Biodiversity and Conservation **1**, 125–142 (1992)

Biological diversity of a temporary pond herpetofauna in north Florida sandhills

C. KENNETH DODD Jr

National Ecology Research Center, US Fish and Wildlife Service, 412 NE 16th Avenue, Room 250, Gainesville, Florida 32601, USA

Received 18 September 1991; accepted 4 February 1992

From 1985 through 1990, the herpetofauna of a temporary pond in an uplands longleaf pine sandhills community in north-central Florida was monitored. A drift fence completely encircled the pond. Animals were captured in pitfall traps and marked as they entered and exited the pond basin. I captured 16 155 individuals of 42 species (16 amphibians, 26 reptiles). The species richness, diversity (using Margalef's Diversity Index) and dominance (using the Berger-Parker Index) varied among years. Between 62.5% and 87.5% of the amphibian species and 65% to 81% of the reptile species were captured in any one year. Daily amphibian capture was positively correlated with rainfall, whereas reptile capture was either not correlated or weakly negatively correlated with rainfall. Hydroperiod duration was not correlated with the numbers of either amphibians or reptiles captured. Neither the amphibian nor the reptile community showed any trends in diversity or dominance indices during the course of the study, although both communities were dominated by a few species. However, the species responsible for community dominance changed somewhat as the study progressed. Assessing the results of this study is hampered by the lack of comparable studies elsewhere, expected natural fluctuations of amphibian populations, and a prolonged drought, especially during the latter stages of the study. The herpetological community at Breezeway Pond does not appear to follow theoretical predictions of community response to stress. Temporary ponds are important centres of herpetofaunal biodiversity in uplands sandhills communities. Long-term studies are needed to monitor the composition, structure, and functional interactions of their resident species.

Keywords: amphibians; reptiles; biodiversity; temporary pond; drought; Florida

Introduction

Biological diversity is a current topic in the fields of life-history evolution, community ecology, and conservation (Wilson, 1985, 1988; Reid and Miller, 1989). Most discussion focuses on the loss of tropical diversity or, at least in North America, the loss of old-growth forests in the Pacific Northwest (Norse, 1990). Relatively scant attention is directed at the loss of the old-growth longleaf pine (*Pinus palustris*) community of the southeastern coastal plain (Noss, 1989). This community (termed 'high pine', see Carr, 1940; Myers, 1990) once stretched from Virginia to Texas and included more than 28.3 million ha. Today, less than 10% of the long-leaf pine forest, and virtually no virgin old-growth, remains (Means and Grow, 1985). In the last 30 years alone, the extent of the long-leaf pine forest decreased by 84% in north Florida (Means and Grow, 1985).

The long-leaf pine community is not homogeneous throughout its extensive range. Clear and red-water lakes, riparian strips along small streams, swamps, flatwoods, and many other smaller communities are interspersed within the dominant pine forest depending on soil and hydrology (Myers and Ewel, 1990). On the uplands, however, the high pine community predominates because of the well drained sandy soils and droughty conditions. The community is maintained in a savannah-like stage by periodic fires which historically swept the forest every few years in late spring and summer (Myers, 1990).

Within the uplands community, temporary ponds form in sink-hole depressions. These ponds form the basis for an aquatic community quite unlike those of the larger lakes because of differing hydrologic regimes and the absence of fish in temporary wetlands. The absence of fish and perhaps certain invertebrates allows larval amphibian development free from, or at reduced levels of, predation. A few species, such as striped newts (*Notophthalmus perstriatus*) and gopher frogs (*Rana capito*), require temporary ponds for reproduction in the otherwise harsh high pine environment. Perhaps because of their small size and sometimes ephemeral nature, temporary ponds have been overlooked as important wildlife habitats in uplands ecosystems (Moler and Franz, 1988; LaClaire and Franz, 1990).

In 1985, I began a five-year study of the herpetological community inhabiting a temporary pond in the high pine uplands of north-central Florida. The objectives of the project were to compile data on the species richness, diversity, and dominance of the community, and to gather basic biological information on the species that frequented the pond and adjacent uplands. The data are being used in the development of a long-term management plan for a 3750 ha biological preserve. These data also provide the foundation for comparisons with the fauna of other temporary ponds in sandhill upland communities and for monitoring long-term trends in the population dynamics of the resident herpetofauna.

North-central Florida experienced a drought during the course of the study. Yearly rainfall averages were below normal between 1981 and 1990, and the drought was especially severe between 1988 and 1990 (Motz *et al.*, 1991). This situation provided the opportunity to examine the effects of an environmental stress on an uplands herpetofaunal community. Although droughts are common in north-central Florida (Motz *et al.*, 1991), the potential bias of this perturbation must be kept in mind when interpreting the results of this study. In this paper, the term *community* is used as defined by Begon *et al.* (1986), that is, 'an assemblage of species populations which occur together in space and time'.

Study area and methods

Field data were collected at Breezeway Pond, a 0.16 ha depression marsh (Florida Natural Areas Inventory, 1990) located in a shallow 1.3 ha basin on the Katharine Ordway Preserve/Swisher Memorial Sanctuary, Putnam Co., Florida (latitude 29°41′N, longitude 82°00′W). The pond is surrounded by a long-leaf pine-turkey oak (*Quercus laevis*) and wiregrass (*Aristida stricta*) community to the south and west, a maidencane (*Panicum hemitomon*) meadow to the east, and a xeric oak hammock dominated by sand live oak. (*Q. geminata*) and laurel oak (*Q. hemisphaerica*) to the north. The distance to the nearest forest cover is generally 20 m, but extends to about 50–60 m behind the *Panicum* meadow.

Breezeway Pond is formed in a shallow sinkhole depression and is not part of a flowthrough drainage system. Water enters the pond solely from rainfall and groundwater recharge. The hydroperiod is thus dependent upon the level of the water table in the nearby surrounding uplands. Water percolates downhill into the basin where it is trapped by stratified organic layers located beneath the soil surface (LaClaire and Franz, 1990). The pond continuously held water for two years prior to the initiation of my study but its soil profile suggests that periodic droughts commonly occur (L.V. LaClaire and L. Smith, unpublished observations).

A 230 m drift-fence made of aluminum flashing (36 cm above ground, 10–15 cm below the surface) was installed completely encircling the pond. No vegetation overhung the fence, and the fence and pond area were exposed to direct sunlight. Within the enclosure, herbaceous hydrophytic vegetation dominated the basin, although a few shrubs, including buttonbush (*Cephalanthus occidentalis*), myrtle holly (*Ilex myrtifolia*), and wax myrtle (*Myrica cerifera*), were present. Several sapling long-leaf and slash pines (*P. elliottii*) grew within the enclosure. Maidencane and carpetgrass (*Axonopus furcatus*) comprised 76% of the ground cover on vegetation transects (L.V. LaClaire and L. Smith, unpublished observations).

Pitfalls (19-1 black plastic buckets) were placed on opposite sides of the fence at 10 m intervals, following the procedures outlined by Gibbons and Semlitsch (1982). The pitfalls were checked five days per week between 0700 h and 0900 h, depending on season, between February 1985 and April 1985 and between October 1985 and September 1990 (1343 days; 87 170 bucket nights). Except for 1985, a year was defined as extending from October until September (e.g. 1986 covers the period between October 1985 and September 1986) for purposes of analysis. This yearly partition corresponds with herpetofaunal activity patterns in north-central Florida more closely than the calendar year. Data for the year 1985 encompassed a 70 day sampling period from early-February until mid-April.

In order to minimize the effects of hot direct sun, the buckets were partially shaded. Slanting pegboard was placed over the opening in such a manner that there was room for transit underneath the board yet not enough space to allow an animal to climb up the outside of the board and over the fence. The board was laid flat across the bucket openings on days when the pitfalls were not checked in order to prevent desiccation of captured animals. Amphibians and reptiles were still captured when the board covered the bucket opening because the seal was not complete. Vegetation was kept cut and away from the fence. Bare white sand was exposed for about 40 cm from the base of the fence outward in either direction.

Amphibians and reptiles were measured for standard length and all animals were weighed to the nearest 0.1 g. The sex of adults was determined. The measurement details are given by Dodd and Charest (1988), and the criteria used to determine sex and life stage (adult versus juvenile) will be presented elsewhere. If there was any doubt about an animal's sex or life stage, it was counted as 'unknown'. Animals were marked by clipping toes (amphibians, lizards), scales (snakes), or shell-notching (turtles) using a year-specific cohort or individual identification sequence. No more than one toe was clipped per foot. All captured animals were examined for regenerated toes and marks. Amphibians, turtles and snakes were released to the opposite side of the fence, but lizards were released to the same side of the fence as captured.

In addition to biological data, maximum and minimum air and water temperatures were recorded as well as rainfall since the pitfalls were last checked, weather conditions, and the occurrence of cyclic weather patterns (e.g. cold fronts, severe storms, etc.).

Statistical analysis

Species diversity was calculated using Margalef's Diversity Index (Magurran, 1988):

$$D_{Mg} = (S\text{-}1)/\ln N$$

where S represents the total number of species and N represents the total number of individuals.

Species dominance using the Berger-Parker Index (Magurran, 1988) was calculated:

$$d = N_{MAX}/N$$

where N represents total number of individuals and N_{MAX} represents number of individuals of the most abundant species.

An increase in the value of the reciprocal form of the index (l/d) indicates an increase in diversity and a reduction in dominance (Magurran, 1988). Diversity and dominance indices were determined separately for amphibians and reptiles. In order to determine if the inclusion of juveniles altered perceptions of diversity and dominance, separate indices were calculated when juveniles were included and excluded. Recaptured individuals were excluded from calculations of diversity and dominance.

The effect of hydroperiod on the number of amphibians and reptiles captured within both the same year and the following year was examined using Spearman Rank Correlation. The latter also was used to determine if yearly, monthly (months treated as independent variables, months treated cumulatively), or daily rainfall affected capture. These analyses were performed using the SAS program for microcomputers (SAS Institute, 1988). Significance was set at $\alpha = 0.05$.

Results

Weather and hydroperiod

From 1985 to 1990, generally small amounts of rain fell in the vicinity of Breezeway Pond, resulting in only five periods in which water remained for more than a month (Fig. 1). Although maximum and minimum air temperatures mirrored the averages from nearby Gainesville and Palatka, the monthly rainfall amounts throughout north-central and north-east Florida were generally well below normal. Low amounts of rainfall resulted in a severe regional drought. Many large lakes dried from 1988 to 1990 as the water table dropped more than 2.5 m to historic lows throughout the Etonia Creek hydrologic basin (Motz *et al.*, 1991). Although the maximum recorded water depth at Breezeway Pond was 75 cm (September 1988), the pond held water for only 14 months between January 1985 and September 1990. The water table was located 60 cm below the surface in October 1989 (L.V. LaClaire and L. Smith, unpublished observations). By February 1991, the water table dropped to 2.5 m below the ground surface and the central pond area was colonized by a thick growth of *Panicum*.

Species richness

A total of 16 155 individuals (13 497 amphibians, 2658 reptiles) representing 42 species (16 amphibians, 26 reptiles) were captured at Breezeway Pond (Table 1). These figures represent 29% of the salamander species, 74% of the frogs, 40% of the turtles, 78% of the lizards, and 65% of the snakes known from the 3750 ha Ordway Preserve. Between

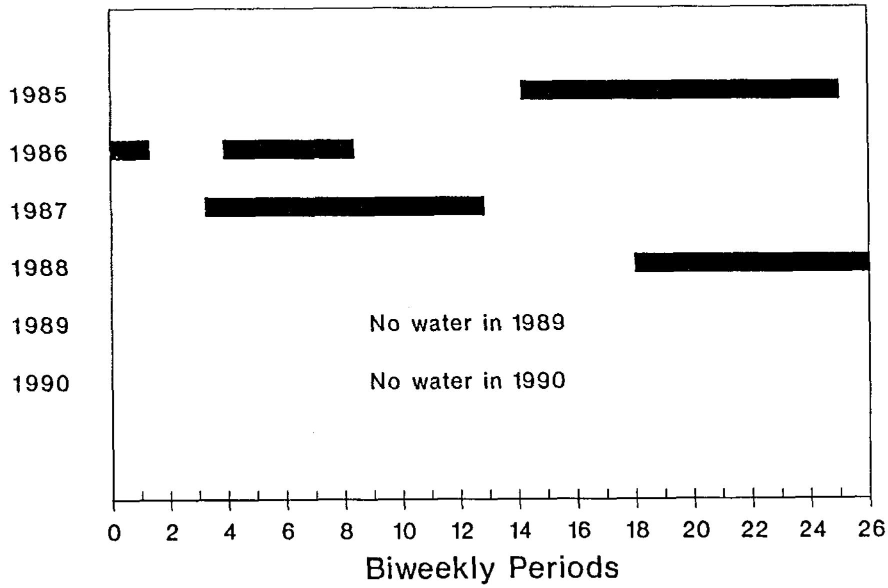

Figure 1. Hydroperiod at Breezeway Pond, 1985–1990. The biweekly periods begin on January 1. Exact dates are as follows: 1985 (6/7–12/13), 1986 (1/10–2/3; 3/14–4/22), 1987 (2/24–6/19), 1988 (9/9–12/23).

65% and 81% of reptile species and from 62.5% to 87.5% of amphibian species, known to have visited Breezeway Pond during the five years of year-round sampling, were caught in any one year (Fig. 2). More than half the amphibians and reptiles captured between 1985 and 1990 were captured during the abbreviated sampling period in the spring of 1985.

Most species initially entered or exited the pond in the first 3 years of the study during favourable weather and hydroperiod conditions. As the drought progressed, the number of amphibian species caught at Breezeway Pond decreased between 1986 and 1990, except for 1989. During that year, a large nearby lake (Smith Lake, 7.55 ha surface area in January 1985) dried to approximately 10% of its 1985 surface area. It seems likely that amphibians emigrating from Smith Lake, including many juveniles, were caught as they dispersed through Breezeway Pond on their way to upland retreat sites. Fewer reptile species also visited the pond basin as the study continued. However, the 42nd species, a juvenile coachwhip snake (*Masticophis flagellum*), was caught in September 1990, and several gopher tortoise (*Gopherus polyphemus*) scats were found within the pond area after the fence was opened in October 1990.

Species diversity

The diversity of reptiles visiting Breezeway Pond was greater than that of amphibians in all years regardless of whether juveniles were included or excluded in the counts (Table 2). When juveniles were included, amphibian diversity was least in 1988 and 1990, and greatest in 1989. With juveniles excluded, the diversity was least in 1988, and greatest in 1989. The diversity indices changed in rank depending on whether juveniles were included or excluded. Exclusion of juveniles lowered the diversity values.

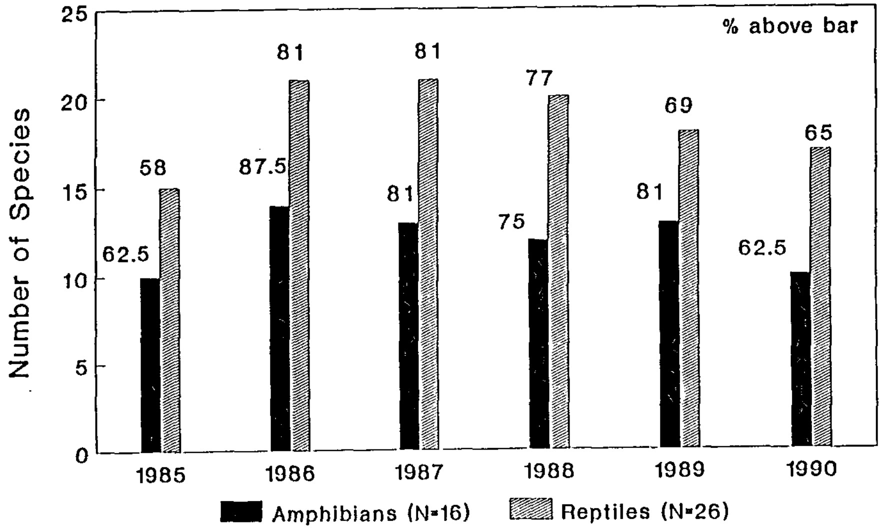

Figure 2. Species richness at Breezeway Pond. The numbers above the bar are the percent-ages of the total number species captured at Breezeway Pond from 1985 through 1990.

Table 1. The species and total number of amphibians and reptiles captured at Breezeway Pond, 1985–1990. The first number represents unmarked individuals and the second number represents recaptures. The 1985 sampling period comprised only 70 days between February and mid-April.

Species	1985	1986	1987	1988	1989	1990
AMPHIBIANS						
Caudata						
Eurycea quadridigitata	5/0	10/0	8/0	30/0	85/0	0/0
Notophthalmus perstriatus	29/5	558/309	744/226	171/254	133/64	16/14
Anura						
Acris gryllus	5/0	76/3	64/1	21/0	42/2	47/4
Bufo quercicus	1/0	111/31	96/50	147/75	177/13	8/3
B. terrestris	6/2	65/46	109/109	28/69	95/75	28/39
Eleutherodactylus planirostris	0/0	1/0	2/0	4/0	2/0	8/0
Gastrophryne carolinensis	2/0	2532/226	379/274	897/327	640/277	123/65
Hyla chrysoscelis	0/0	1/0	0/0	0/0	0/0	0/0
H. femoralis	0/0	4/0	39/2	6/2	99/0	1/0
H. squirella	0/0	3/0	0/0	0/0	1/0	0/0
Pseudacris ocularis	14/0	20/0	49/0	39/0	49/0	1/0
Rana capito	0/0	9/5	44/23	15/6	8/5	0/0
R. catesbeiana	2/4	9/4	0/0	0/0	0/0	0/0
R. grylio	1/0	0/0	5/0	1/0	0/0	0/0
R. utricularia	0/0	6/0	15/2	0/0	41/22	4/0
Scaphiopus holbrooki	1/1	66/19	165/92	1444/819	71/93	26/18
Total Amphibians	66/12	3484/643	1719/779	2843/1552	1443/551	262/143

Table 1. *Continued*

Species	1985	1986	1987	1988	1989	1990
REPTILES						
Testudines						
Apalone ferox	0/0	5/4	1/0	0/1	0/0	0/0
Deirochelys reticularia	0/0	2/0	0/0	4/1	0/0	0/0
Kinosternon subrubrum	9/0	6/0	11/4	14/8	3/4	1/1
Pseudemys floridana	0/0	14/13	2/2	0/0	3/2	1/0
Lacertilia						
Anolis carolinensis	0/0	1/0	0/0	1/0	0/0	1/0
Cnemidophorus sexlineatus	18/7	121/135	122/115	96/148	133/104	115/76
Eumeces egregius	14/2	54/8	30/4	28/1	12/0	10/0
E. inexpectatus	0/0	0/0	1/0	0/0	0/0	1/0
Ophisaurus ventralis	0/0	13/2	15/0	3/0	1/0	8/1
Sceloporus undulatus	4/0	1/0	2/0	13/1	15/0	2/0
Scincella lateralis	23/0	217/2	207/2	94/1	42/0	74/0
Serpentes						
Cemophora coccinea	1/1	2/0	2/0	2/0	3/1	4/1
Coluber constrictor	2/0	4/0	8/8	4/2	8/1	8/2
Diadophis punctatus	0/0	2/0	2/2	2/2	3/1	5/0
Farancia abacura	0/0	0/0	0/0	1/1	2/2	0/0
Heterodon platyrhinos	1/0	0/0	1/0	1/1	0/0	0/0
Masticophis flagellum	0/0	0/0	0/0	0/0	0/0	1/0
Micrurus fulvius	0/0	5/0	8/0	0/0	1/0	3/1
Nerodia fasciata	3/0	4/1	13/1	0/0	1/1	0/0
N. floridana	1/0	6/1	4/0	2/0	0/0	0/0
Regina alleni	2/1	3/0	1/0	0/0	0/0	0/0
Seminatrix pygaea	59/14	18/10	13/11	13/3	4/1	15/7
Sistrurus miliarius	0/0	4/0	2/1	2/0	4/1	0/0
Tantilla relicta	4/0	12/0	4/0	8/0	10/0	13/2
Thamnophis sauritus	1/0	0/0	2/0	0/0	0/0	0/0
T. sirtalis	1/1	5/0	18/4	2/0	7/1	2/4
Total Reptiles	143/26	499/176	470/154	290/170	252/119	264/95

The pattern of reptile diversity varied depending on whether juveniles were included or excluded (Table 2). Apart from 1986 and 1990, the exclusion of juveniles increased diversity values. With juveniles included, the reptile diversity was greatest in 1988 and least in 1990. With juveniles excluded, the greatest diversity shifted to 1987 whereas the least diversity remained in 1990. There was no trend toward increasing or decreasing reptile diversity as the study progressed.

In the spring of 1985, diversity values were relatively high for both amphibians and reptiles considering the short sampling duration. Excluding juveniles decreased diversity values for amphibians in 1985 but slightly increased them for reptiles.

Table 2. Species diversity at Breezeway Pond calculated using Margalef's Diversity Index (D_{MG}).

	1985	1986	1987	1988	1989	1990
Juveniles Included						
Amphibians	2.12	1.59	1.61	1.38	1.65	1.43
Reptiles	2.82	3.22	3.25	3.35	3.09	2.86
Juveniles Excluded						
Amphibians	1.69	1.49	1.36	1.25	1.67	1.28
Reptiles	2.90	3.17	3.66	3.38	3.15	2.86

Species dominance

When juveniles were included, amphibian dominance values varied little between 1986 and 1990 (Table 3), except for 1986 when large numbers of post-metamorphic eastern narrow-mouthed toads (*Gastrophryne carolinensis*) emigrated from the pond basin. When juveniles were excluded, however, the amphibian community showed distinct dominance by adult spadefoot toads (*Scaphiopus holbrooki*) in 1988 and by adult *G. carolinensis* in both 1989 and 1990. In other years, large numbers of striped newts (*Notophthalmus perstriatus*) and oak toads (*Bufo quercicus*) tended to offset the large numbers of *G. carolinensis*. In such instances, the low dominance values resulted from dominance by several species rather than a single species. The individual patterns varied from one year to the next. Amphibian dominance values showed no trends.

When juveniles were excluded, reptile dominance values were much higher than when they were included, indicating that the reptile community was dominated by juveniles between 1986 and 1990 (Table 3). Dominance is particularly evident in 1989 when large numbers of six-lined racerunners (*Cnemidophorus sexlineatus*) were captured at a time when few ground skinks (*Scincella lateralis*) were captured. The large numbers of ground skinks captured in other years tended to reduce the dominance by racerunners. As with amphibians, there were no trends in dominance values as the study progressed.

Table 3. Species dominance at Breezeway Pond calculated using the reciprocal of the Berger-Parker Index (d). Lower values indicate increasing dominance of the community by one or more species.

	1985	1986	1987	1988	1989	1990
Juveniles Included						
Amphibians	2.12	1.37	2.34	1.97	2.26	2.15
Reptiles	2.42	2.30	2.27	3.02	1.82	2.34
Juveniles Excluded						
Amphibians	2.17	2.02	2.27	1.90	1.81	1.91
Reptiles	2.10	4.19	4.00	3.92	2.75	3.88

During the spring sampling period in 1985, both the amphibian and reptile dominance values were similar to other years regardless of whether juveniles were included or excluded. However, the 1985 spring values were lower when juveniles were excluded. The reptile community was clearly dominated by the swamp snakes (*Seminatrix pygaea*) which were captured as they emigrated from the drying pond.

Capture versus hydroperiod and rainfall

The duration of hydroperiod was not correlated with the total number of captured amphibians in any year ($r_s = 0.667, p > 0.05$) or with the number captured the following year ($r_s = 0.800, p > 0.05$). Likewise, there was no correlation between the total yearly rainfall amount and the numbers of amphibians ($r_s = 0.500, p > 0.05$) or reptiles ($r_s = 0.400, p > 0.05$) captured.

The number of captured amphibians was correlated with daily rainfall ($r_s = 0.327, p = 0.0001$, N = 1275), monthly rainfall with months treated as independent sampling periods ($r_s = 0.405, p = 0.0013$, N = 60), and monthly rainfall with grouped months ($r_s = 0.629, p = 0.0283$, N = 12). However, there were no significant correlations between the number of captured reptiles and total rainfall in these three categories ($r_s = -0.050$, $p = 0.0755$, N = 1275; $r_s = 0.083, p = 0.5293$, N = 60; $r_s = 0.434, p = 0.1591$, N = 12). The relationship between total daily captures and rainfall varied among months (Table 4). Amphibian captures were positively correlated with rainfall amounts whereas reptile captures were negatively correlated with rainfall amounts. The relationship between the total number of captured animals and yearly hydroperiod and rainfall amounts is shown in Fig. 3.

Table 4. The relationship between daily rainfall amounts per month and the capture of amphibians and reptiles at Breezeway Pond, 1986–1990. N = the total number of days per month for which data were recorded. The values are based on Spearman Rank Correlation.

Month	Amphibians			Reptiles	
	r_s	P	N	r_s	P
January	0.322	0.0006	111	−0.112	0.2423
February	0.372	0.0002	97	0.241	0.0176
March	0.423	0.0001	109	−0.054	0.5778
April	0.172	0.0808	104	−0.104	0.2923
May	0.446	0.0001	112	−0.095	0.3199
June	0.509	0.0001	109	−0.355	0.0002
July	0.257	0.0069	109	−0.386	0.0001
August	0.405	0.0001	109	−0.352	0.0002
September	0.457	0.0001	106	−0.206	0.0346
October	−0.047	0.6409	102	−0.204	0.0396
November	0.100	0.3085	105	−0.087	0.3776
December	0.159	0.1112	102	0.150	0.1312

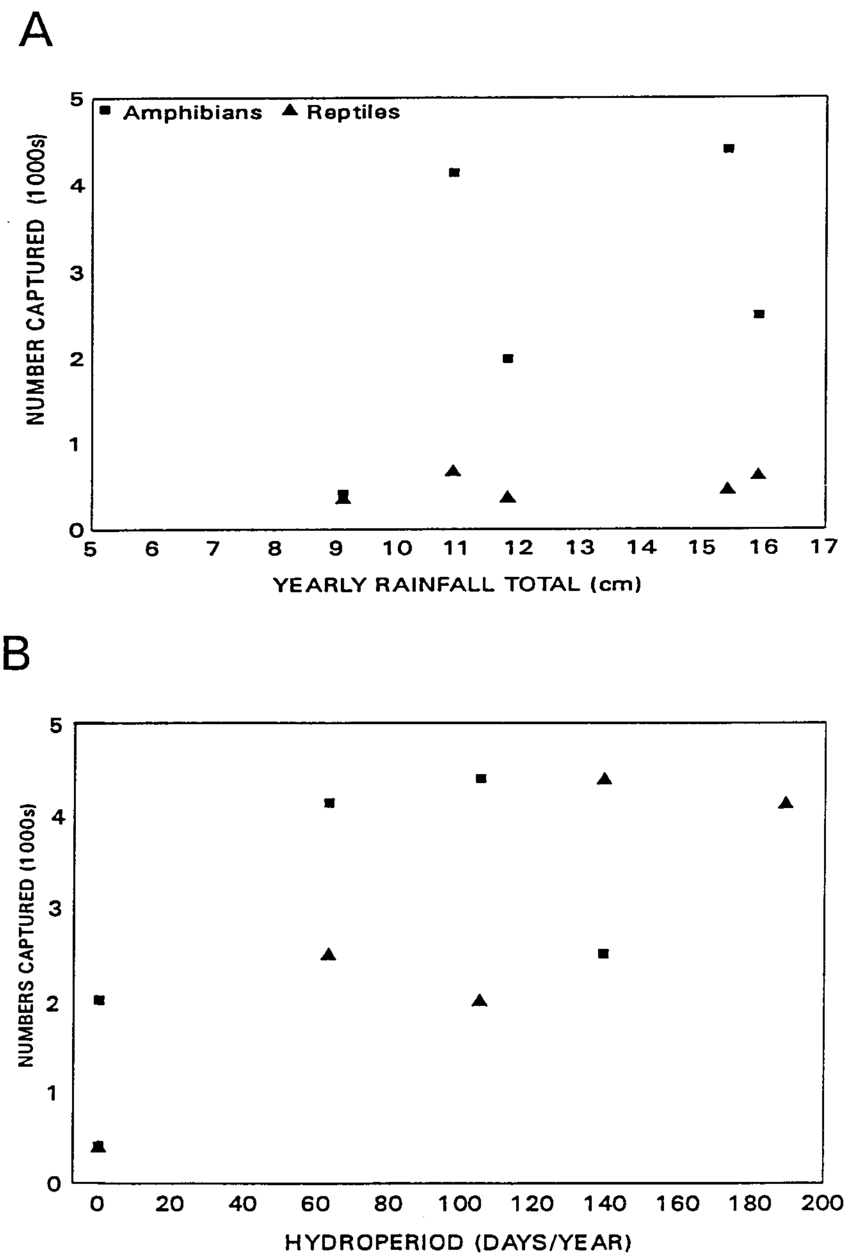

Figure 3. a. Relationship between yearly rainfall totals and the total number of amphibians and reptiles captured at Breezeway Pond, 1986–1990. b. Relationship between hydroperiod and the number of amphibians captured within a year (■) and the following year (▲).

Amphibian community composition

The amphibian community can be partitioned into four visitation categories. Three categories involve species that bred or attempted to breed at Breezeway Pond. In addition, both adults and juveniles most likely entered Breezeway Pond as they dispersed from nearby wetlands, particularly Smith Lake (located 400 m to the north), as these wetlands disappeared during the drought. Only striped newts and eastern narrow-mouthed toads successfully produced metamorphosed young between 1986 and 1990 (Dodd, 1992a, 1992b). However, *Rana* tadpoles were seen on several occasions and spadefoot toads produced large numbers of eggs but no tadpoles in the autumn of 1988.

Category 1 includes species that regularly visited the pond in large numbers, presumably for breeding purposes. Only the winter/spring breeding striped newt and the summer breeding eastern narrow-mouthed toad are included in this category (Dodd, 1992a, 1992b). As the drought progressed, the numbers of striped newts declined whereas the numbers of eastern narrow-mouthed toads fluctuated from 1986 through 1989 (Table 1). In 1990, the numbers of eastern narrow-mouthed toads declined dramatically, perhaps in response to drought.

Category 2 includes only the eastern spadefoot toad, an explosive breeder (Pearson, 1955) that occasionally visited the pond in all years. Both juveniles and adults were captured at the drift fence throughout the year. Adult spadefoot toads entered the pond in large numbers only in September 1988 after 270 cm of rain fell at Breezeway Pond in a four-day period. This was the only time during the study that mating calls were heard. Mating occurred, but eggs never developed.

Category 3 includes species that probably breed at Breezeway Pond when environmental conditions permit, but perhaps in smaller numbers than Category 1 species. These species include the salamander *Eurycea quadridigitata*, the bufonids, several hylids (*Acris gryllus*, *Hyla femoralis*, *Pseudacris ocularis*), and certain *Rana* (*R. capito* and *R. sphenocephala*). Males were heard calling from the pond basin, even when water was not present. Both juveniles and adults were captured. Juveniles were captured more in the latter part of the breeding season presumably as they dispersed from other breeding sites. No successful metamorphosis of Category 3 species occurred in Breezeway Pond.

Category 3 species' visitations fluctuated considerably from one year to the next. The years 1986, 1988, and 1990 were years of relatively low visitation whereas moderate numbers entered the pond in 1987 (Table 1). The greatest number of animals entered in 1989. Six out of seven species in Category 3 showed similar patterns among years in the relative number of individuals that entered the pond (Fig. 4). Only *B. quercicus* increased visitation substantially in 1988, a year of decreased visitation for all other species.

Category 4 species were rare visitors to the pond, and consisted mostly of juveniles, e.g. *Hyla squirella*, *Rana catesbeiana*, and *R. grylio*. Adults of the introduced terrestrial greenhouse frog, *Eleutherodactylus planirostris*, occasionally were captured at the drift fence. As the drought progressed, Category 4 species were the first species to disappear, except for the greenhouse frog.

Reptile community composition

There are three, possibly four, categories of reptile visitation at Breezeway Pond. Category 1 includes those species whose home range contacted the drift fence but do not

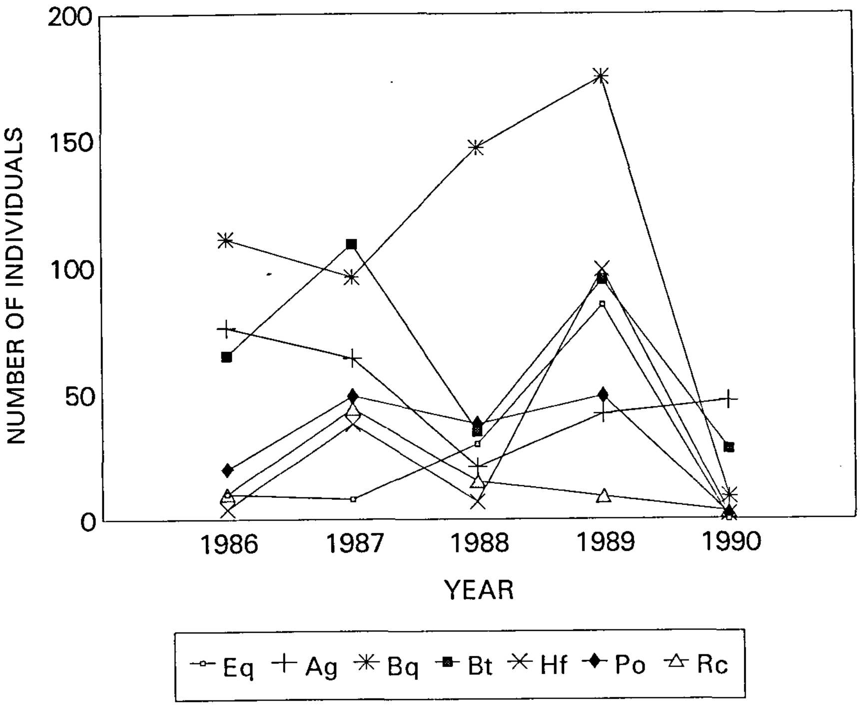

Figure 4. Fluctuation in the numbers of seven species of amphibians captured at Breezeway Pond, 1986–1990. Eq = *E. quadridigitata*, Ag = *A. gryllus*, Bq = *B. quercicus*, Bt = *B. terrestris*, Hf = *H. femoralis*, Po = *Pseudacris ocularis*, Rc = *R. capito*.

rely on wetland habitats for any part of their life history requirements. Species in this category, mostly lizards such as six-lined racerunners (*Cnemidophorus sexlineatus*), ground skinks (*Scincella lateralis*), red-tailed skinks (*Eumeces egregius*), and the fossorial snake *Tantilla relicta*, were captured incidentally to the presence of the pond, that is, the pond has no special importance to these species. These species did not appear to be directly affected by the drought's impact on the pond basin.

Category 2 includes mostly adults of species that occasionally used the pond for foraging but probably do not remain within the small basin even when the pond is full. Transitory species include the water snakes (*Nerodia*, *Thamnophis*), the adult turtles, and the adults of large snake species (*Coluber, Masticophis*) that are not amenable to sampling by drift fence-pitfall trap techniques. Temporary ponds may form important feeding areas for these species when amphibian abundance is high, but visitation decreases when the pond is dry.

Category 3 comprises juveniles that hatched from nests adjacent to the fence and were caught as they dispersed. Most turtles, the lizards *Ophisaurus* and *Sceloporus*, and the young of the larger snakes (*Coluber, Masticophis*) fall into this category. Adults of these species are transitory at Breezeway Pond. The pond drought appeared to have little impact on Category 3 species.

The large numbers of striped swamp snakes that exited Breezeway Pond as it dried in 1985 (Dodd and Charest, 1988) may indicate that this species inhabited the pond on more than a transitory basis. During the remainder of the study, small numbers of *S. pygaea* entered the pond basin but individuals stayed for only a short period of time if water was not present. If this species resides in the pond for the duration of hydric conditions, it may constitute a fourth visitation category, that of semi-permanent resident.

Discussion

The first step in the conservation of biological diversity is to conduct an inventory of the species present. Prior to my survey, community inventories of sandhill herpetofaunas focused on species away from breeding sites (Campbell and Christman, 1982; Mushinsky, 1985; Stout *et al.*, 1988), although Moler and Franz (1988) gave data on species richness and the calling phenology of frogs that breed in uplands sandhill wetlands. The results of my study provide the first quantitative data on the herpetofaunal species richness and diversity at an uplands sandhill temporary pond based on somewhat longterm intensive sampling.

It is difficult to compare species richness data from Breezeway Pond with data from other studies on pond-related herpetofaunas because of differences in sampling techniques, duration, intensity of coverage, sampling area, and habitat type. Most studies report data on amphibians but not on reptiles or *vice-versa*. In the south-east, Breezeway Pond had similar numbers of species of frogs, turtles, and snakes with Karen's Pond and Pond C on the US Department of Energy's Savannah River Site in South Carolina, but far fewer salamanders (Gibbons *et al.*, 1979). Breezeway Pond also had fewer species of all taxa than the much larger Rainbow and Sun Bays, also on the Savannah River Site (Gibbons and Semlitsch, 1982). Complete species inventories are not available for other temperate-zone ponds. Better reporting of community-wide data is necessary before trends in pond species richness can be discerned.

Indices of species diversity do not provide a wholly adequate description of the biological diversity of the community. As pointed out by Noss (1990), biodiversity should be characterized by different levels of understanding, including composition, structure, and function. Although the composition and structure of the herpetofaunal community at Breezeway Pond is reasonably well-understood, there are no data regarding the functional interactions of its members. Perceptions of species richness and diversity will need to be revised once data are available from a comparable study during a wet weather cycle.

Species richness, diversity, and dominance values provide a good measure of community composition and structure as long as their conceptual limitations are kept in mind (Magurran, 1988). I share the concerns of Noss (1990) regarding the use of diversity indices, but I suggest that the relatively intensive sampling conducted at Breezeway Pond makes the use of the indices valuable for multi-year comparisons. If future sampling is conducted at Breezeway Pond in a manner similar to my study, then the Berger-Parker and Margalef's indices will provide an insight to changes in community composition and structure. Comparing the values obtained at Breezeway Pond with the results of studies at other locations would not be valid.

Separating juveniles from adults altered the perception of diversity and dominance given by the indices. When juveniles were excluded, perceptions of the magnitude of among-year variation changed. Exclusion of juveniles increased reptile diversity values but decreased amphibian values. Excluding both juvenile amphibians and reptiles increased perceptions of dominance. The interpretation of the indices is thus somewhat dependant on whether certain life history stages are included or excluded.

In studies of biodiversity, including juvenile amphibians in the derivation of diversity indices seems appropriate because juveniles reflect reproduction and recruitment, in part, at a site. Juvenile amphibians and reptiles may also use a temporary pond as a developmental habitat which is different from the habitats where they were hatched. High diversity values probably reflect the importance of a particular temporary pond to regional herpetofaunal diversity, and comparing indices among years will give an indication of long-term trends.

Dominance indices at a temporary pond, however, might be more useful when juvenile amphibians were excluded unless the specific focus of the investigation was the larval community. Very large fluctuations can occur in amphibian reproductive output (Gill, 1978; Semlitsch, 1983; Pechmann *et al.*, 1989; 1991), and high juvenile mortality normally occurs. Therefore, a low dominance value does not say much about the importance of a site, and trends in community structure are easily masked. For reptiles, the inclusion of juveniles when deriving dominance indices has less significance because there is generally less dramatic fluctuation in reproductive output from one year to the next. Investigators should be careful to state the composition of the data used to derive diversity and dominance indices.

Long-term studies provide an accurate assessment of biological diversity because they allow investigators to sample rare species that might not be captured in short-term studies, to monitor slow processes and processes with high variability, and to understand complex interactions (Franklin, 1989). Undertaking long-term studies allows an investigator to examine variation in community composition and population biology. The ability to separate cyclical variation from long-term population trends is a serious concern in conservation biology and the management of ecosystems. Unfortunately, very little is known about either type of variation among Florida's herpetofauna.

At Breezeway Pond, the number of captured amphibians was correlated with rainfall, as expected, since amphibian movements are influenced by precipitation during favourable activity periods. The relationship is complex (Semlitsch and McMillan, 1980; Semlitsch, 1985; Sexton *et al.*, 1990) and probably varies among species. For most species at Breezeway Pond, successful metamorphosis did not occur which is not unexpected because of the generally short hydroperiod durations or the presence of water at non-breeding times of the year. Amphibian reproductive output is correlated with the length of hydroperiod (e.g. Semlitsch, 1987; Pechmann *et al.*, 1989). Without data during a wet weather cycle, the potential importance of this particular wetland to the local temporary pond-breeding amphibian species is probably masked, despite five years of data, by both the direct and indirect effects of drought.

The Breezeway Pond study took place during only a short portion of a potential drought cycle. Therefore, it is difficult to say without doubt that declines, especially in the last year, were caused by drought effects. Droughts normally occur in cycles of various intervals in the southeastern United States (Motz *et al.*, 1991; Stahle *et al.*, 1985,

1988) and amphibian populations fluctuate dramatically even without drought conditions (Pechmann *et al.*, 1991). However, it is unlikely that complete or significant reproductive failure over a five year period had no effect on the amphibian population. Although drought-related local extinctions probably occur routinely within the long-leaf pine community, the extent of present habitat loss and fragmentation means that refugia are isolated or more vulnerable than they would be without a human presence. Hence, environmental stresses that are 'natural' take on a greater importance when superimposed upon an already stressed ecosystem.

Rapport *et al.* (1985) and Gray (1989) predicted that a reduction in species diversity will occur during ecosystem stress. Gray (1989) extended the concept to include retrogression to dominance by opportunist species and a reduction in mean body size of the dominant species. At Breezeway Pond, neither amphibian nor reptile diversity indices decreased as the drought progressed contrary to model predictions. However, the numbers of individuals of both groups generally declined. Diversity indices *per se* do not appear to be reliable as indicators of ecosystem stress in-as-much as alien species can even increase during stress conditions and thus influence indices (Morgan and Philipp, 1986). The difference in the magnitude of the values between reptile and amphibian indices may reflect a difference in the dependence of the two groups on the small wetland.

Reptile numbers decreased and certain species disappeared, especially species associated with wetlands. A fairly stable diversity index may not indicate that environmental stress is not occurring, only that members of the community, in this case one wetland-related and the other not, are affected differently. Although there were no overall trends, both communities were dominated by one or a few species. As the drought progressed, the rarer species dropped out and the numbers of most other species declined. Gray (1989) predicted that as the rare species disappeared, moderately common species would increase in abundance. This did not occur at Breezeway Pond. With the exception of *N. perstriatus* early in the study, *S. holbrooki* in 1988, and *S. pygaea* in 1985, those species that dominated the community initially did so throughout the study.

Data to test Gray's (1989) prediction that a reduction in mean body size of the dominant species occurs as stress is prolonged are not yet available for the reptile species at Breezeway Pond. However, whilst the numbers of the two dominant breeding amphibians, striped newts (*N. perstriatus*) and eastern narrow-mouthed toads (*G. carolinensis*), fluctuated from 1986 to 1988 and decreased from 1989 through 1990, the mean adult snout-vent length and weights increased yearly (Dodd, 1992a, 1992b). The response of a community to stress may be more complex than Gray (1989) indicated, although the differences might indicate that the herpetofaunal community at Breezeway Pond was too localized or studied for too short a time to conform with his predictions. As he noted, statistically-significant diversity reductions occur late in the sequence of a stress-related impact, and the regional drought in northern Florida, with its potential to adversly affect the amphibian community, has continued through 1992 without any signs of change.

Long-term studies designed to monitor a community's composition, structure, and function are critically needed to assess and separate the impacts and consequences of environmental and anthropogenic stress on the maintenance of biological diversity. Without monitoring programs (see Taylor, 1989, for examples), biological diversity will remain a topic of species lists and diversity indices. Five years is not enough time to gain adequate knowledge to assess the importance of factors that influence amphibian and reptile community structure and composition at a temporary pond.

Acknowledgements

I thank George Dalrymple, Dick Franz, Reed Noss and an anonymous reviewer for offering helpful suggestions to the manuscript. Bert Charest, Kevin Enge, James Stuart, Michael Blouin, Karl Studenroth, and Russell Burke assisted in data collection. I especially thank Dick and Shelley Franz for encouragement, advice, and shared information over the years.

References

Begon, M., Harper, J.L. and Townsend, C.R. (1986) *Ecology: Individuals, Populations and Communities*. Oxford: Blackwell.

Campbell, H.W. and Christman, S.P. (1982) The herpetological components of Florida sandhill and sand pine scrub associations. In *Herpetological Communities* (N.J. Scott Jr, ed.). Washington, DC: Fish and Wildlife Service, Wildlife Research Report 13, pp. 163–71.

Carr, Jr A.F. (1940) A contribution to the herpetology of Florida. Uni. Fla. Pub., *Biol. Sci. Ser.* **3**, 1–118.

Dodd, Jr C.K. (1992a) The cost of living in an unpredictable environment: the ecology of striped newts *Notophthalmus perstriatus* during a prolonged drought. *Copeia* (submitted).

Dodd, Jr C.K. (1992b) The ecology of a sandhills population of the eastern narrow-mouthed toad, *Gastrophryne carolinensis*, during a drought. *Bull. Florida Mus. Nat. Hist., Biol. Sci.* (in press).

Dodd, Jr C.K. and Charest B.G. (1988) The herpetofaunal community of temporary ponds in north Florida sandhills: species composition, temporal use, and management implications. In *Management of Amphibians, Reptiles, and Small Mammals in North America* (R.C. Szaro, K.E. Severson and D.R. Patton, eds). USDA For. Serv. Gen. Tech. Rep. RM-166, pp. 87–97.

Florida Natural Areas Inventory (1990) A Guide to the Natural Communities in Florida. Tallehassee: Florida Natural Areas Inventory and Florida Dep. Nat. Resourc.

Franklin, J.F. (1989) Importance and justification for long-term studies in ecology. In *Long-term Studies in Ecology. Approaches and Alternatives* (G.E. Likens, ed.), pp. 3–19. New York: Springer-Verlag.

Gibbons, J.W. and Semlitsch, R.D. (1982) Terrestrial drift fences with pitfall traps: An effective technique for quantitative sampling of animal populations. *Brimleyana* **7**, 1–16.

Gibbons, J.W., Nelson, D.H., Patterson, K.K., and Greene, J.L. (1979) The reptiles and amphibians of the Savannah River Plant in west-central South Carolina. In *Proceedings of the First South Carolina Endangered Species Symposium* (D.M. Forsythe and W.B. Ezell, Jr, eds). Columbia, SC: South Carolina Wildl. and Mar. Resourc. Dep., pp. 133–43.

Gill, D.E. (1978) The metapopulation ecology of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque). *Ecol. Monogr.* **48**, 145–66.

Gray, J.S. (1989) Effects of environmental stress on species rich assemblages. *Biol. J. Linn. Soc.* **37**, 19–32.

LaClaire, L.V. and Franz, R. (1990) Importance of isolated wetlands in upland landscapes. In (M. Kelly, ed), *Florida Lake Management Society, Proceedings of the 2nd Annual Meeting, Winter Haven, Florida*, pp. 9–15.

Magurran, A.E. (1988) Ecological Diversity and its Measurement. Princeton, New Jersey: Princeton University Press.

Means, D.B. and Grow, G. (1985) *The endangered long-leaf pine community*. ENFO (Florida Conservation Foundation) Sept: 1–12.

Moler, P.E. and Franz, R. (1988) Wildlife values of small, isolated wetlands in the Southeastern coastal plain. In *Proceedings of the Third Nongame and Endangered Wildlife Symposium, Georgia Dep. Nat. Resourc., Social Circle, Georgia* (R.R. Odom, K.A. Riddleberger and J.C. Ozier, eds), pp. 234–41.

Morgan, M.D. and Philipp, K.R. (1986) The effect of agricultural and residential development on aquatic macrophytes in the New Jersey Pine Barrens. *Biol. Conserv.* **35**, 143–58.

Motz, L.H., Heaney, J.P., Denton, W.K. and Leiter, G. (1991) *Upper Etonia Creek hydrologic study. Phase I final report*. Palatka, FL: St Johns River Water Management, Dist., Special Publication SJ 91-SP5, pp. 101.

Mushinsky, H.R. (1985) Fire and the Florida sandhill herpetofaunal community: with special attention to responses of *Cnemidophorus sexlineatus*. *Herpetologica* **41**, 333–42.

Myers, R.L. (1990) Scrub and high pine. In *Ecosystems of Florida* (R.L. Myers and J.J. Ewel, eds), pp. 150–93. Gainesville: University Presses of Florida.

Myers, R.L. and Ewel, J.J. (1990) *Ecosystems of Florida*. Gainesville: Univ. Presses of Florida.

Norse, E.A. (1990) *Ancient Forests of the Pacific Northwest*. Washington, D.C.: Island Press.

Noss, R.F. (1989) Longleaf pine and wiregrass: keystone components of an endangered ecosystem. *Nat. Areas J.* **9**, 211–3.

Noss, R.F. (1990) Indicators for monitoring biodiversity: A hierarchical approach. *Conserv. Biol.* **4**, 355–64.

Pearson, P.G. (1955) Population ecology of the spadefoot toad, *Scaphiopus h. holbrooki* (Harlan). *Ecol. Monogr.* **25**, 233–67.

Pechmann, J.H.K., Scott, D.E., Gibbons, J.W. and Semlitsch, R.D. (1989) Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. *Wetlands Ecol. Manag.* **1**, 3–11.

Pechmann, J.H.K., Scott, D.E., Semlitsch, R.D., Caldwell, J.P., Vitt, L.J. and Gibbons, J.W. (1991) Declining amphibian populations: the problem of separating human impacts from natural fluctuations. *Science* **253**, 892–5.

Rapport, D.J., Regier, H.A. and Hutchinson, T.C. (1985) Ecosystem behavior under stress. *Amer. Nat.* **125**, 617–40.

Reid, W.V. and Miller, K.R. (1989) *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity*. Washington, D.C.: World Resources Institute.

SAS Institute inc. (1988) *SAS procedures guide for personal computers, Version 6.03 edition*. Cary, North Carolina: SAS Institute Inc.

Semlitsch, R.D. (1983) Structure and dynamics of two breeding populations of the Eastern tiger salamander, *Ambystoma tigrinum*. *Copeia* **1983**, 608–16.

Semlitsch, R.D. (1985) Analysis of climatic factors influencing migrations of the salamander *Ambystoma talpoideum*. *Copeia* **1985**, 477–89.

Semlitsch, R.D. (1987) Relationship of pond drying to the reproductive success of the salamander *Ambystoma talpoideum*. *Copeia* **1987**, 61–9.

Semlitsch, R.D. and McMillan, M.A. (1980) Breeding migrations, population size structure, and reproduction of the dwarf salamander, *Eurycea quadridigitata*, in South Carolina. *Brimleyana* **3**, 97–105.

Sexton, O.J., Phillips, C. and Bramble, J.E. (1990) The effects of temperature and precipitation on the breeding migration of the spotted salamander (*Ambystoma maculatum*). *Copeia* **1990**, 781–7.

Stahle, D.W., Cleaveland, M.K. and Hehr, J.G. (1985) A 450-year drought reconstruction for Arkansas, United States. *Nature* **316**, 530–2.

Stahle, D.W., Cleaveland, M.K. and Hehr, J.G. (1988) North Carolina climate changes reconstructed from tree rings: AD 372 to 1985. *Science* **240**, 1517–9.

Stout, I.J., Richardson, D.R. and Roberts R.E. (1988) Management of amphibians, reptiles, and small mammals in xeric pinelands of peninsular Florida. In *Management of Amphibians, Reptiles, and Small Mammals in North America.* (R.C. Szaro, K.E. Severson and D.R. Patton, eds). USDA For. Serv. Gen. Tech. Rep. RM-166, pp. 98–108.

Taylor, L.R. (1989) Objective and experiment in long-term research. In *Long-term Studies in Ecology. Approaches and Alternatives* (G.E. Likens, ed.), pp. 20–70. New York: Springer-Verlag.

Wilson, E.O. (1985) The biological diversity crisis. *Bioscience* **35**, 700–6.

Wilson, E.O., ed. (1988) *Biodiversity*. Washington, DC: National Academy Press.