Perceptions of Species Abundance, Distribution, and Diversity: Lessons from Four Decades of Sampling on a Government-Managed Reserve

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ABSTRACT / We examined data relative to species abundance, distribution, and diversity patterns of reptiles and amphibians to determine how perceptions change over time and with level of sampling effort. Location data were compiled on more than one million individual captures or observations of 98 species during a 44-year study period on the US Department of Energy's (DOE) Savannah River Site National Environmental Research Park (SRS-NERP) in South Carolina. We suggest that perceptions of herpetofaunal species diversity are strongly dependent on level of effort and that land management decisions based on short-term data bases for some faunal groups could result in serious errors in environmental management. We provide evidence that acquiring information on biodiversity distribution patterns is compatible with multiyear spatially extensive research programs and also provide a perspective of what might be achieved if long-term, coordinated research efforts were instituted nationwide.

To conduct biotic surveys on government-managed lands, we recommend revisions in the methods used by government agencies to acquire and report biodiversity data. We suggest that government and industry employees engaged in biodiversity survey efforts develop proficiency in field identification for one or more major taxonomic groups and be encouraged to measure the status of populations quantitatively with consistent and reliable methodologies. We also suggest that widespread academic cooperation in the dissemination of information on regional patterns of biodiversity could result by establishment of a peer-reviewed, scientifically rigorous journal concerned with status and trends of the biota of the United States.

KEY WORDS: Abundance; Amphibian; Biodiversity; Distribution; Land management; Reptile

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During the past 44 years, the US Department of Energy's (DOE) Savannah River Site National Environmental Research Park (SRS-NERP) has been the focus of extensive biotic inventory and research efforts (Cohn 1994, Gibbons 1994). The 803-km^2 SRS-NERP was established in west-central South Carolina during 1951 to support five nuclear production reactors and associated cooling canals, roads, office buildings, and industrial facilities. Approximately 95% of the site consists of planted pine forests, second-growth hardwood habitats, and a variety of natural terrestrial and aquatic habitats. Since 1951, biotic surveys and ecological studies have been conducted on the SRS-NERP to quantitatively sample resident biota and assess the environmental effects of site development (Golley 1965, Gibbons 1994). Thus, the SRS-NERP ranks among the largest tracts of land in North America for which species abundance, distribution, and diversity have been measured on a long-term basis.

The herpetofauna have been a primary focus of extensive and intensive research on the SRS-NERP since 1951, resulting in the capture and processing of more than one million individuals of 98 species of reptiles and amphibians (Gibbons and Semlitsch 1991). (A 99th herpetofaunal species, the gopher tortoise (*Gopherus polyphemus*) was documented as a resident of the SRS-NERP in 1996, after completion of analyses for this paper.) Most of the individuals captured have been amphibians at numerous freshwater wetland habitats known as Carolina bays [e.g., Lost Lake (N = 79,990), Rainbow Bay (N = 404,332), Ellenton Bay (N > 250,000)].

Herpetological studies on the SRS-NERP have resulted in the publication of more than 150 peer-reviewed scientific papers and completion of 33 dissertations and theses. Research supported by the US DOE on the SRS-NERP has included studies on behavior, diet, demography, life history, reproductive traits, and genetics of more than half of the herpetofaunal species. These SRS-NERP research studies have contributed to establishing the status and trends of species populations in the area.

Herpetological data collection began with the Freeman Survey, an inventory funded by the Atomic Energy Commission (predecessor of DOE) and conducted from 1951 to 1954 (Freeman 1955a–c, 1956). Research efforts were intensified during the 1960s (Bellis 1964, Duever 1967) and have continued through 1996. Recent studies have included theoretical modeling, tests of ecological theories, and applied ecological field research (Gibbons and Semlitsch 1991, Jaeger 1995). Herpetological studies have concurrently accrued data on distribution, abundance, status, trends, and processes affecting species and populations.

The collective herpetological experiences by research groups on the SRS-NERP provide an opportunity to evaluate how the perceptions of abundance, distribution, and diversity change over time. Here we discuss interpretation of biological assessments and changes in perceptions as a function of sampling effort and time. We also assess the need for and challenge of conducting biotic surveys on government-managed lands, holdings that encompass 29% of the land area in the United States.

Perceptions of Distribution and Abundance

Understanding distribution and abundance patterns is a fundamental goal of ecology (Andrewartha and Birch 1954, Krebs 1972, Ricklefs 1990). However, accurate determination of the distribution and demographic status of most species in the United States has not been achieved. To examine spatiotemporal perceptions of herpetofaunal geographic distribution on the SRS-NERP, we assessed distribution patterns of all species across 24 physiogeographic compartments (Figure 1). To assess changes in perceived distribution patterns of the herpetofauna, we quantified the cumulative information on species distributions among these 24 compartments and analyzed changes in the perceived distributions over time.

Surveys conducted during 1951–1954 (Freeman 1955a–c, 1956) documented the presence of 34 reptile and 42 amphibian species on the SRS-NERP. Only 20 species were found in six or more of the 24 compartments (Figures 1 and 2), and no species were recorded from one of the compartments (Figure 1), presumably because construction activities precluded sampling. Ironically, this same compartment now ranks among the highest in herpetofaunal diversity (N = 71 species) (Semlitsch and others 1981, Pechmann and others 1991).

During the 41 years following 1954, the known ranges of most species on the SRS-NERP have expanded dramatically. The addition of distribution data for many species has primarily been from records obtained incidentally during long-term, intensive field research efforts on related species. Furthermore, many species are clandestine (but not necessarily rare) due to cryptic habits (e.g., fossorial behavior), and their captures are reflections of time directed toward faunal surveys during field research efforts with a variety of techniques not used in the 1951–1954 survey [e.g., drift fences with pitfall traps, coverboards, diversity of aquatic trapping methods (Gibbons and Semlitsch 1981, Gibbons 1990, Grant and others 1992)].

In recent decades, the presence of 22 additional species has been confirmed, and 53 of the 98 herpetofaunal species have been documented from more than ten compartments (Figure 2). Currently, 33 species are known to have ranges that encompass more than half of the SRS-NERP compartments. In contrast, several species exhibit remarkably restricted ranges on the SRS-NERP despite continued efforts to locate additional populations. For example, worm snakes (*Carphophis amoenus*), pine woods snakes (*Rhadinaea flavilata*), eastern coral snakes (*Micrurus fulvius*), carpenter frogs (*Rana virgatipes*), and pig frogs (*Rana grylio*) have each been found at only one or two localities on the SRS-NERP. Thus, long-term survey efforts may be necessary to assert that an animal species has a restricted range or is rare in a region. Overall, the extensive survey efforts on the SRS-NERP have documented more species of reptiles and amphibians than have been confirmed from any other public land area in the United States.

Some species on the SRS-NERP have undergone dramatic revisions of distribution estimates. For example, the eastern crowned snake (*Tantilla coronata*) was known from only one specimen in one compart-

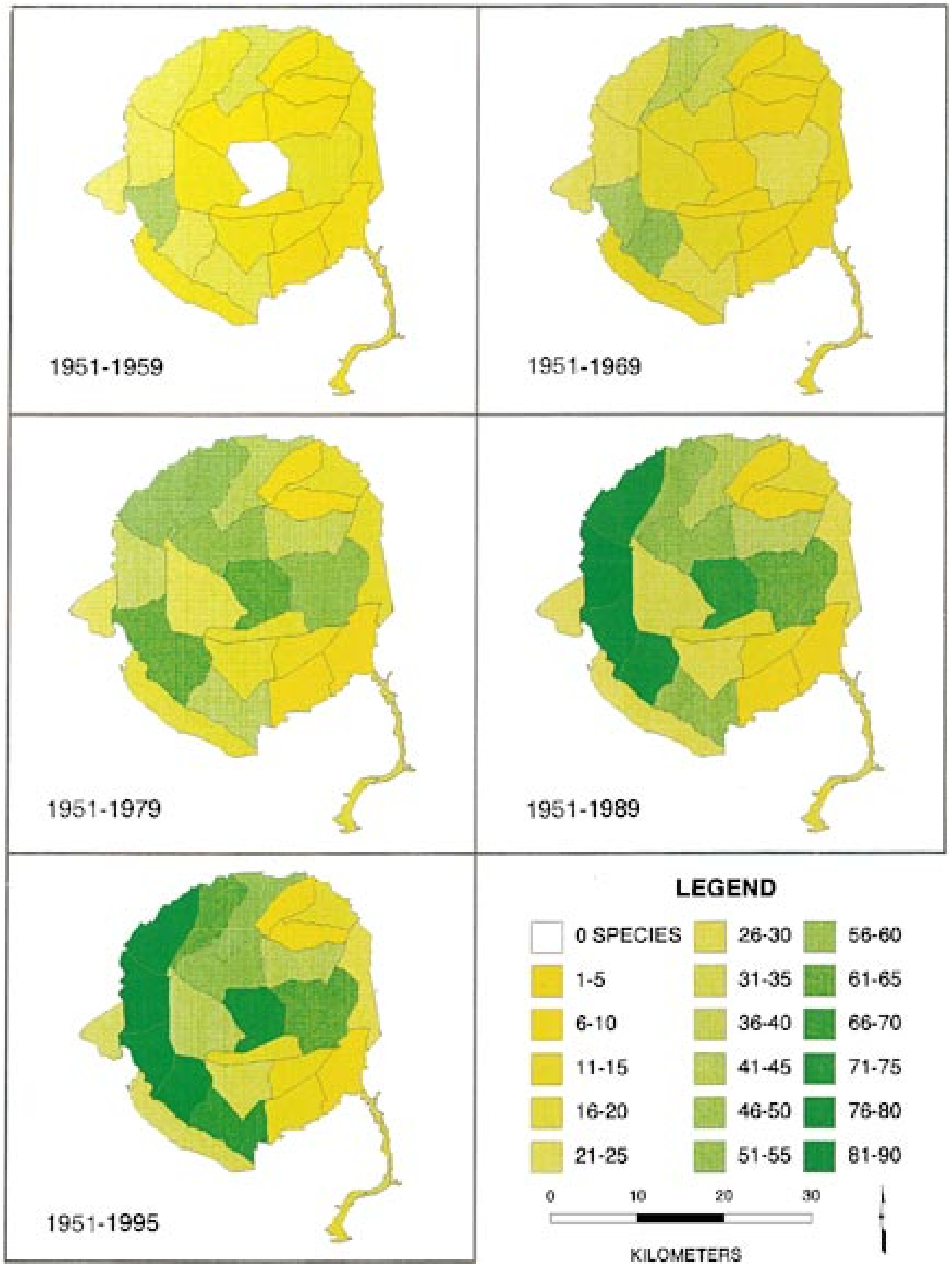

Figure 1. Change in documented distribution pattern of reptile and amphibian species in 24 spatial compartments on the US Department of Energy's 803-km^2 SRS-NERP in South Carolina from 1951 to 1995. To track the changing perception in species distributions across such a large land mass over time, we arbitrarily divided the SRS-NERP into 24 unequal-sized compartments based primarily on a combination of natural habitat features and man-made landmarks consolidated from 89 timber units previously established by the US Forest Service.

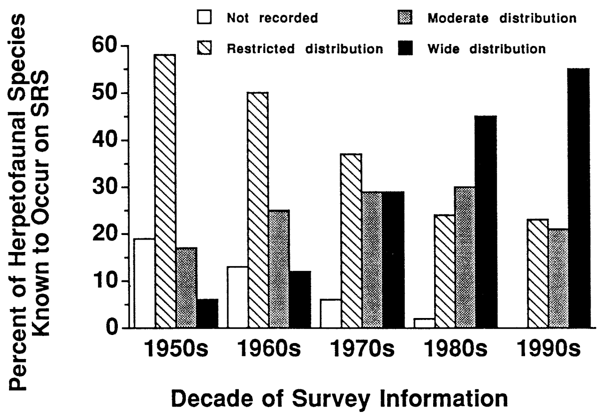

Figure 2. Changes in perceptions of species presence and distribution patterns of reptiles and amphibians on the SRS-NERP in five decades. Proportion of species in the Not Recorded (number of species not yet found in any compartment by the end of the decade) and Restricted Distribution [number of species documented to be present in one to five compartments (see Figure 1)] categories decreased across decades. Proportion of species in the Wide Distribution (number of species documented to be present in more than ten compartments) category steadily increased over the decades. The leveling off of the Restricted Distribution and Moderate Distribution (number of species documented to be present in six to ten compartments) categories is presumably a manifestation of some species being truly limited in their microgeographic distribution in the region. Nonetheless, the changes in categories over the decades are primarily a consequence of accumulating more information about the system rather than reflecting true changes in species distribution patterns on the SRS-NERP.

ment during the 1950s (Freeman 1955a–c, 1956). Additional survey and research efforts have revealed that this small, relatively sedentary snake is widespread on the SRS-NERP (Figure 3). The crowned snake is generally a common species in wooded areas throughout much of the Southeast and probably occurs in other compartments on the SRS-NERP from which it has not been reported. The species is the most frequently captured snake in pitfall traps (Gibbons and Semlitsch 1981) and under coverboards (Grant and others 1992) at many sites on the SRS-NERP, and its known presence in some of the habitat compartments is a consequence of the use of these sampling techniques to conduct ecological research on other species of herpetofauna. The crowned snake serves as an example of how ecological research can be enhanced through establishment of distribution patterns. Verification of greater distribution and abundance of the species on the SRS-NERP led to ecological research on its demography, reproductive traits, and behavior (Gibbons and Semlitsch 1981, Semlitsch and others 1981, Aldridge and Semlitsch 1992a,b).

Changes in distribution patterns may reflect either real range expansions or discovery of previously unknown populations. The SRS-NERP has undergone habitat changes in all physiogeographic compartments to some extent over the past four decades (Workman and McLeod 1990). Many of these changes have been advantageous to wildlife, but others have been clearly deleterious (e.g., United States Department of Energy 1982, Caldwell 1987, Pechmann and others 1989).

The SRS-NERP studies demonstrate how estimates of herpetofaunal abundance can change over time. Fluctuations in population size have been observed among many species of reptiles and amphibians in a variety of habitats on the SRS-NERP. For example, annual surveys of turtle populations in isolated wetlands with fluctuating water levels have revealed a pattern of high density following years of sustained wet conditions, low density during drought years, and moderate density during years immediately following droughts (Gibbons 1990, Burke and others 1995). Rivers, streams, and other permanent aquatic habitats that act as refugia during droughts presumably experience opposite trends (Gibbons 1990, Burke and others 1995). Amphibian densities have also been found to fluctuate substantially in response to environmental conditions, with reproductive output being correlated to rainfall and hydroperiod (Pechmann and others 1989, 1991). Such variation in herpetofaunal population sizes highlights the potential danger of using short-term data to form conclusions regarding the current population status of these species (Dodd 1994). Thus, understanding patterns of abundance may often require long-term studies (Gibbons and others 1983, Semlitsch 1983, Peterman and Bradford 1987, Blaustein and others 1994, Pechmann and others 1991, Bryant 1995, Seigel and others 1995, Wilbur 1996).

Accurate estimates of the distribution and abundance of species in managed habitats are critical to prudent management of biodiversity. Distribution and abundance information is available for many national and state-owned lands, but at least some of the data appear to be seriously flawed or have the potential to be misinterpreted. For example, the US National Park Fauna Database (National Park Service 1994) indicates that Everglades National Park contains 66 species of amphibians and 156 species of reptiles, and bison (*Bos bison*) are included on the species list for Great Smoky Mountains National Park. However, the Everglades contain no more than 23 species of amphibians and 72 species of reptiles (Ashton and Ashton 1985, 1988a,b), and bison have not roamed the Smokies for more than a century (Linzey and Linzey 1971).

Generating reliable estimates of species distribution

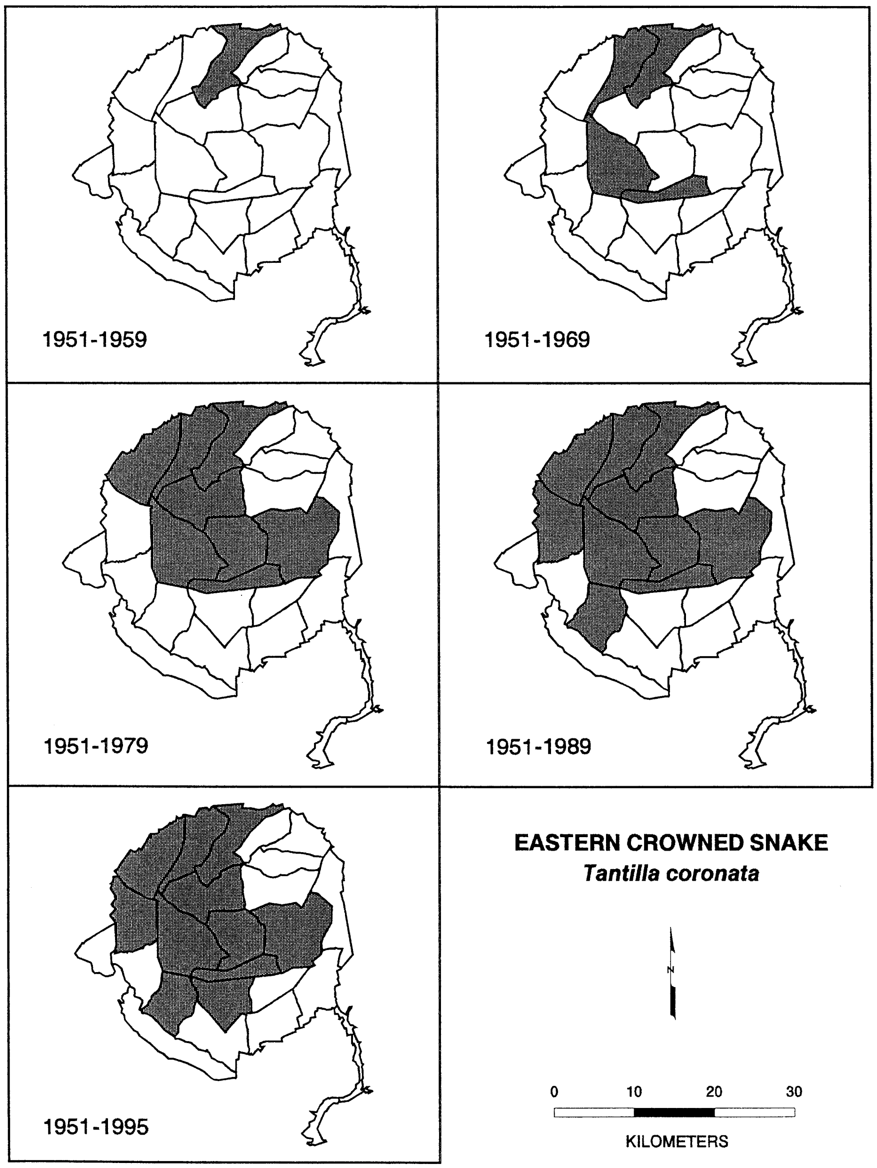

Figure 3. Changes in perceptions of presence and distribution pattern of the eastern crowned snake (*Tantilla coronata*) with continued sampling on the SRS-NERP over a 40-year period. Each decade resulted in an increase in the known microgeographic range of the species.

and abundance requires revision of the methods by which many government agencies and industry acquire and report such data. Our experience suggests that increased accuracy in data acquisition and recording can be achieved by establishing two goals. First, encourage field employees of national and state parks, national forests, wildlife refuges, and other institutions involved in survey efforts to develop proficiency in field identification for one or more major taxonomic groups (e.g., mammals, mushrooms, aquatic insects). Criteria for determining if a potential employee or researcher has the expertise to census flora and fauna should include evidence of the individual's competency with the particular taxonomic group(s).

Second, publication of studies that quantitatively or reliably measure the status of populations should be encouraged. However, many professional journals are not disposed to publishing such studies. This situation has led to a reduction of ecological surveys by well-qualified demographers and the publication of faunal inventories in "gray" literature without requisite peer review, having equivocal credibility, and often being inaccessible (see reviews by Bury and Germano 1994, Germano and Bury 1994, Bury and Corn 1995). One solution to this dilemma is for an academic group, governmental agency, or nonprofit organization to publish a peer-reviewed, scientifically rigorous journal on status and trends of the nation's biota and be open to submissions from researchers conducting biological surveys. Such a journal could augment or replace many government reports, which are often poorly circulated, lacking in critical peer review, and difficult to obtain. A precedent for the publication of a peer-reviewed journal by a governmental agency was established by the Commerce Department's National Marine Fisheries Service with its respected journal *Fishery Bulletin*.

Perceptions of Biodiversity

Biodiversity is a natural resource often measured in terms of species richness on regional, national, and global scales. The value of biotic diversity as an exploitable natural resource has been widely discussed (Wilson 1988), and compelling arguments in favor of biodiversity preservation have been proposed on intrinsic and aesthetic bases (Soulé and Wilcox 1980).

Numerous indices have been developed and used in attempts to explain patterns of ecological diversity (see reviews by Hurlbert 1971, Peet 1974, Kempton 1979). Computation of most indices requires data on the number of species (richness) and the abundance of individuals contained within each species (evenness; Peet 1975). Many of the long-term studies on the SRS-NERP have generated data sets suitable for computing diversity indices. However, data for some of the less intensively studied physiogeographic compartments provide information only on whether each species is present or absent (i.e., not recorded) and thus are insufficient to compute a diversity index. To simply provide information on the geographic distribution of the herpetofauna, the use of number of species per compartment at SRS-NERP is an appropriate measure of biodiversity. As Peet (1974) points out, species richness is perhaps "the least ambiguous" of all diversity indices.

Our experience indicates that measures of herpetofaunal species diversity are strongly dependent on level of effort. The SRS-NERP has among the highest number of field researchers per unit area in the United States, numerous personnel trained in herpetofaunal identification, and some of the longest-running field research projects in the world (Gibbons 1990, Gibbons and Semlitsch 1991, Pechmann and others 1991, Semlitsch and others 1996). Thus, the cumulative search effort for reptiles and amphibians has been high. For example, intense survey and research efforts of localized study sites on the SRS-NERP have yielded stable species diversity estimates over relatively short intervals. Rainbow Bay, a Carolina bay wetland studied for 18 years, has shown little change in diversity since the fourth year of study, despite the capture of more than 300,000 additional specimens at the site (Figure 4).

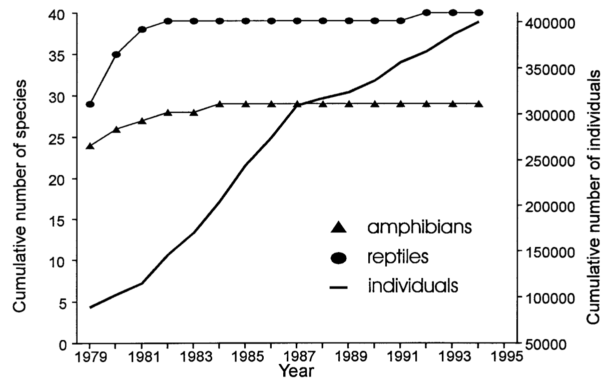

Figure 4. Annual increases in cumulative numbers of species and individual reptiles and amphibians captured at Rainbow Bay. Rainbow Bay is a temporary freshwater wetland habitat (geologically defined as a Carolina bay) and has been completely encircled with a drift fence and pitfall traps since 1978 (18 years).

Two primary challenges related to biodiversity measurement must be addressed during any censusing efforts. The first involves securing the commitment of an adequate force of trained personnel. The ability to differentiate the species within even one major group of flora or fauna for scientific purposes can necessitate extensive training and experience. For example, taxonomic confusion existed in distinguishing between the widely distributed eastern mud turtle (*Kinosternon subrubrum*) and the habitat-restricted striped mud turtle (*K. baurii*) on the SRS-NERP. Duever (1972) reported that *K. baurii* was present on the site, but Gibbons and others (1976) examined classical morphological characters and contended that *K. baurii* was absent from the site. The presence of *K. baurii* on the SRS-NERP was subsequently verified, however, during a study involving multivariate analysis of morphological features (Lamb 1983). Gross morphological similarities had caused the congeneric *K. baurii* to be misidentified as *K. subrubrum* for more than a decade from the time it was first reported from the SRS-NERP. Much taxonomic confusion also has been alleviated through use of molecular genetic techniques on SRS-NERP herpetofauna (Davis and Mulvey 1993, Lamb and others 1994, Scribner and Avise 1994).

Academic involvement is presumably a cost-effective method for obtaining reliable data on species diversity. Universities have the ability to train and supervise personnel conducting floral and faunal censuses. Such surveys can often be conducted economically with equipment already available at universities. Master's theses and undergraduate research projects based on such surveys could result in meaningful contributions to both the scientific community and the public through production of field-tested ecologists and qualified wildlife biologists. However, endeavors involving basic distribution and abundance of species populations are often criticized as being unsophisticated. We suggest that widespread academic cooperation could result if status and trend surveys have the potential to be published in one or more respected, peer-reviewed journals such as that proposed earlier in this paper.

The second challenge that must be met to document biotic diversity is establishment of a long-term commitment to this goal. We concur with E. O. Wilson's statement: "Biological diversity must be treated more seriously as a global resource, to be indexed, used, and above all, preserved" (Wilson 1988). Herpetological studies on the SRS-NERP demonstrate that documentation of diversity patterns for major groups of flora and fauna in the United States is an achievable goal, but could take decades to complete. Because neither biota nor landscapes remain static, understanding the status of biodiversity will require initial assessments and periodic reassessments. Thus, to be successful, biodiversity research programs must be sustained well into the future.

In the United States, responsibility for conducting biodiversity surveys falls largely on the shoulders of the Department of the Interior (DOI). Until recently, such activities were carried out by DOI's National Biological Service (indeed originally named "National Biological Survey"). However, recent political compromises resulted in elimination of the National Biological Service and reassignment of its capabilities and personnel into the US Geological Survey. It remains to be seen if the DOI will maintain its former commitment to establishing data bases on biodiversity in the United States. Without such a commitment, it doubtful that meeting Wilson's goal of indexing biodiversity on a national, let alone regional, level can be achieved.

Sampling Effort

Understanding abundance, distribution, and diversity is complicated by the fact that assessments for entire species require interpretation of numerous independent, geographically specific studies. Even coordinated efforts designed specifically to survey and monitor animal populations often use dissimilar capture techniques, with each technique exhibiting inherent bias.

The use of a wide variety of herpetological collecting techniques on the SRS-NERP (Gibbons 1990, Gibbons and Semlitsch 1991) has revealed differential effectiveness of field sampling methods, even among closely related species. Species vary in habitat preference, behavior, and diet; therefore, capture techniques highly effective for one species may be of little use for a congener. The use of coverboards (Grant and others 1992), for example, has proved to be an efficient method for capturing several species of ambystomatid salamanders during their terrestrial stage. However, the coverboard technique is inefficient for the more fossorial tiger salamander (*Ambystoma tigrinum*), whereas the species is readily captured at drift fences with pitfall traps (Gibbons and Semlitsch 1981).

The use of a variety of capture techniques has proved successful in creating a freshwater turtle data base, which represents one of the largest long-term capture–recapture data bases for any vertebrate group in the world (Gibbons 1990). Its success is due in part to the lack of adherence to standard methodology for collecting turtles. Instead, a variety of techniques were employed including terrestrial drift fences, hoop traps, fyke nets, basking traps, dipnetting, temporary draining of aquatic habitats, road surveys, and extensive terrestrial searches for shells (Gibbons 1990). Although such a potpourri approach was effective for documenting the presence of species, comparative population studies of individual turtle species in disjunct habitats or geographic regions are often skewed because of the use of dissimilar capture techniques.

We concur with the position of the North American Amphibian Monitoring Program (Heyer 1995) that surveys with standardized field sampling techniques (Heyer and others 1994) and effort across regions and over time are essential. However, we suggest that rigid guidelines for techniques should be instituted only for continuing surveys within the same habitats or for individual species that do not exhibit strong differences in capture probability based on habitat or geographic location. Protocols should not be mandated for surveys seeking simply to verify the presence of rare or unreported species. Broad-based or opportunistic sampling has occasionally revealed that abundance estimates of putatively rare species were actually a reflection of low capture probabilities when using standard techniques (Gibbons 1983).

We suggest a balance between protocols for comparative purposes and opportunistic methods for documenting rare species. This balance can be achieved when trained and experienced researchers are involved in the surveys. This approach will allow for the creation of new field techniques, will advance knowledge of animal and plant distribution by encouraging broad surveys, and will produce surveys that can be compared both spatially and temporally.

During any collection effort, a variety of nontargeted organisms are encountered incidentally. Recording and reporting anecdotal information is often viewed as a low priority by some investigators, but such information can be crucial in establishing distribution and abundance patterns (Fitch 1987). We suggest that funding agencies require a ''survey and inventory'' component when sponsoring basic ecological research. Encouraging this philosophy would assure that experts are involved in the collection of survey data suitable for biotic inventories while fulfilling their basic research objectives.

Implementing the survey component would entail placing greater emphasis on the conventional practice used by many field biologists of maintaining field notebooks or data sheets that prompt for information on peripheral observations. Ultimately, the success of such an effort will depend on the ease of reporting and retrieving the information and on the establishment of quality control mechanisms that assure the certainty of observations.

Conclusions

Herpetofaunal research on the SRS-NERP suggests that the accuracy of species distribution estimates is dramatically improved by a long-term commitment to survey and research efforts, although intensive sampling as brief as four years has yielded reliable diversity estimates for small target areas. The research experiences on the SRS-NERP provide evidence that species abundance, distribution, and diversity information can be acquired while conducting an academic research program. However, many opportunities for censusing and sampling are not taken advantage of because such efforts are not viewed as sufficiently academic. We suggest that many master's theses and government or industry surveys could provide much needed data on species distribution, abundance, and diversity if properly coordinated. A peer-reviewed outlet for biotic status and trend data would help focus the survey efforts and would provide a rigorous and readily available format for biodiversity research.

Changes in perceptions of distribution for many herpetofauna on the SRS-NERP appear to be largely a function of additional sampling effort. The long-term nature of research on the SRS-NERP has revealed that many ecological patterns require several years and sometimes decades to become apparent. Thus, the tendency among organizations to conduct brief surveys and among funding agencies to provide short-term support may lead to erroneous conclusions on species abundance, distribution and diversity.

The SRS-NERP's land area represents 0.03% of the 2,628,000-km^2 of federally owned public lands in the United States (Bureau of Land Management 1994), with an additional 620,000 km^2 of public lands owned by state and local governments. The level of understanding regarding ecological patterns of herpetofauna on the SRS-NERP has required the commitment of at least ten personnel per year. Given the vast acreage of government-owned lands and the limited number of researchers on most of those lands, we suggest that the time and effort required to reach satisfactory levels of understanding for most plant and animal groups will require a coordinated commitment of resources by federal and state agencies (Winter and Hughes 1995).

In the United States and many other countries, there is currently a poor level of basic understanding of the abundance, distribution, and diversity of most taxonomic groups. This lack of information complicates efforts to conserve and manage native flora and fauna (Noss and Cooperrider 1994). In the face of growing human pressures on ecological systems, a strong commitment to collecting data pertinent to estimating distributions and abundances of species is warranted. Recognition of changes in patterns of distribution, abundance, and diversity is often the first step toward identifying positive or negative influences of human impacts on ecological integrity.

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