparable similarity indices among habitats, an even species distribution, and habitat continuity suggested management practices would have little impact on the herpetofauna community. Nevertheless, future management practices should be carefully considered and planned to mitigate effects to individual species. We recommend studies employ species richness, relative abundance, species composition, and distribution as conservation tools when inventorying or monitoring herpetofauna communities.

Keywords: amphibians, conservation, forest management, nestedness, relative abundance, reptiles, species composition, species richness.

Introduction

Reptile and amphibian populations are declining worldwide (Pechman et al., 1991; Wake, 1991; Heyer et al., 1994; Gibbons et al., 2000) with more species at risk than either birds or mammals (IUCN, 2006; Gardner, Barlow and Peres, 2007a). Reptiles and amphibians hold vital positions in forest and aquatic food webs, are important for nutrient cycling (Burton and Likens, 1975; Pais, Bonney and McComb, 1988; Hanlin et al., 2000), are indicators of ecosystem health (Bury and Corn, 1988; Wake, 1991; Dunson, Wyman and Corbett, 1992; Gibbons et al., 2000; Hanlin et al., 2000), and compose an important portion of the vertebrate biomass (e.g., over 18,000 individuals/ha of terrestrial salamanders in the southern Appalachians [Petranka and Murray, 2001]) (Burton and Likens, 1975; Pais, Bonney and McComb, 1988).

Declines of reptile and amphibian species have been attributed to normal population fluctuations (Wake, 1991), climate change, pollution, disease, and acidification (Gardner, Barlow and Peres, 2007a). However, conversion to agriculture, habitat fragmentation, logging, mining, and urbanization are major contributors to land-use change and are largely accepted as the primary cause of large-scale biodiversity loss (Pechman et al., 1991; Wake, 1991; Gardner, Barlow and Peres, 2007a; Gardner et al., 2007b). Forestry practices (i.e., prescribed burning, clear-cutting, and pre-commercial thinning) at Bull Neck Swamp, a pocosin wetland in eastern North Carolina, required we quantify silvicultural and site preparation effects on the reptile and amphibian community.

In light of recent declines, more studies are attempting to quantify reptile and amphibian

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species diversity by measuring species richness or species evenness (Gardner, Barlow and Peres, 2007a; Gardner et al., 2007b). Species richness is a measure of the number of species detected within an area, whereas species evenness is a frequency of the individuals detected per species (Purvis and Hector, 2000; Ma, 2005; Bock, Jones and Bock, 2007). Also, due to the positive relationship of species richness to measures of abundance, such as biomass, many studies include information on species relative abundance (Ma, 2005; Bock, Jones and Bock, 2007). However, diversity is multidimensional and cannot be represented by a single number (Purvis and Hector, 2000). Nonetheless, comparable measures of diversity from different locations can elucidate the best methods for conservation (Margules and Pressey, 2000; Purvis and Hector, 2000).

In this study, we used species diversity, defined as measures of species richness and relative abundance of reptile and amphibian assemblages within four habitat preserves and a Forest manageable area, to: (1) calculate community variables for habitat preserves and the Forest manageable area, (2) determine whether habitat preserves provided refuge to reptiles and amphibians by harboring species from the effects of timber harvest or other land-use practices, and (3) provide recommendations for future monitoring and management practices at Bull Neck Swamp with implications for the conservation of the reptile and amphibian community.

Materials and methods

Study area

We conducted this study at Bull Neck Swamp (BNS; 35.96667°N, 076.41667°W; fig. 1), a 2,491 ha pocosin wetland in Washington County, North Carolina. The wetland was a small peninsula, created by the Roanoke River delta and Albemarle Sound, containing five recognized habitats. The Natural Heritage Trust Fund established four habitat preserves (937 ha) safe from future land management practices. The four designated habitats included Atlantic white-cedar (*Chamaecyparis thyoides*), Pond pine (*Pinus serotina*), Non-riverine swamp, and Shoreline/Islands preserves. Although the original designations were based on plant community, all of these habitats were contiguous and shared many of the same tree species, such as red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), red bay (*Persea borbonia*), sweet bay (*Magnolia virginiana*), and wax-myrtle (*Myrica cerifera*). Three dry ridges ran west to east and allowed oaks (*Quercus* spp.) and American beech (*Fagus grandifolia*) to flourish. The Forest manageable area, those hectares not designated as a preserve (1,554 ha), was available for land-use practices, including clear-cutting, pre-commercial thinning, and forestry site preparation applications (i.e., prescribed burning). Bottomland forests and hardwood swamps with patchy cultivated areas comprised the southern border of the property.

Sampling techniques

To determine reptile and amphibian species richness, 11 different sampling techniques were used throughout BNS. Techniques employed included drift fence arrays with pitfall and funnel traps ($n = 10$); visual encounter surveys ($n = 25$); coverboard arrays ($n = 5$); standardized road searches; polyvinyl chloride (PVC) piping grids ($n = 6$); line transects; auditory surveys; opportunistic encounters; and aquatic funnel ($n = 6$), crayfish ($n = 2$), and basking traps ($n = 1$). We constructed two drift fence arrays with pitfall and funnel traps in each of the five habitats at BNS. We checked drift fences every morning during late-May to mid-June and August, 2005 and 2006. During June, 2005 and July, 2006, we established five-100 m^2 visual encounter survey plots in each habitat in a systematic random distribution. We surveyed each plot twice, in the mornings, for 30 minutes with at least two observers. Coverboard arrays, comprised of nine-128 $\times$ 128 cm sheets of 0.6 cm plywood in a diamond formation, sampled only the Forest manageable area. (Inundated conditions in the other habitats precluded coverboard use.) We checked randomly placed coverboard arrays once every week from June to August, 2006.

To survey reptile and amphibian activity after dusk, we conducted 12 2-km long road searches on each of four roads at BNS from May to June, 2005 and May to August, 2006. We standardized road searches to road length, time-of-day, and speed. To better sample hylid frogs, we randomly established one PVC grid in each habitat that we checked once per week from May to August, 2006. Grids consisted of 12-3.75 cm pipes driven 5 cm into the ground and spaced two meters in 4-pipe $\times$ 3-pipe arrangements. We established a 0.8 km line transect on each of four roads not used by standardized road searches or opportunistic encounters. We walked each transect twice, between 0900 and 1100 and between 1300 and 1500 during July and August, 2006. To better sample anurans, we conducted two auditory surveys between 2100 and 2300 at a single, randomly distributed location within each of the five habitats. Opportunistic encounter described the capture of reptiles and amphibians at any time in the study area from May to August, 2005 and 2006. Aquatic funnel traps (essentially funnel traps manufactured for drift fence arrays), crayfish traps, and the basking trap were randomly distributed in the canals bordering the five habitats. We redistributed these traps every week.

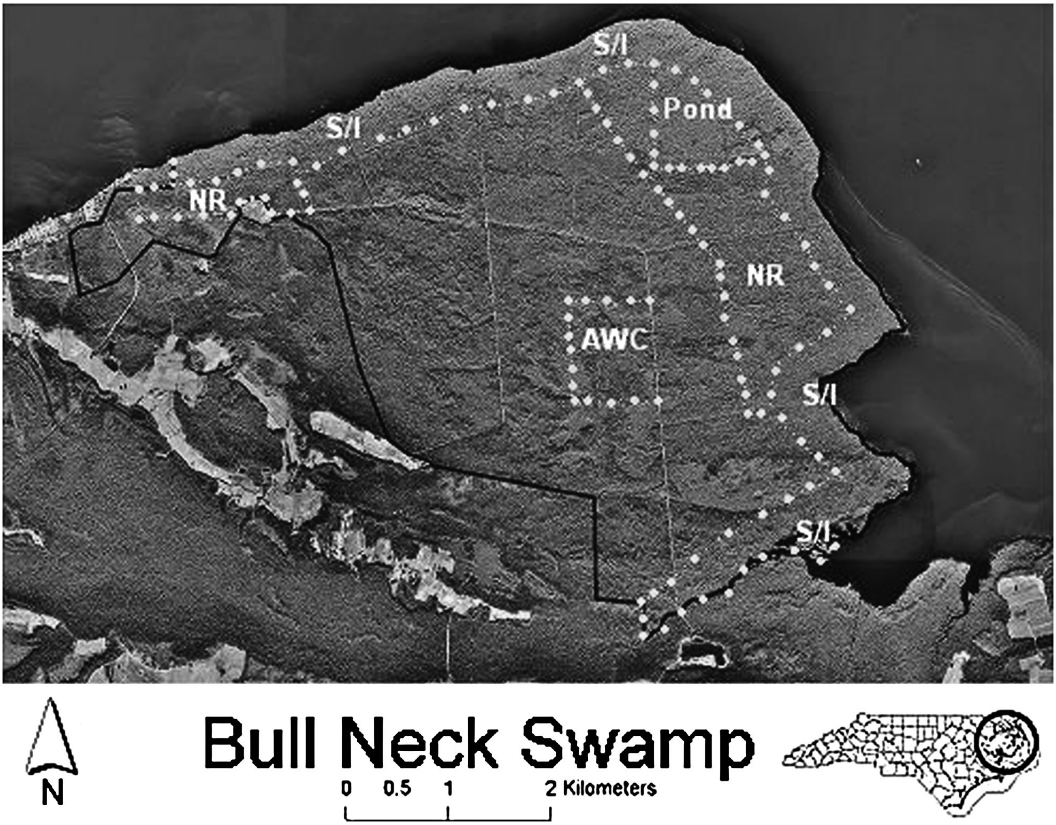

Figure 1. Infrared photograph of Bull Neck Swamp, Washington County, North Carolina (35.96667°N, 076.41667°W) taken in 1996. Outlined in dashes are the four habitat preserves abbreviated as NR – Non-riverine swamp, AWC – Atlantic white-cedar (*Chamaecyparis thyoides*), Pond – Pond pine (*Pinus serotina*), and S/I – Shoreline/Islands.

Analyses

We calculated classic Chao2 estimates of species richness for each habitat and the entire study area using EstimateS 8.0 (Colwell, 2005). To derive variables for each habitat, we pooled detection data from all sampling techniques within a habitat. Also, to compare species compositions among habitat preserves and the Forest manageable area, we derived Chao-Jaccard Similarity Indexes (JSI) using EstimateS 8.0. We calculated estimates for species richness and JSI using 500 randomizations, with replacement, from X-matrices of initial detection data, which excluded recaptures. To discern differences in species detection between 2005 and 2006, we compared estimates of total species richness between years using a two-tailed t-test with a null hypothesis of equal mean species richness.

We compared species richness among preserves and the Forest manageable area using observed (S_{obs}) and estimated species richness (S) and determined relative abundances as detection data for each species within preserves and the Forest manageable area. To allow for differences in area among preserves and the Forest manageable area, we standardized species richness values by 75 ha, which was the smallest preserved area. Additionally, we calculated nestedness temperature, a ratio of distribution order where higher temperatures represent greater disorder in distribution, using the Nestedness Temperature Calculator Program (Atmar and Patterson, 1995). We ordered presence/absence data from each habitat by descending species richness (i.e., Forest manageable area first) in X-matirx format to calculate our nestedness matrix. Although we incorporated marking techniques, such as passive integrated transponder (PIT) tags for most reptiles and visible implant fluorescent elastomer for amphibians and as a double-mark for snakes (Hutchens et al., 2008), all analyses were performed using initial capture data.

Results

During May to August, 2005 and 2006, we detected 1,496 individuals representing 33 observed species (S_{obs}; table 1). We did not detect a significant difference in species richness estimates between years ($P = 0.094$, $t_{90} = 1.69$). Therefore, pooled detection data from both

Table 1. Relative abundances within habitat preserves and the Forest manageable area for observed species (S_{obs}) at Bull Neck Swamp, Washington County, North Carolina from May to August, 2005 and 2006. Habitat preserves and the Forest manageable area were abbreviated as AWC – Atlantic white-cedar, Pond – Pond pine, NR – Non-riverine swamp, S/I – Shoreline/Islands, Fman – Forest manageable.

Common Name	Scientific Name	AWC	Pond	NR	S/I	Fman	Total Individuals
Green Frog	*Rana clamitans*	55	105	227	74	521	982
Southern Cricket Frog	*Acris gryllus*	16	6	26	10	38	96
Plain-bellied Watersnake	*Nerodia erythrogaster*	1	1	1	3	6	12
Green Treefrog	*Hyla cinerea*	2	1	5	2	3	13
Southern Leopard Frog	*Rana sphenocephala*	0	1	3	32	46	82
Southern Watersnake	*Nerodia fasciata*	11	0	1	0	14	26
Yellow-bellied slider	*Trachemys scripta*	1	0	1	0	20	22
Southern Toad	*Bufo terrestris*	2	0	0	5	96	103
Common Kingsnake	*Lampropeltis getula*	3	0	1	0	17	21
Eastern Racer	*Coluber constrictor*	0	0	1	3	6	10
American Bullfrog	*Rana catesbeiana*	3	2	0	0	9	14
Spotted Turtle	*Clemmys guttata*	0	0	3	1	2	6
Snapping Turtle	*Chelydra serpentina*	4	0	0	0	9	13
Eastern Ratsnake	*Elaphe obsolete*	0	0	3	0	6	9
Eastern Ribbonsnake	*Thamnophis sauritus*	0	0	1	0	2	3
Cottonmouth	*Agkistrodon piscivorus*	1	0	0	0	19	20
Striped Mud Turtle	*Kinosternon baurii*	0	0	1	0	3	4
Eastern Box Turtle	*Terrapene carolina*	0	0	1	0	3	4
Pine Woods Treefrog	*Hyla femoralis*	0	2	0	0	4	6
Rough Greensnake	*Opheodrys aestivus*	0	0	0	0	2	2
Coastal Plain Cooter	*Pseudemys concinna floridana*	0	0	0	0	3	3
Two-toed Amphiuma	*Amphiuma means*	0	0	0	0	6	6
Ground Skink	*Scincella lateralis*	0	0	0	0	7	7
Atlantic Coast Slimy Salamander	*Plethodon chlorobryonis*	0	0	0	0	5	5
Eastern Mud Trutle	*Kinosternon subrubum*	0	0	0	0	1	1
Painted Turtle	*Chrysemys picta*	0	0	0	0	7	7
Stinkpot Turtle	*Sternotherus odoratus*	0	0	0	0	6	6
Dekay's Brownsnake	*Storeria dekayi*	0	0	0	1	0	1
Gray Treefrog	*Hyla versicolor*	0	0	0	0	4	4
Rainbow Snake	*Farancia erytrogramma*	0	0	0	0	1	1
River Cooter	*Pseudemys concinna*	0	0	0	0	1	1
Southeastern Five-lined Skink	*Eumeces inexpectatus*	0	0	0	0	5	5
Green Anole	*Anolis carolinensis*	0	0	0	0	1	1

years yielded a total estimate of 34 reptile and amphibian species at BNS (table 2). Observed species richness values among habitat preserves and Forest manageable area ranged from 7 to 32 species and estimated richness ranged from 13 to 44 species (table 2, fig. 2a). Relative abundances within habitats ranged from 1 to 521 individuals, dominated by Green Frogs (*Rana clamitans* [$n = 982$]; table 1). More captures occurred in the Forest manageable area (fig. 2b), with the remaining captures of common species distributed among the preserves. Interestingly, most species ($n = 21$) were represented by $\leqslant 10$ individuals (table 1).

Of the total species recorded, we detected 19 species in at least two habitats, with four species (Green Frog [*Rana clamitans*], Southern Cricket Frog [*Acris gryllus*], Plain-bellied Watersnake [*Nerodia erythrogaster*], and Green Treefrog [*Hyla cinerea*]) detected in all four habitat preserves and the Forest manageable area (table 1); two of these four species (Plain-bellied Watersnake [*N. erythrogaster*] and Green Treefrog [*H. cinerea*]) were represented by 13 or fewer detections. Moreover, we sampled the second most abundant species (Southern Toad [*Bufo terrestris*]) in only three habitats (table 1). We detected the 14 remaining species in only

Table 2. Area, observed species richness (S_{obs}), estimated species richness (S), and initial captures for the four designated habitat preserves and Forest manageable area at Bull Neck Swamp, Washington County, North Carolina, May to August, 2005 and 2006.

Habitat Preserves	Hectares	S_{obs}	S	Initial Captures
Atlantic white-cedar	75	11	13	99
Pond pine	96	7	13	118
Non-riverine swamp	314	14	22	275
Shoreline/Islands	452	9	17	131
Forest manageable	1,554	32	44	873
Totals	2,491	33	34	1,496

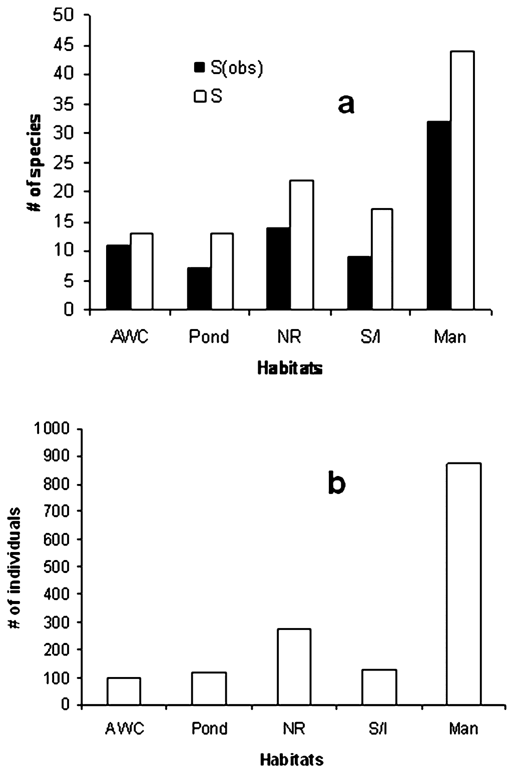

Figure 2. Observed (S_{obs}) and estimated (S) species richness (a) and total number of initial species detections (b) for each habitat preserve and the forest manageable area at Bull Neck Swamp. Habitats were arranged by increasing area and abbreviated as AWC – Atlantic white-cedar, Pond – Pond pine, NR – Non-riverine swamp, S/I – Shoreline/Islands, and Fman – Forest manageable.

the Forest manageable area with the exception of DeKay's Brownsnake (*Storeria dekayi*), which was captured in the Non-riverine swamp preserve (table 1). Standardizing observed and estimated species richness by the smallest preserved area (75 ha) did not reduce proportional differences in values among habitats (table 3).

Chao-Jaccard indices were similar among habitats, with 90% of indices greater than 0.75 (table 4). The comparison between Atlantic white-cedar and Shoreline/Islands habitats yielded a much lower index (JSI = 0.59) whereas, comparison between Forest manageable area and Non-riverine swamp produced a similarity index of 1.0 (table 4). Five comparisons had similarity indices greater than or equal to 0.90, with 3 having an index of 0.97 (i.e., Shoreline/Islands – Non-riverine swamp, Shoreline/Islands – Pond pine, and Non-riverine swamp – Pond pine; table 4). Important results from nestedness temperature calculation included matrix temperature and percent of matrix fill. These variables dictate the distribution order and, thus, the extinction threshold for assemblages (fig. 3), where a temperature of 0° and 50% fill indicate a perfectly ordered distribution. Nestedness calculation for BNS yielded a low matrix temperature of 12.6° and a 38.6% fill (fig. 3).

Discussion

Observed and estimated values of species richness revealed the Forest manageable area to be the most species rich (table 2). Similarly, the Forest manageable area dominated numbers of relative abundance (table 1) and initial capture ($n = 873$; table 2), which comprised 58.4% of total captures. Higher values for observed and estimated species richness and relative abundances could be expected from the Forest manageable area due to its larger acreage (table 2; fig. 2a; Dunn and Loehle, 1988; Atmar and Pat-

Table 3. Standardized diversity measures of the four designated habitat preserves and Forest manageable area at Bull Neck Swamp, Washington County, North Carolina, May to August 2005 and 2006. Observed (S_{obs}) and estimated species richness (S) were standardized by 75 ha, the size of the smallest preserved area, to compare proportional differences in species richness due to area.

Habitat Preserves	Hectares	S_{obs}	S
Atlantic white-cedar	75	0.15	0.17
Pond pine	96	0.09	0.17
Non-riverine swamp	314	0.19	0.29
Shoreline/Islands	452	0.12	0.23
Forest manageable	1,554	0.43	0.59
Totals	2,491	0.44	0.45

Table 4. Chao-Jaccard similarity indices (JSI) for comparisons of the species assemblages among the four habitat preserves and Forest manageable area at Bull Neck Swamp, Washington County, North Carolina, May to Agust, 2005 and 2006. Habitat preserves and the Forest manageable area were abbreviated as AWC – Atlantic white-cedar, Pond – Pond pine, NR – Non-riverine swamp, S/I – Shoreline Islands, and Fman – Forest manageable.

Habitats	AWC	Pond	NR	S/I	Fman
AWC	0.00	0.79	0.96	0.59	0.90
Pond	0.79	0.00	0.97	0.97	0.77
NR	0.96	0.97	0.00	0.97	1.00
S/I	0.59	0.97	0.97	0.00	0.82
Fman	0.90	0.77	1.00	0.82	0.00

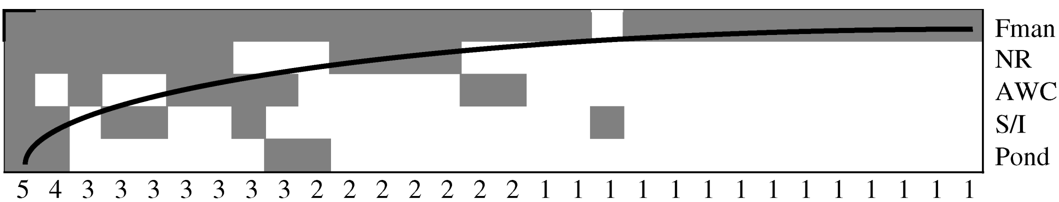

Figure 3. Nestedness distribution of the species assemblages of each habitat preserve and the Forest manageable area at BNS. Habitat occurrences of species are plotted along the X axis, with "most stable" species on the left to "most tenuous" on the right. Habitats are plotted along the Y axis, with "most hospitable" at the top and "least hospitable" at the bottom. The nestedness calculator automatically removed three "idiosyncratic" species, species that occurred in all five habitats, when calculating matrix temperature and fill (Atmar and Patterson, 1993 and 1995). Habitats were abbreviated as AWC – Atlantic white-cedar, Pond – Pond pine, NR – Non-riverine swamp, S/I – Shoreline/Islands, Fman – Forest manageable. The extinction threshold is represented by the curved line.

terson, 1993) and standardizing observed and estimated species richness by area did not alter this result (table 3). However, comparing habitat assemblages with species richness alone could be misleading and a poor indicator for conservation value by masking species responses to disturbance (e.g., natural or anthropogenic) or rare species (Ma, 2005; Bock, Jones and Bock, 2007; Gardner, Barlow and Peres, 2007a). Similarly, care must be taken when using relative abundances to compare assemblages (van Horne, 1983; Purvis and Hector, 2000; Gardner, Barlow and Peres, 2007a). Further, to be used reliably, relative abundances must provide a basis for quantifying or comparing the similarity of an assemblage to the entire community (Cao, Williams and Larsen, 2002). Employing similarity indices, such as the Chao-Jaccard Similarity Index (JSI), could ameliorate the failings of species richness and relative abundance.

Similarity indices assess composition between two assemblages based on the number of shared species between assemblages and the numbers unique to each and are often resistant to undersampling, due to the continued presence of abundant species, and less likely to be dominated by a particular species (Chao et al., 2005, 2006). Resistance to undersampling is an important characteristic, given the inability of most studies to sample adequately (Cao, Williams and Larsen, 2002). Abundance-based comparisons among the five assemblages in this study demonstrated high similarity (table 4). In fact, 90% of comparisons revealed values $\geqslant 0.75$ in similarity. We derived our lowest index between Atlantic white-cedar and Shoreline/Islands preserves (JSI $= 0.59$) likely due to alternating abundances of species common between the two habitats (Chao et al., 2005). Importantly, employing an abundance-based similarity index accounted for unseen shared species among assemblages (Chao et al., 2005; Colwell, 2005; Chao et al., 2006).

In conclusion, our analyses demonstrated the four habitat preserves and Forest manageable area at BNS contained similar species assemblages of the reptile and amphibian community, with 90% of comparisons sharing over 75% of species (table 4). Further, the low temperature ($T = 12.6°$) of our nestedness matrix (fig. 3) illustrated the ordered nature of the community, as temperatures closer to zero represent greater distribution order. Additionally, a 38.6% fill indicated that all assemblages were ordered subsets of one another (Atmar and Patterson, 1993). These data indicated the four designated habitat preserves at BNS did not act as refuges to reptile and amphibian species by maintaining higher species diversity or greater numbers of rare species. Moreover, timber harvesting, demonstration practices, and site preparation techniques should not adversely affect the overall reptile and amphibian community. However, nestedness calculation indicated that some species in the Forest manageable area could be more vulnerable to land-use change, demonstrated by their proximity to the extinction threshold (fig. 3) and management decisions require careful consideration before implementation. Based on the large size of the Forest manageable area, habitat continuity, and high species similarity among habitats, we believe the loss of most species from BNS is unlikely.

We recommend land-use planning consider small-scale practices where management practices have already been implemented. Small-scale, circle-shaped clear-cuts, thinnings, or site preparations could reduce major land-use effects, edge area, and patchiness, while encouraging spatial heterogeneity (Hunter, 1990). Although reptile and amphibian responses would be variable among species (McLeod and Gates, 1998; Grialou, West and Wilkins, 2000), land-use practices of this size and shape, or confined to areas that were already managed, would protect more vulnerable and sedentary species detected in similar microhabitats of the Forest manageable area, such as Atlantic Coast Slimy Salamanders (*Plethodon chlorobryonis*; Petranka, 1998). Hence, remaining areas of dry forest would be maintained to provide habitat for the species. An intermediate level of management intensity should maintain the highest species diversity, but the relationship among management practices, managed areas, and biotic exchange are critical to retaining characteristic species composition (Hobbs and Huenneke, 1992). Finally, we recommend the use of observed and estimated species richness, relative abundance, species composition, and distribution for all studies comparing species assemblages. Future monitoring studies should employ a large diversity of sampling techniques to derive accurate inventory statistics. Employing 11 sampling techniques provided a better representation of reptile and amphibian assemblages and allowed for better conclusions regarding the potential effects of land-use practices (Gardner, Barlow and Peres, 2007a; Hutchens and DePerno, in press).

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