National Park Service
U.S. Department of the Interior

Northeast Region
Natural Resource Stewardship and Science

Biodiversity Inventory: Approaches, Analysis, and Synthesis

Technical Report NPS/NER/NRTR--2005/015

ON THE COVER
Top Left - Golden-winged warbler (*Vermivora chrysoptera*); Top Right - Spotted Salamander (*Ambystoma maculatum*); Bottom Left - Southern Red-backed Vole (*Clethrionomys gapperi*); Bottom Right - Eastern Milk Snake (*Lampropeltis triangulum*); and Center - Purple Trillium (*Trillium erectum*).

Photographs by B. Ross; except Golden-winged Warbler by J. Kubel.

Biodiversity Inventory: Approaches, Analysis, and Synthesis

Technical Report NPS/NER/NRTR--2005/015

James H. Boone[1], Carolyn G. Mahan[2], and Ke Chung Kim

Center for BioDiversity Research, Environmental Consortium
Frost Entomological Museum
Department of Entomology
The Pennsylvania State University
University Park, PA 16802

[1]current address
Field Museum of Natural History
1400 S. Lake Shore Drive
Chicago, IL 60605-2496

[2]current address
209 Hawthorn Building
Penn State Altoona
Division of Mathematics and Natural Science
Altoona, PA 16601

May 2005

U.S. Department of the Interior
National Park Service
Northeast Region
Philadelphia, Pennsylvania

The Northeast Region of the National Park Service (NPS) comprises national parks and related areas in 13 New England and Mid-Atlantic states. The diversity of parks and their resources are reflected in their designations as national parks, seashores, historic sites, recreation areas, military parks, memorials, and rivers and trails. Biological, physical, and social science research results, natural resource inventory and monitoring data, scientific literature reviews, bibliographies, and proceedings of technical workshops and conferences related to these park units are disseminated through the NPS/NER Technical Report and Natural Resources Report series. The reports are a continuation of series with previous acronyms of NPS/PHSO, NPS/MAR, NPS/BSO-RNR, and NPS/NERBOST. Individual parks may also disseminate information through their own report series.

Natural Resources Reports are the designated medium for information on technologies and resource management methods; "how to" resource management papers; proceedings of resource management workshops or conferences; and natural resource program descriptions and resource action plans.

Technical Reports are the designated medium for initially disseminating data and results of biological, physical, and social science research that addresses natural resource management issues; natural resource inventories and monitoring activities; scientific literature reviews; bibliographies; and peer-reviewed proceedings of technical workshops, conferences, or symposia.

This technical report was accomplished under Cooperative Agreement 4000-3-2012, Supplemental Agreement No. 14, with assistance from the NPS. The statements, findings, conclusions, recommendations, and data in this report are solely those of the author(s), and do not necessarily reflect the views of the U.S. Department of the Interior, National Park Service.

Reports in these series are produced in limited quantities and, as long as the supply lasts, may be obtained by sending a request to the address on the back cover. When original quantities are exhausted, copies may be requested from the NPS Technical Information Center (TIC), Denver Service Center, PO Box 25287, Denver, CO 80225-0287. A copy charge may be involved. To order from TIC, refer to document D-19.

This report may also be available as a downloadable portable document format file from the Internet at http://www.nps.gov/nero/science/.

Please cite this publication as:

Boone, J. H., C. G. Mahan, and K. C. Kim. May 2005. Biodiversity Inventory: Approaches, Analysis, and Synthesis. Technical Report NPS/NER/NRTR--2005/015. National Park Service. Philadelphia, PA.

NPS D-19 May 2005

Table of Contents

Table of Contents (continued)

Figures

Table

Summary

Many national parks have completed biological inventories for specific taxa. The data generated by these inventories are important in assisting resource managers in the development of General Management and Resource Management Plans. However, biological inventories are often not coordinated across taxa and may not be conducted in a statistically relevant manner. Therefore, combining or integrating data from these inventories in order to assess biodiversity conditions at national parks may be difficult.

We conducted an extensive search and review of literature and internet-based resources to determine the availability of current biodiversity inventory approaches and analysis and synthesis techniques. Specifically, we reviewed analytical and statistical tools used to analyze and integrate biodiversity data collected through site-specific, taxon-based inventories. Based upon the type of inventory data collected at national parks, we determined that Decision Support Systems (DSS) would be able to integrate multi-taxa inventory data sets for analysis and provide tools such as biodiversity maps to help resource managers make sound management decisions.

Acknowledgments

This project could not have been undertaken and completed without the help of many people. We wish to thank the National Park Service staff who assisted in many aspects of this effort. John Karish provided funding, contract management, and project direction. The staff at Valley Forge National Historic Park provided valuable input in conceptualizing this project. For professional assistance via technical reviews and comments, we thank Richard Yahner, Michael Saunders, Diane Debinski, Nicholas J. Gotelli, and Robert Colwell. We thank Susan Mann for formatting earlier drafts of this document. Emily Hill formatted the final document and we thank her for her assistance.

Introduction

The natural resources that the National Park Service (NPS) is mandated to protect are ecosystem products, namely biodiversity, wildlife, habitats, and landscapes, and ecosystem services, such as pollination, photosynthesis, and water purification (National Park Organic Act, 16 United States Code [USC] 1, 1(1)-1,3,20). To sustain healthy ecosystem structure and function for these products and services, the focus of natural resources management becomes sustainable management of the ecosystem and its constituent biodiversity (LaRoe et al. 1995; Mac et al. 1998). Furthermore, NPS policy specifically requires natural resource managers to know the condition of biodiversity and ecosystems, and understand the dynamic nature of these ecosystems within their jurisdiction (National Park Service Management Policies, Chapter 4). To meet these goals natural resource managers need site-specific, current biodiversity inventory data from NPS lands. Biodiversity inventory provides the baseline information on living organisms for making management decisions, identifying research and management needs, and establishing monitoring protocols (Stohlgren et al., 1995). However, biodiversity inventory data alone cannot help resource managers change management practices from extraction of products and services to protection and sustainable management of ecosystems (Grumbine 1997).

Ecosystem management, the now widely accepted paradigm for natural resource management on public lands, is a holistic approach that aims to sustain ecological function and productivity by protecting habitats and their biodiversity in the context of human needs and impacts on the ecosystem (Grumbine 1994; Christensen et al. 1996; Salwasser et al. 1996; Grumbine 1997). Ecosystem management involves three processes: (1) assessing the occurrence and distribution pattern of biodiversity and physical structure of ecosystems (inventory process); (2) monitoring of ecological changes in biodiversity due to human-induced stressors and/or management (monitoring process); and (3) mitigating or controlling emerging threats to ecosystem function and productivity (mitigating process). Furthermore, the mitigation process involves the evaluation of monitoring data that is compared to an initial biodiversity inventory or some known desirable or historic condition and against socio-political reactions to human factors (e.g., policy and management decisions) (Zorn et al. 2000).

Despite the efforts of resource managers, we still know little about biodiversity in national parks (Mac et al. 1998). In addition, site-specific data that describe vegetation, habitats, soil, and geology of park resources are also limited (Stohlgren and Quinn 1992; Lemons 1994; Stohlgren et al. 1995). Site-specific data that describe the physical attributes of a site are critical because habitat patchiness and heterogeneity will often result in high variability in species occurrences between and among habitats. Of the national parks that have completed baseline taxonomic inventories, the focus has been primarily limited to a few major taxa such as vascular plants, mammals, birds, herptofauna, and select invertebrates such as butterflies and beetles (e.g., Tiebout 2002). These flora and fauna inventories are accomplished by either assigning the task to park biologists or contracting specialists and researchers from universities. Researchers and park biologists design and implement their inventories independently based on the latest techniques in their fields or by following guidelines established by the NPS. The results of these inventories are included in NPS reports and may be as simple as a list of species or analyzed using statistical tests depending on the sampling design.

NPS species lists and databases, such as NPSpecies, include this species information. These databases are important tools for park managers but are only the first phase of conducting site-specific biodiversity inventories for resources management. To date, no standard analysis and assessment techniques of biodiversity data sets have been developed (Debinski and Brussard 1994). Moreover, the integration and analysis of numerous taxon-based data sets have not been done for assessment and interpretation of biodiversity found within national parks. The application of biodiversity inventory data to natural resources management has not been rigorously studied, particularly in relation to measuring the state of human-induced stressors and management effects on biodiversity in parks (Woodley 1992). Furthermore, the application of quantitative measures related to biodiversity, such as indices of species richness and diversity, may have occurred without critical evaluation of the appropriate sampling methodology for each application (Ludwig and Reynolds 1988; Brower et al. 1998).

In this report, we review the state of current biodiversity assessment and biodiversity inventory analysis techniques and relate these techniques to natural resources management in national parks. Specifically, we wanted to determine if there are methods that will integrate data sets from a variety of independently conducted taxa-specific inventories. In addition, we wanted to know if these integration methods could be used to make useful management decisions based on the entire biodiversity of the park where the data were collected. To achieve these goals, we reviewed analytical and statistical tools used to analyze and integrate biodiversity data collected through site-specific, taxon-based inventories. In addition, we provide recommendations and guidelines for analyzing biodiversity inventory data needed for General Management and Resource Management Plans for national parks.

Methods and Materials

Literature Search

The literature search process for our report involved the use of electronic databases, reference sections of book chapters, proceedings of conferences, meetings, and workshops, United States Department of Agriculture (USDA) and National Park Service (NPS) technical bulletins, journal articles, and Web sites. Electronic databases included Agricola, Biological Abstracts®, Biological and Agricultural Index®, and Cab Abstracts®.

Agricola is compiled and distributed by the National Agricultural Library of the Department of Agriculture of the United States of America. It has over four million bibliographic records of journal articles, theses, patents, software, and technical reports related to agriculture from 1979 to the present. Agricola covers agriculture and related subjects including animal and plant science, entomology, agronomy, horticulture, rural sociology, agricultural economics, family living, and food and nutrition. The following are indexed: journal articles, books, book chapters, and USDA, State Experiment Station, and State Extension service publications. Agricola was accessed through the Penn State University Library Web site. The targeted deadline for this literature search in Agricola was 1970–2002.

Biological Abstracts® and Biological and Agricultural Index® were accessed via compact discs on Ovid Technologies Web site, which was accessed through the Penn State University Library web site. Biological Abstracts® includes bibliographic references (records) with abstracts derived from life sciences research journals published worldwide. The targeted deadline for this literature search in Biological Abstracts® and Biological and Agricultural Index® was 1969-2002.

Cab Abstracts® is a bibliographic database compiled by CABI Publishing. It covers the significant research and development literature in the fields of agriculture and forestry, and the related aspects of human health, human nutrition, animal health, and the management and conservation of natural resources. Cab Abstracts® was accessed through the Penn State University Library Web site. The targeted deadline for this literature search in Cab Abstracts® was 1973-2002.

Keywords and Reference Selection

Keywords used in the literature searches included biodiversity inventory, biodiversity assessment, assessing biodiversity, national parks, data integration, biodiversity analysis, landscape diversity, spatial analysis, biodiversity models, quantifying biodiversity, measuring biodiversity, species analysis, multi-species analysis, multiple species analysis, species database analysis, amphibian diversity, avian diversity, plant diversity, vegetation diversity, small mammal diversity, monitoring biodiversity, decision support systems, biodiversity decision support systems, natural resources decision support systems, and ecosystem management decision support systems. When the term biodiversity was used, a second search followed using the term biological diversity. The criteria for selecting works for inclusion in this manuscript included articles, papers, book chapters, etc., that dealt with current methods and recent advances in qualitative and quantitative techniques for analyzing biodiversity inventory data. Also, papers that dealt with facilitating the assessment of ecosystem health and its measurement at the landscape scale within a national park were included. The World Wide Web was a valuable resource in locating analytical software and current biodiversity projects within the NPS and many other natural resource organizations. The targeted deadline for Web searches was 2004.

Biodiversity Assessment

Biodiversity assessment is used to evaluate and determine the status of biodiversity in a defined area or management unit (target site) that may contain one or more types of ecosystems or habitats. Biodiversity assessment must involve a clear definition of the management and sampling objectives for the target site, selection and design of specific biodiversity inventory techniques, field sampling, identification and classification of species in the context of habitats and communities, and presentation and analysis of the results in an appropriate format for management application (Diefenbach and Mahan 2002). A biodiversity assessment can be used to: (1) evaluate if any specific mitigation needs to be implemented, and/or any management strategy be developed, for conserving or restoring biodiversity of the defined target site; (2) develop a resource management plan considering human-induced development or construction within the target site; (3) develop site-specific monitoring programs; (4) prioritize areas of conservation and restoration concerns; (5) provide baseline information for scientific inquiry; and (6) develop testable hypotheses on patterns of geographic variation in species assemblages to selected environmental factors (Kim 1993; Dallmeier 1996; Dennis and Ruggiero 1996; Debinski and Humphrey 1997; Fuller et al. 1998; Mahan et al. 1998).

In natural resource management agencies, such as the NPS, a resource management plan based upon biodiversity assessment is now routinely developed to meet the objectives of sustainable management of natural resources. Such a plan is often initiated because of: (1) a threat to the management unit, such as loss of habitat due to human infringement, urban development, or habitat fragmentation; (2) the presence of non-indigenous invasive species, or rare, endangered or threatened species; or (3) a policy mandate (e.g., Pennsylvania Department of Military and Veterans Affairs Environmental Impact Assessment Vol II Integrated Natural Resources Management Plan. Enhanced Training & Operations at the National Guard Training Center at Ft. Indiantown Gap, March 2002).

Biodiversity Inventory and Species Lists

Historically, biodiversity inventories were important undertakings for systematics and conservation of global and regional biodiversity. For the last decade many international environmental agreements and programs (e.g., Convention of Biological Diversity, Agenda 21, The Global Biodiversity Strategy and Guidelines for Country Studies on Biological Diversity) called for accelerated efforts to inventory global biodiversity and to monitor changes in the state of biodiversity worldwide because of rapid degradation of biodiversity and loss of species (Solbrig 1991; WRI/IUCN/UNEP 1992; UNEP 1993; Stork and Samways 1995). A biodiversity inventory may be defined as a formal cataloging of the occurrence and distribution of particular taxa in a defined geographic unit. These inventories usually are presented in the form of species lists, which are important for identification of: 1) rare or threatened species (e.g., Pennsylvania Natural Diversity Inventory), 2) useful or harmful species, 3) geographical distribution of taxa, and 4) new species for research on future industrial and agricultural application (Dennis and Ruggiero 1996; Stork and Davies 1996; Debinski and Humphrey 1997). Inventories also provide the data for establishing biodiversity pattern and endemism, evolution, and phylogeny (Stork and Davies 1996).

At the same time, biodiversity inventories became important because ecosystem management requires baseline data on the occurrence, distribution, and the state of biodiversity for each management unit. Information from a species list can be used to calculate the percent of taxa per collecting site. For example, the result of an inventory of a wetland habitat may include 30% salamanders, 30% birds, 15% toads and frogs, 15% turtles, 5% snakes, and 5% lizards (Fig. 1). Within the same habitat, each of the faunal groups can be further identified by guilds, and percent within habitat can be calculated (e.g., 60% phytophagy [guild 1], 15% omnivory [guild 2], 10% zoophagy [guild 3], 5% predatory [guild 4], 5% herbivory [guild 5], and 5% mycophagy [guild 6]) (Fig. 2).

These species lists, however, are only a first step in natural resources and ecosystem management. Historically, taxonomic specialists have conducted taxon-based inventories (e.g., search-based inventory by Baldi [1999]) for taxonomic or biotic research following specific collecting or survey techniques suitable for specific taxon. Such biodiversity inventories provide important taxonomic and distributional baseline data for a specific taxon within a specific area of interest (e.g., a target site within a national park). However, most of these inventories lack information on habitats and associated substrata or animal/plant hosts of the species as well as relative abundance (Kim 1993; Debinski and Hymphrey 1997; Baldi 1999). In addition, species lists for a variety of taxa, such as vascular plants, birds, and mammals, are not usually integrated (Kim 1993; Baldi 1999). Thus, it is important that existing or archival information from research papers and reports, books, databases, and museum specimens be collected, carefully reviewed, and assembled into a specific biodiversity database. This information provides the overview of the biodiversity knowledge base for a specific area. These data, however, must be carefully evaluated before being included in a species list for a particular area because they may contain incomplete or incompetent details in taxonomy, obsolete habitats, missing collection dates, or other important collection information. These problems often can be alleviated if voucher collections associated with the reports and databases are available. Therefore, resource management agencies should require voucher collections for all biodiversity inventories so that every inventory record can be verified with voucher specimens.

Approaches to Biodiversity Inventory

Traditional approaches to biodiversity inventory were taxon-based and the results were partial and skewed to taxa that are better known, such as vascular plants, birds, and mammals. Although these data certainly enriched the taxonomy and systematics of these taxa, they have not contributed much to conservation and sustainable management of local biodiversity because they do not contain information about more obscure organisms present in the ecosystem (Kim 1993). Considering the roles small, often seemingly obscure organisms such as invertebrates, fungi, and lower plants, play in ecosystem function, taxon-based biodiversity information that does not include these organisms is incomplete and often leads to biased application in scientific analysis and conservation actions. Furthermore, integration of taxon-based metadata such as National Gap Analysis (e.g., Scott et al. 1993), that are based on specimen data in museum collections that mostly are archival in nature, has not been very helpful to resource management and conservation of local biodiversity.

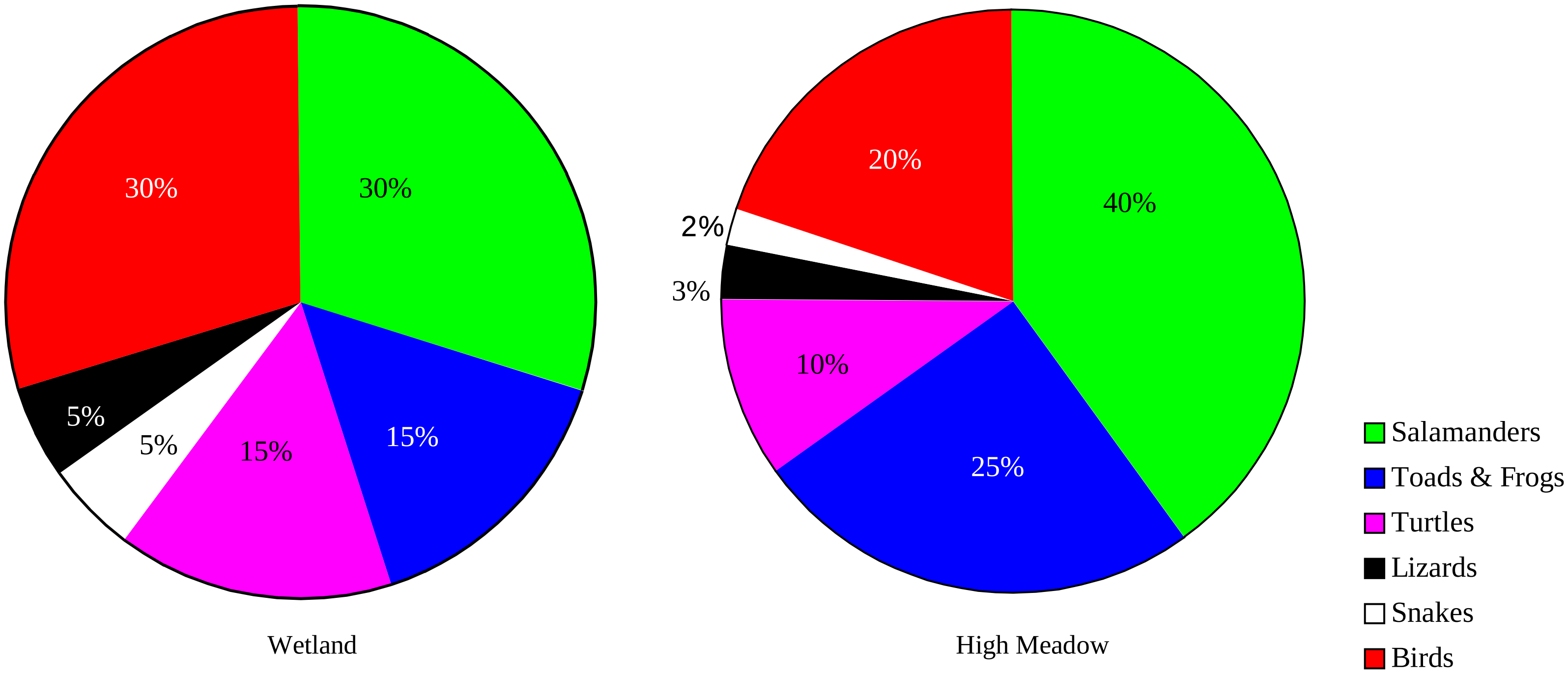

Figure 1. Example of describing the percent of taxa by different habitats. (Fictitious percentages for example purpose only.

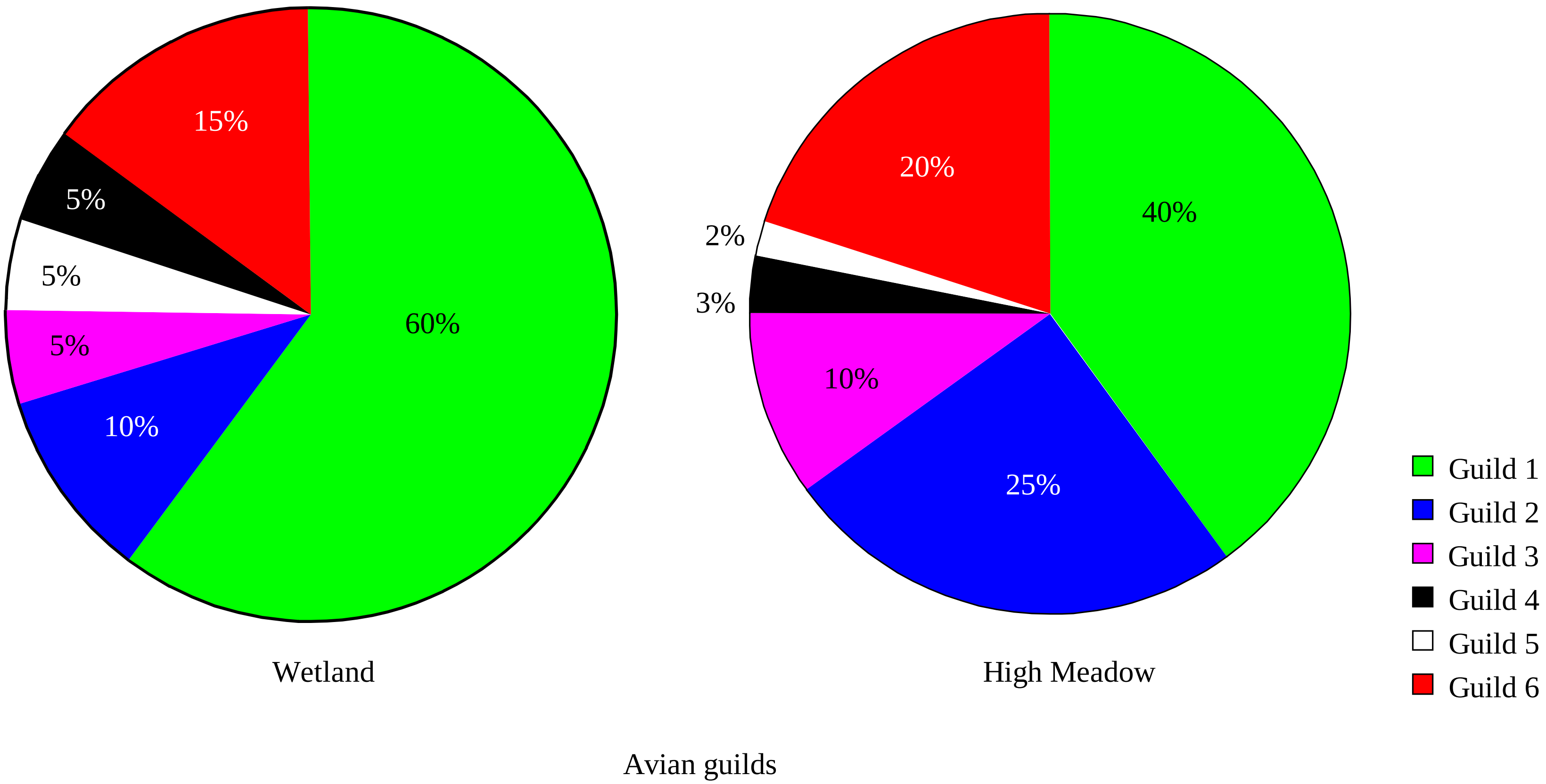

Figure 2. Example of describing the percent of guilds by different habitats. (Fictitious percentages for example purposes only.)

To rectify these difficulties, several all-taxa approaches with different ecological and conservation goals and at different scales, such as All Taxa Biodiversity Inventory (ATBI), All Biotic Taxonomic Inventory (ABTI), Rapid Biodiversity Assessment (RBA), Rapid Biodiversity Inventory (RBI), Biodiversity/Ecosystem Profile Assessment (B/EPA), and BioBlitz Inventory (BBI), have been developed. ATBI and ABTI have been proposed and minimally implemented to complete inventories of all species of life on Earth within a designated time line; for example, five years for ATBI sites of Costa Rica's IMBio (Janzen and Hallwach 1994; Janzen 1997) and 25 years for ATBIs of the All Species Foundation (http://www.all-species.org/). RBA is an emergency rescue approach to save biodiversity information and germplasm for endangered or threatened habitats, ecosystems, or regions, and is also used for developing environmental indicators for land use (Kerr et al. 2000). These approaches are heavily dependent on taxonomic experts—the human resource that is in serious shortage and continues to decline.

All Biota Taxonomic Inventory (ABTI)

The All Biota Taxonomic Inventory (ABTI) is an inventory approach to expand biodiversity knowledge, primarily for systematics or biodiversity science, by focusing on a number of "important taxa." Important taxa are chosen based on systematic, economic, or medical criteria. This approach focuses on concerted collecting and study of key taxa within a defined timeline. The expected outcome of this approach is to expand the knowledge base of the biology and taxonomy of important taxa that will match that of well-known vertebrate taxa like birds and mammals. The rationale for this approach is to provide balance in biodiversity inventories and conservation. These data can be used for diverse applications at different spatial and geographical scales (Wheeler 1995; Wheeler and Cracraft 1995; Stork and Davies 1996).

All Taxa Biodiversity Inventory (ATBI)

Developed strictly from ecological and economic perspectives, All Taxa Biodiversity Inventory (ATBI) was initially proposed to collect and identify all the species of local biodiversity at a single geographical site selected for a specific purpose, such as Wildland Biodiversity Management sites in the tropics (Janzen and Hallwachs 1994; Janzen 1997) and the Great Smokey Mountains National Park (Sharkey 2001). The Wildland Biodiversity Management ATBI is a five-year, species level, total biodiversity inventory of a selected site, such as Guanacaste Conservation Area in Costa Rica. Biodiversity information and voucher specimens collected from this effort are available to different user groups. This program generates baseline information on biodiversity of the site for sustainable uses that include education, ecotourism, biodiversity prospecting, and environmental monitoring (Stork and Davies 1996; Dangerfield and Pik 1999).

In practice, however, ATBI is expensive and time consuming, requiring extensive input from many taxonomic experts that are in a serious shortage worldwide (Stork and Davies 1996; Janzen 1997). The ATBI of the Great Smokey Mountains National Park (GSMNP) is the first ATBI site for national parks in North America to explore and describe all the species inhabiting the park by willing systematists (Taxonomic Working Groups [TwiGS]) who will describe new findings, including new species (Sharkey 2001). However, it will take 22.5 years and 100 systematists to collect and describe 10% of the extant species within GSMNP. As described earlier, the outcome of the GSMNP-ATBI will provide necessary baseline information on natural history and protection of GSMNP biodiversity that will be of tremendous benefit to conservation and education (Dangerfield and Pik 1999). Following the Janzen's Costa Rican ATBI model, the GSMNP-ATBI was organized in December 1997 by scientists, educators, and administrators with great fanfare and expectation. Although it is an ambitious program with well-meaning scientists, administrators, and interested public, it will take a long time before the biodiversity data become available for use. Large parts of the voucher collections from ATBIs in many countries remain unidentified and stored in museums awaiting identification. The ATBI is an important undertaking for biodiversity and should be promoted and supported; yet, it will take a long time before natural resource management programs can make use of biodiversity information collected through ATBI.

Rapid Biodiversity Assessment (RBA)

In conservation practice there frequently is the need to rapidly assess biodiversity in endangered habitats and ecosystems for conservation or resource management practices. Both ABTI and ATBI require a relatively long time to produce necessary information and therefore do not meet the short-term needs of providing scientific advice for resource managers and policy makers. To meet these needs, Rapid Biodiversity Assessment (RBA) approaches have been developed (Beattie et al. 1993; Stork and Davies 1996). Different survey techniques have also been developed for specific taxa. For example, Margules and Austin (1991) developed RBAs for vertebrates and vascular plants and Oliver and Beattie (1996a) and Trueman and Cranston (1997) developed RBAs for invertebrates. In RBA, a group of taxonomic specialists, often associated with a museum, taxonomic, or conservation organization, organize a rapid biodiversity expedition to a site that is planned to be exploited or converted to human enterprise. The purpose of a RBA is to collect voucher specimens and document the threatened biodiversity before it is permanently lost.

Many conservation organizations use RBA for assessing the state of a specific taxon. For example, Conservation International often uses RBA for conservation of South American primates. RBA data on species richness or endemism are used to set priorities for conservation (Stork and Davies 1996). RBA is also used to assess or estimate the status of target habitats for conservation or environmental impacts of planned large-scale development projects, or for ecological risk analysis, for which morphospecies or "recognizable taxonomic units" (RTU) are used as taxonomic units to shortcut the species identification for practicality (Oliver and Beattie 1996b; Kerr et al. 2000). Similarly, for some taxa, such as vertebrates, trees, and butterflies, RBAs have used Visual Encounter Surveys (VES) to determine the presence and absence of particular species or to estimate species counts for the defined sampling sites (Crump and Scott 1994).

RBA is an effective approach to rapid assessment of the state of biodiversity or rapid measurement of stressor impacts on habitats or ecosystems of biodiversity that can be designed specifically for diverse inventory programs (Oliver and Beattie 1996a; Stork and Davies 1996). However, RBA does not replace an intensive all-taxa survey to describe the occurrence, distribution, microhabitat, host plant or animal association, and relative abundance of biodiversity at a given management site.

Rapid Biodiversity Inventory (RBI)

The Field Museum of Natural History in Chicago, IL incorporates rapid biodiversity inventories into their Environmental and Conservation Program. The goal is to influence effective action for conservation in threatened regions of high biological diversity and uniqueness. During RBI scientific teams focus on groups of organisms that indicate habitat type and condition and that can be surveyed quickly and accurately. These identify the important biological communities in the site or region of interest and determine whether these communities are of outstanding quality and significance in a regional or global context. The Field Museum's RBI has a social component. During rapid social asset inventories, scientists and local communities collaborate to identify patterns of social organization and opportunities for capacity building. In-country scientists are central to the field teams. The experience of local experts is crucial for understanding areas with little or no history of scientific exploration. Once these rapid inventories have been completed (typically within a month), the teams relay the survey information to local and international decision makers who set priorities and guide conservation action in the host country (http://fm2.fieldmuseum.org/rbi/).

Biodiversity-Ecosystem Profile Assessment (B-EPA)

In sustainable management of natural resources, particularly for ecosystem management, the B-EPA describes the occurrence and distribution patterns of biodiversity while focusing on the interactions of all the resident taxa and their habitat relationships. Biodiversity profile represents the description of species composition in a defined sampling unit, whereas ecosystem profile represents the description of ecosystem structure by the summation of biodiversity profiles of a defined sampling plot unit (Mahan et al. 1998). In this approach, invertebrates and non-vascular plants are focused as the target organisms because they are major webmasters in ecosystems (Kim 1993) and also represent the great majority of species in terrestrial ecosystems. They are sufficiently diverse in species composition to provide appropriate data for estimating species diversity and confidence limits for taxonomic diversity.

Based on satellite and aerial images of landforms and vegetation, B-EPA begins with site selection and plot sampling design for biodiversity inventory. This approach requires a multi-scale and multi-seasonal assessment using many different collecting and sampling techniques targeting all taxa of plants, animals, fungi, and microorganisms. This approach, when applied to biodiversity inventory in Shenandoah National Park and Gettysburg National Military Park, provides not only the catalog of resident species, but also yields many new records for the geographical areas and new species for science. The outcome is not surprising because barely 50 percent of the North American arthropods have been described (Kosztarab and Schaefer 1990). For the purpose of developing a monitoring program to detect ecological changes, all species represented in the sampling unit are classified into functional groups or guilds from which indicator species can be defined and selected. A monitoring strategy, with a set of indicator species, is then developed for the resource management program specific to the defined management goals of the ecosystem management unit.

The biodiversity profile coupled with the description of the physical ecosystem will provide a better understanding of the structure and interactive processes of ecosystems for assessing the state of biodiversity across spatial and temporal scales. Data from the B-EPA will enable researchers and resource managers to manage interactions among ecological components across spatial scales, assess and predict changes in biotic communities of the ecosystems at regional levels, and explore human dimensions of predicted or realized ecological changes across spatial and temporal scales.

BioBlitz Inventory (BBI)

The BioBlitz approach has a strong public interest since the 24-hour (May 31-June 1, 1996) "public" expedition to the Kenilworth Park and Aquatic Gardens National Park upon the banks of the Anacostia River in Washington, DC. Since then, numerous BioBlitz inventories have taken place in many regions. Traditionally, the BioBlitz is a 24-hour inventory event to document the biodiversity present at designated management units, such as municipal parks or nature reserves, using the natural history talents of established scientists, local naturalists, and the interested public. Considering the lack of biodiversity inventory data for most urban green spaces, and for invertebrates (Koszatarab and Schaefer 1990) and lower plants (e.g., LaRoe et al. 1995; Hassinger et al. 1998; Mac et al. 1998, for United States), the BioBlitz approach provides an opportunity for the public and scientific community to seek and document biodiversity. The BioBlitz approach attracts media attention and enhances public knowledge about what organisms occur in a variety of habitats. Although BioBlitz does not provide a complete inventory, it does provide baseline information on local biodiversity, taxonomic and biogeographic information, an opportunity for bridge-building between scientists and the public, and for public education in local natural history (USGS/DOI 2001).

Taxonomic Reality, Species, and Morphospecies

Despite all of these efforts to conduct biodiversity inventories, the taxonomic reality of cataloging, describing, and storing site-specific biodiversity information remains outstanding. There are still many millions of specimens in collection boxes, drawers, jars, and freezers of museums and personal collections worldwide that have been collected and stored, unsorted, and unidentified into species because of the lack of funds, personnel, and taxonomic expertise. Similarly, many collections from biodiversity inventories have remained, and will remain, unattended for a long time before they are sorted and identified, and new species are described for science and conservation, unless a concerted effort is made to facilitate and fund the species identification process.

There is no easy alternative for biodiversity assessment in the context of sustainable natural resource management to protect and conserve biodiversity while human needs of land use or land conversion are met. In other words, we should know what we have before we use or alter it for human enterprise. It is imperative that every effort is made to identify or describe specimens to species level collected from biodiversity assessments. The use of morphospecies as a naming device can be used as a limited and temporary alternative when species are initially sorted from samples and not immediately identified. This alternative works well for the purpose of preliminary mathematical or statistical analysis of the specimen data. Specimens labeled morphospecies need to be identified or described at some point by a specialist of the particular group before such specimens are published in species lists. As many different approaches and techniques are now available for biodiversity assessment, the selection of the appropriate biodiversity inventory method depends upon the specific objectives of each project. For some conservation projects, RBA may serve the purpose of assessing the biodiversity that is expected to be lost (Stork and Davies 1996; Oliver and Beattie 1996a). For the purpose of systematics and natural history, ATBI and ABTI are good approaches to global or regional biodiversity inventory. However, for localized natural resource management, biodiversity assessment must provide site-specific data in each management unit. Therefore, it is necessary for natural resource management agencies to develop a specific biodiversity inventory strategy that is to be systematically implemented with specific timelines and necessary budgetary supports.

As many different approaches and techniques are now available for biodiversity assessment, the selection of the appropriate biodiversity inventory method depends upon the specific objectives of each project. For some conservation projects, RBA may serve the purpose of assessing the biodiversity that is expected to be lost (Stork and Davies 1996; Oliver and Beattie 1996a). For the purpose of systematics and natural history, ATBI and ABTI are good approaches to global or regional biodiversity inventory. However, for localized natural resource management, biodiversity assessment must provide site-specific data in each management unit. Therefore, it is necessary for natural resource management agencies to develop a specific biodiversity inventory strategy that is to be systematically implemented with specific timelines and necessary budgetary supports.

Analysis and Synthesis of Biodiversity Inventory Data

The analysis and synthesis of biodiversity data is complex and involves various disciplines such as taxonomy, ecology, conservation biology, economics, public opinion, and environmental planning. Several approaches and applications have been used to help researchers analyze and synthesize biodiversity data. These approaches and applications include: 1) support tools, 2) indices and models, and 3) decision support systems. Support tools are used to integrate, present, and analyzed biodiversity inventory data in a comprehensive manner. Indices and/or models are calculated or developed to present biodiversity data as a concept or algorithm. For example, indices and models can be used to describe functional relationships among taxa, identify critical components of ecosystems, and/or communicate complex relationships among taxa in simple ways (Wright 2002). Decision support systems integrate support tools, indices, and models into one system and provide resource managers and researchers with the information necessary to make complex decisions more efficiently (Malafant and Davey, 1996).

Support Tools

A variety of support tools are used to integrate, analyze, and present data and results in a comprehensible manner. These tools include database management, Geographic Information Systems (GIS), image processing and visualization, and statistical sampling and analysis.

Database Management

Databases are developed to store, retrieve, and update biodiversity inventory data and to provide access to data for people in the private and public sectors (Kim 1993). Microsoft Access® and Filemaker Pro® are commonly used to store and use biodiversity data.

Products on the market that are designed for the intent of biodiversity databases include Biota® (http://viceroy.eeb.uconn.edu/biota) and Alice® (http://www.alicesoftware.com/Products.htm). A list of other databases used to store biodiversity data can be found at the International Working Group on Taxonomic Databases Web site http://bgbm3.bgbm.fu-berlin.de/TDWG/acc/Software.htm. The Expert Center for Taxonomic Identification (ETI) World Biodiversity Database contains 200,000 taxa and is one of many biodiversity databases accessible on the Internet (http://www.eti.uva.nl/Database/Database.html, http://biodiversity.soton.ac.uk/database/webdb.shtml, and http://iris.biosci.ohio-state.edu/home/list_dbs.html. NPSpecies is the National Park Service's biodiversity database that manages inventory data and is used to share species information to researchers and other interested parties (http://science.nature.nps.gov/im/apps/npspp/index.htm).

Geographic Information Systems

GIS is useful for mapping locations where species were collected and different habitat characteristics that were recorded for these populations. The GIS most commonly used by conservation and biodiversity agencies are the ESRI products ARC/Info® and ARC/View®. Considerable expertise in their use and a large body of additional software that interacts with the products exists (e.g., http://www.esri.com/index.html).

Image Processing and Visualization

Image processing and visualization software are computer-generated graphics, art, and design programs that enhance the understanding of concepts and processes and are used for effective presentations of data, results, and models. Examples include scene analysis, image compression, image restoration, image enhancement, image preprocessing, spatial filtering, and construction of two- and three-dimensional models of objects. Digital image processing software packages that have the ability to manipulate images, change formats, and process a variety of remotely sensed data (such as Landsat and aerial photographs) include U.S. Geological Survey's (USGS) Mini Image Processing System (http://terraweb.wr.usgs.gov/software/mips/) and U.S. Department of Agriculture's (USDA) Stand Visualization System (http://forsys.cfr.washington.edu/svs.html). Image processing and visualization are used to enhance GIS layers, maps, and presentations (e.g., http://www.innovativegis.com/papers/vis/p347.htm and http://www.vectorone.info/vertical.htm).

Statistical Sampling and Analysis

In order to conduct an appropriate analysis and/or synthesis of data collected from biological inventories, the goals and sampling objectives of a project should be determined *a priori* (Figures 3, 4, and 5). Often, preliminary or baseline inventory data can be used to set specific sampling objections (Diefenbach and Mahan 2002). Once specific sampling objectives are set, an appropriate, statistically-sound sampling design can be implemented. A statistically-sound sampling design ensures that biological inventory data can be used to understand ecological relationships through testable hypotheses, monitor community changes over time, or prioritize areas of conservation concern (Debinski and Humphrey 1997; Gibbs 1998). For instance, Diefenbach and Mahan (2002) used Long-Term Ecological Monitoring (LTEM) vegetation data from Shenandoah National Park (SHEN) to set specific sampling objectives that linked vegetation management objectives to a degree of statistical rigor, including alpha-levels and statistical power. An example of a sampling objective that was formulated for SHEN was, "we want to be 90% sure of detecting a 50% change in the density of any one species of tree within any one forest cover type at SHEN over a five year period and are willing to accept a two in 10 chance that a change took place when it really did not" (Deifenbach and Mahan 2002). A statistically sound sampling design based upon this sampling objective was then designed and implemented at SHEN. However, the preliminary vegetation inventory was necessary in order to determine the appropriate sampling design to meet the sampling objective.

Hone (1991) collated the types of statistical analysis used in faunal surveys published in the journals Australian Wildlife Research and Journal of Wildlife Management from 1984 to 1987. The most frequent statistical tests used to analyze time, space, and habitat effects on species occurrence were Chi-square analysis, correlation and regression, Student's t-test, and analysis of variance. How the data are analyzed, however, depends on the scientific questions being asked (Table 1).

Multivariate statistical analysis is a common approach for observing patterns in species composition relative to environmental physical conditions (Debinski and Humphrey 1997). Principal Components Analysis (PCA), Correspondence Analysis (CA), and Discriminant Function Analysis are examples of commonly used statistical tests used in multivariate analysis (Table 1). PCA is appropriate for abundance data and CA is more appropriate for

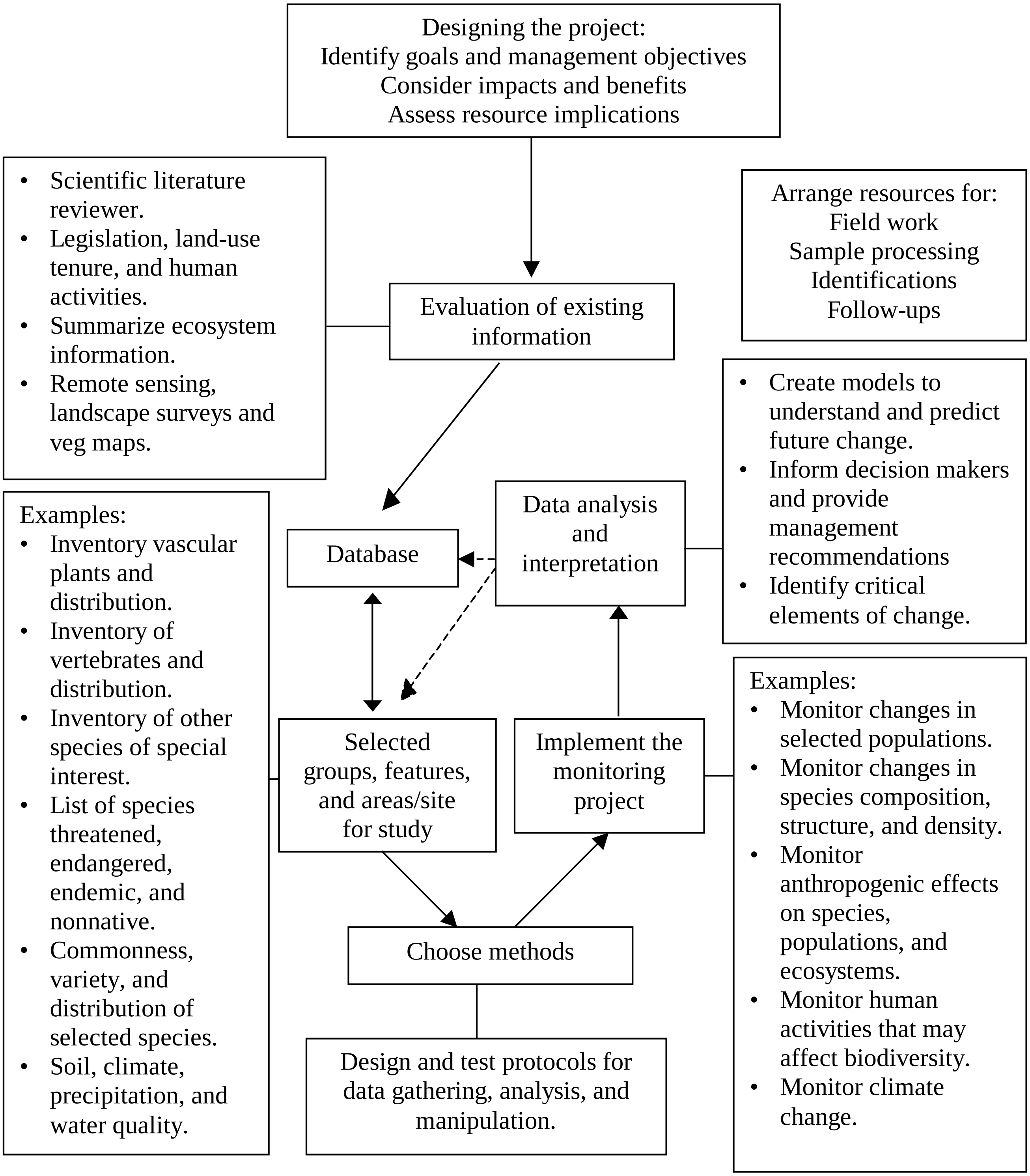

Figure 3. Example of how to plan a biodiversity inventory (Stork and Davies 1996).

1. Identify clear management goals for conducting biodiversity assessment and develop testable hypotheses; and
2. Establish sampling sites and choose taxa to survey.

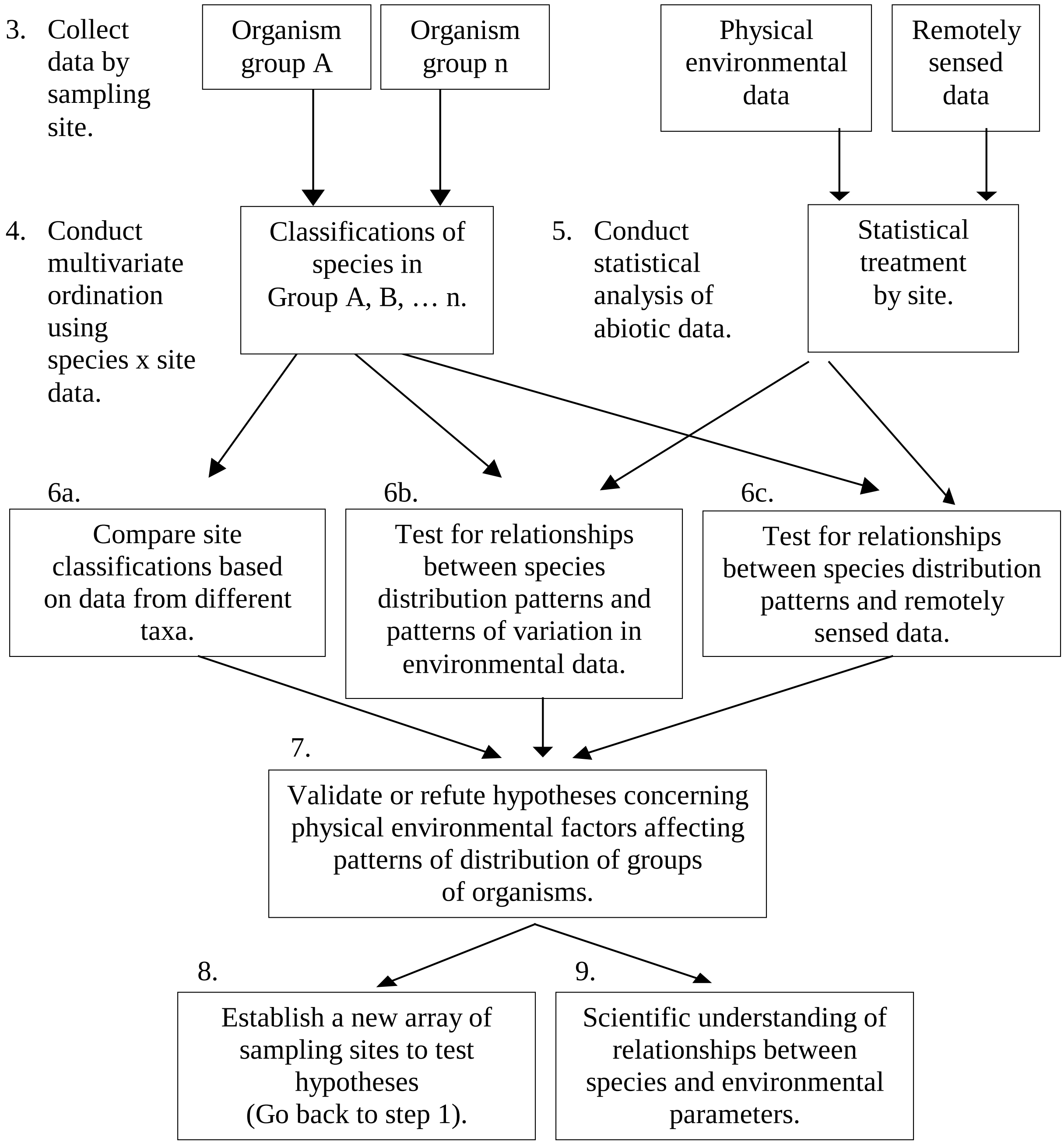

Figure 4. An example of a research design for a biodiversity assessment (Debinski and Humphrey 1997).

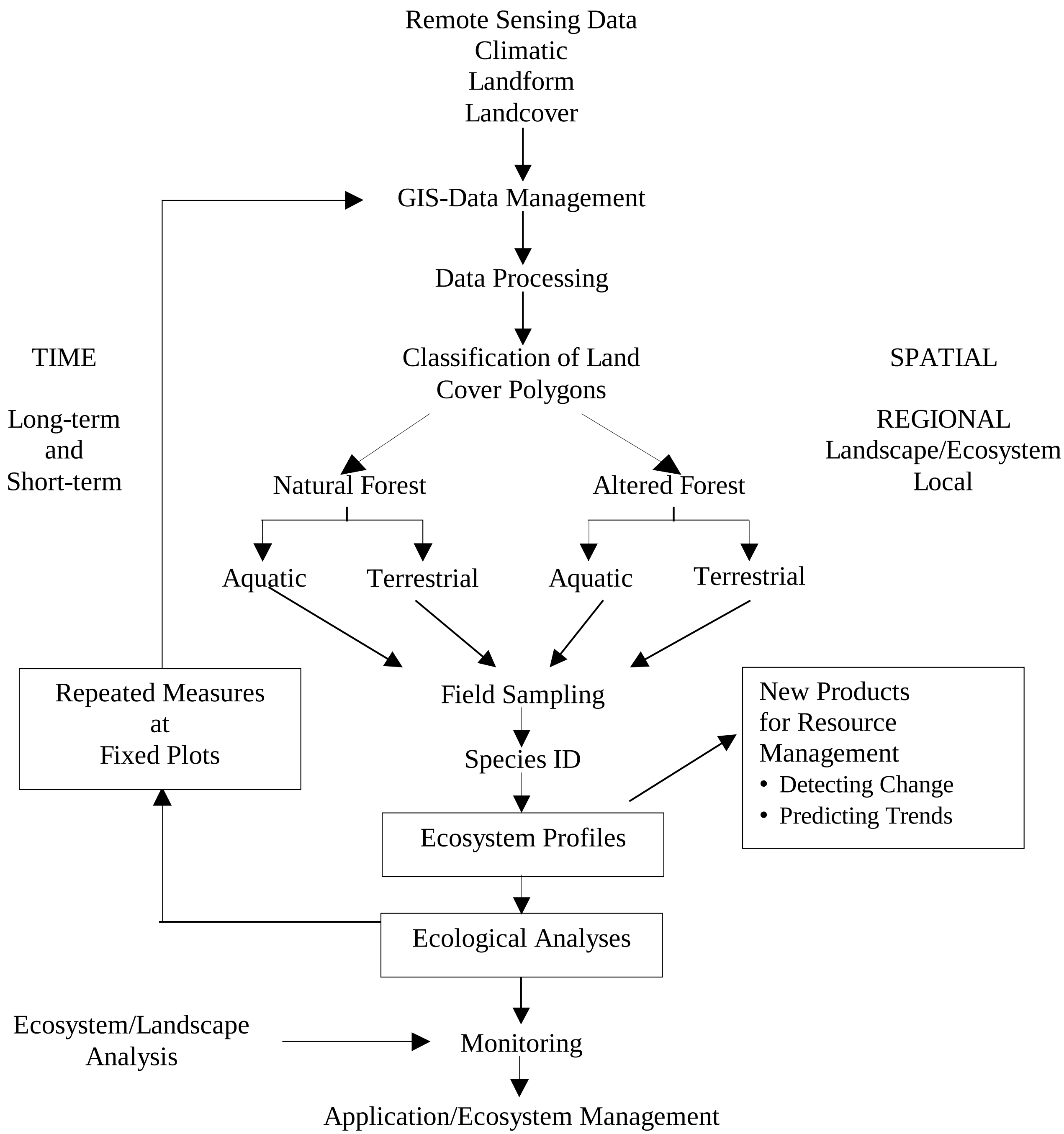

Figure 5. Schematic of process for developing biodiversity profiles related to ecosystem and landscape analyses (Mahan et al. 1998).

Table 1. Examples of faunal survey objectives and the statistical tests used to test them (after Hone 1991).

Research or Inventory objectives	Statistical tests
Characterize the species distribution patterns of each group of organisms in quadrats representing different habitats	Principal Components Analysis or Correspondence Analysis
Compare species associations of two or more groups of organisms inventoried in sampling sites for similarities and differences	Principal Components Analysis or Correspondence Analysis
Prioritize sampling sites based upon the presence of unique species	Chi-square or Discriminant Function Analysis

presence/absence data (Debinski and Humphrey 1997). Multivariate analysis software programs for ecological and species diversity analysis that are available on the market include Multivariate Statistical Package (http://www.kovcomp.com/mvsp/), PC-ORD (http://home.centurytel.net/~mjm/), and Primer (http://www.pml.ac.uk/primer/). A list of multivariate statistical software also is provided by Oklahoma State University (http://www.okstate.edu/artsci/botany/ordinate/).

Indices and Models

Indices and models present biodiversity inventory data as a concept or algorithm. They form the basic building blocks for more complicated analyses and modeling frameworks. Indices are presented as numerical units that characterizes a set of data. Models are used to identify relationships and interactions among biodiversity data. For example, models do not only include the components of the system (taxa), but can describe functional relationships between these components as well. Models can help clarify understanding, identify areas of uncertainty, identify critical components of ecosystems, and communicate complex ideas in simple ways (Wright 2002). Models take many forms; verbal, qualitative and graphical, mathematical, and computer- based. Much of the value comes from designing models, which involves determining how elements are related to one another. There are a number of models used in community ecology and biodiversity conservation, but for the purpose of this paper we will limit our discussion to biodiversity and guild models.

Species Diversity Indices and Models

Species diversity can be divided into the following two categories: species richness, which is the number of species in the assemblage; and relative abundance or evenness, which is the relative distribution of individuals among species. Species richness measures the number of species in a defined sampling unit, the simplest being the count of species, and is often associated with quantifying or analyzing biodiversity (Gotelli and Colwell 2001). Because it is impossible to sample the whole population of a particular community, ecologists and mathematicians developed statistical indices and models for measuring diversity. These indices and models estimate the expected number of species and abundance of individuals in the population based on the sample of data collected from studies and inventories.

The use of more than one index is recommended when quantifying diversity (Southwood 1978; Magurran 1988; Gotelli and Graves 1996). Computer software is available to calculate diversity models and indices. EcoSim® is a program to analyze species diversity using rarefaction, PIE, and dominance (Gotelli and Entsminger 2004, http://www.garyentsminger.com/ecosim/index.htm). EstimateS® computes randomized species accumulation curves and statistical estimators of true species richness (Colwell 2004, http://viceroy.eeb.uconn.edu/estimates). Other available programs include Pisces (http://www.pisces-conservation.com/indexsoftdiversity.html) and Statistical Ecology (http://nhsbig.inhs.uiuc.edu/wes/ludwig_and_reynolds.html).

Some habitats may have high species diversity due to a prevalence of nonnative species. As such, composition (e.g., percent of species that are native vs. nonnatives) is often more valuable in prioritizing conservation areas than a species richness or diversity index. However, not all nonnative species are invasive or destructive to natural communities. Most nonnative species do not cause extinctions of natives, while other nonnative species can adversely affect native communities (Simberloff 1981, 2001). Therefore, setting management goals about which nonnative species are damaging and which habitats are vulnerable to these invasions will require a broad range of ecological expertise (Meffe and Carroll 1994). Furthermore, management goals may vary depending upon the larger landscape context. For example, in relatively disturbed (e.g., highly-urbanized, agricultural) landscapes nonnative species may be accepted as a part of the “natural” environment, while in less disturbed areas nonnative species should be limited or controlled. In any case, it may be important to use inventory data to indicate which nonnative species are present and where they are located. The USGS has developed a model that helps forecast exotic and invasive species (http://bp.gsfc.nasa.gov/isfs.html).

There are no standard recommendations on what index or model to use when measuring species diversity within or among habitats. Many different indices are used and numerous problems are associated with each. Vanclay (1996) states the literature reflects a preoccupation with computing indices rather than gathering reliable data, and more research is needed to determine what, when, and how to measure biodiversity data. Data for many biodiversity studies are rapidly gathered from many sites over large areas and consequently focus on presence/absence data rather than detailed time-consuming measures of quantity. Furthermore, species diversity indices and models have mainly been used to analyze single taxon data, however, to assess biodiversity, multi-taxa data sets need to be analyzed. Some researchers have attempted multi-taxa analyses using diversity indices and models. For example, Ratsirarson et al. (2002) compared ants, wasps, Opiliones, and Amphipoda from leaf-litter samples on the same graph (all taxa graph) using accumulation curves (Ratsirarson et al. 2002). Lawton et al. (1998) correlated different taxa species richness across plots using different sampling methods.

Species Richness Indices and Models: These indices and models are used to represent or predict the number of species in a defined sampling unit. However, it is not always possible to ensure that all sample sizes in a biodiversity inventory are equal, and the number of species invariably increases with sample size and sampling effort. To solve this problem, Sanders (1968) devised a model, called rarefaction, for calculating the number of species expected in each sample if all samples were of a standard size (the smallest sample size in the collection is often used as the standard). A curve can be plotted on a graph if the rarefaction procedure is done for several abundances (Gotelli and Graves 1996). Assumptions of the rarefaction model are: sufficient sample size (large), individuals are spatially dispersed at random, species are taxonomically ‘similar’ and are drawn from the ‘same’ community type, and standardized sampling techniques are used for all collections. Often, plotting rarefaction curves and their 95% confidence intervals is enough to reveal differences in expected species (Gotelli and Graves 1996) (Fig. 6).

Rarefaction is used to estimate the number of species from a large sample to a smaller one, whereas estimating the number of species from a small sample to a larger one is necessary to determine the total number of species present in the assemblage. Methods for estimating the number of species in a population or whether the sampling effort was sufficient to have collected all of them from a habitat are known as species richness estimators. These non-parametric estimators use data from sub-samples to estimate species richness of a larger area (Colwell and Coddington 1994). Some of these estimators are based on incidence (presence/absence) data while others require relative abundance data. Examples of these richness estimators are Chao 1 and 2, First and Second Order Jackknife, Bootstrap, Abundance-based Coverage Estimator (ACE), and Incidence-based Coverage Estimator (ICE) (Chazdon et al. 1998). Curves can be

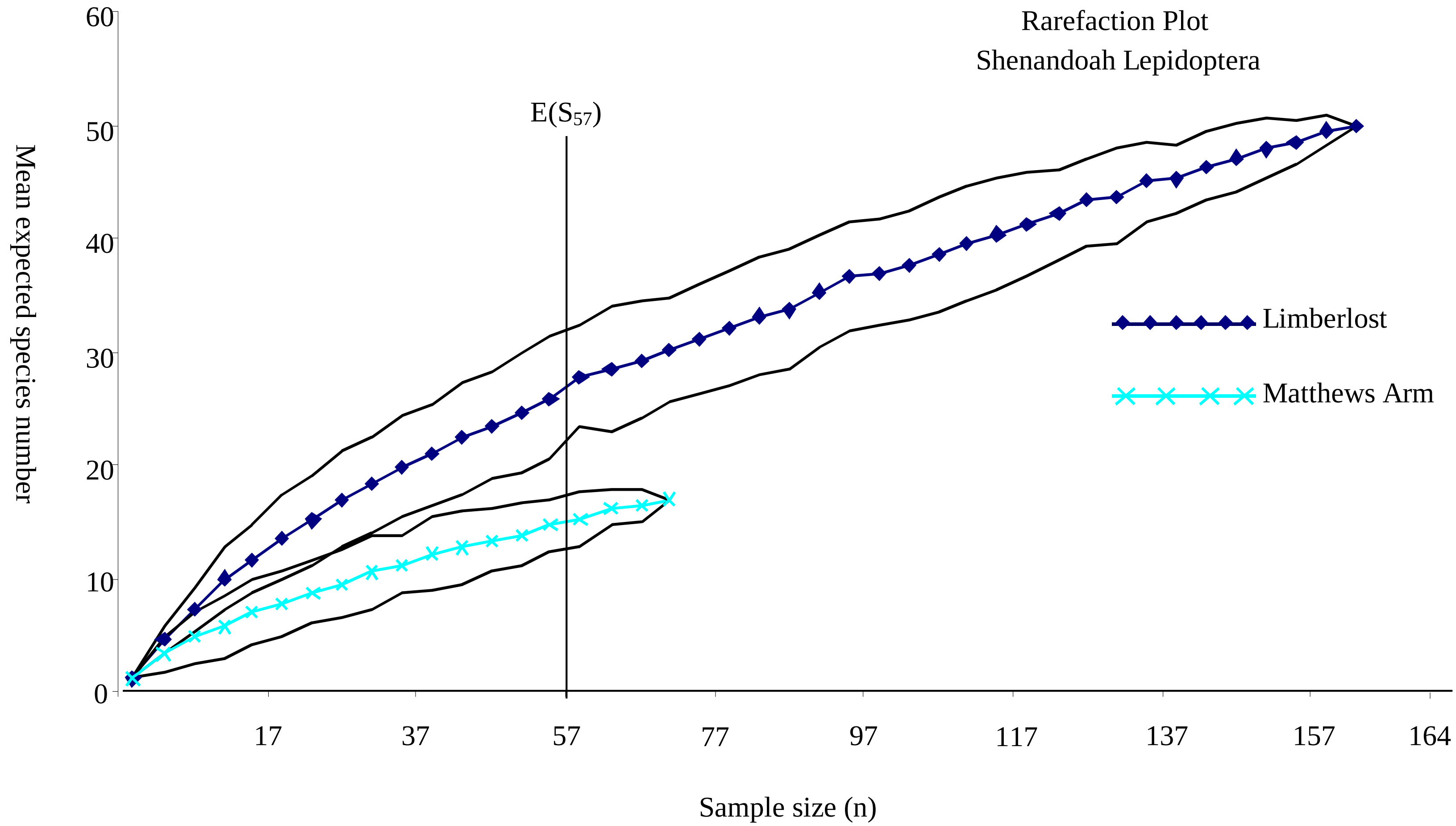

Figure 6. Rarefaction curves and 95% confidence intervals. This example shows that Limberlost (Hemlock site) has a higher Lepidoptera species richness than Matthew's Arm (Hardwood site) at a sample size of 57 individuals (data taken from the NPS Shenandoah Biodiversity Inventory 1997).

plotted for estimated species richness and compared with the observed species accumulation curve or collector's curve.

Species Abundance Models: These models are used to describe the distribution of species abundance within a particular habitat. Species are not equally common in a particular habitat. For example, a few individuals represent most species, some species have medium abundance, and a few species are very abundant. These patterns led to the development of four models of species abundance: the log normal distribution, geometric, log series, and MacArthur's broken stick model (Southwood 1978).

Evenness or Equitability Indices and Models: Evenness or equitability indices describe the relative distribution of individuals among species. An example of an evenness index is Hurlbert's Probability of an interspecific encounter index (PIE) (Gotelli and Graves 1996). This index provides the probability that two randomly sampled individuals from the same community represent two different species (Gotelli and Graves 1996). Other evenness indices include Brillouin's measure, Lloyd and Ghelardi's index, and McIntosh's measure (Magurran 1988). When analyzing a particular inventory data set, another method for determining equitability is the Caswell Neutral Model. This model calculates a measure of equitability, based on the Shannon index H' (see below), which is robust to sample size and is a useful adjunct to rarefaction. It calculates the V-statistic and when $V=0$ the sample is predicted to be from a neutral assemblage. If $V>0$ then the samples are more diverse (excess equitability) and if $V<0$ the samples are less diverse (excess dominance) (Platt and Lambshead 1985).

Proportional Abundance of Species Indices: One example of this type of index is the information statistic index or diversity index. This index combines species richness and evenness into a single figure. However, by combining species richness and evenness into a single statistic, such as the Shannon index, it is hard, if not impossible, to determine what parameters have the greatest influence on the community (Gotelli and Graves 1996). Despite this drawback, diversity indices are the most common indices used when presenting biodiversity inventory data. Some authors continue to suggest measuring and presenting species richness and evenness separately (Magurran 1988; Gotelli and Graves 1996). Another proportional abundance index is dominance. Dominance is the fraction of the collection that is represented by the common species (Gotelli and Graves 1996). Dominance can be a useful index to determine if a habitat is monopolized by a dominant competitor especially in communities that have been invaded by exotic species.

Comparing diversity between habitats can be represented and measured using a wide range of indices, multivariate analysis, and statistical tests. The diversity is higher when the different habitats share fewer species. One way of measuring the diversity between habitats is with methods that use species presence and absence data. Similarity coefficients such as Jaccard index are used to measure the common species or individuals found in two or more habitats (Southwood 1978). Cluster analysis provides a good representation of diversity when several sites are used in a study. It pairs similar sites and joins them to form a cluster and continues joining similar pairs until all sites are joined. Then dendrograms are used to visually interpret the results.

Biodiversity Models

Biodiversity models have been developed for a number of different uses such as to estimate the number of species on a global or local scale, to work out conservation problems, to help design biodiversity reserves and management areas, and to analyze data for the preservation of biodiversity (Glover et al. 1995; Bassett 2001). For example, the Biodiversity Management Area Selection (BMAS) model is used to identify public or private lands that contribute to regional maintenance of native genetic, species, and community levels of biodiversity. The BMAS model identifies plant communities that are vulnerable due to land use activities. Therefore, this particular biodiversity model integrates cultural, land use, and biological data sets to select biodiversity management areas.

Guild Models

Multi-species models, focusing on well-defined groups of wildlife species or guilds, have been used to evaluate the effects of habitat changes on the overall functional, structural, and compositional conditions of ecosystems (Roloff et al. 2001). Guild models have been primarily developed for songbirds (e.g., O'Connell et al. 2000), but have also been applied to other taxa (Coyle 1981; Severinghaus 1981; Moran and Southwood 1982; Hairston 1987). An example of a guild model, the Bird Community Index (BCI), is based on response guilds, which are defined as groups of bird species that require similar habitat, food, or other elements for survival (O'Connell et al. 2000). This model assumes that high-integrity environmental conditions will be reflected by the presence of guilds containing more specialist than generalist species. High-integrity environmental conditions are those typifying the habitat type or ecosystem in the absence of human disturbance. Other guild models have used occurrence, abundance, and locations of ecological communities to predict animal responses. For example, Haufler et al. (1996) stratified landscapes into “ecological land units” on the basis of similar disturbance regimes and geological conditions, which were then used to describe and predict floral and faunal diversity for planning purposes.

Decision Support Systems

Decision support systems (DSS) integrate support tools, indices, and models into one system and provide resource managers and researchers with the information necessary to make complex decisions more efficiently. DSS are used in many profit and nonprofit businesses, and governmental and nongovernmental agencies for management, planning, and predicting, or forecasting outcomes. DSS for biodiversity are being used in conservation planning, public land management, waterways and watershed management, habitat assessment, wildlife refuge planning and management, and ecosystem management. DSS usually consist of and integrate a combination of databases, GIS software, conceptual, statistical and scenario models, and image processing and visualization software into one system. DSS can be shells that are application frameworks that need to be customized and designed to meet user goals. For example, DSS take large, complicated data sets (such as data gathered from all-taxa biodiversity inventories) and organize and standardize them within the framework of management goals so that they are easier to understand and can be used to make more accountable decisions.

The decision support process begins with the experts (research managers and researchers) defining the management or scientific goals, which formulate the questions that the DSS will try to answer. The experts have to decide who (stakeholders) will be affected by the outcome of the decisions. Next, the data (screened, cleaned, and accurate) is transferred (assuming the data has already been collected) into a knowledge base, which is a collection of data organized so it can easily produce information from which knowledge or answers can be derived. The data is then analyzed based on the experts' questions to produce the best possible management alternatives that fit within the goals. Then the experts have to decide which alternative is the best solution to a particular research question, management challenge, or problem. DSS can be pre-designed to answer specific management questions. For example, in national parks DSS can be used to examine and use multiple data sets, support tools (e.g., GIS presentations), indices, and models to determine areas or habitats that contain significant biodiversity assemblages. Specific examples of the application of DSS in biodiversity assessment and conservation follow:

- The San Diego Supercomputing Center's (SDSC) Data-Intensive Computing Environments (DICE) group used advance computational technologies to integrate biodiversity data from various sources associated with the San Diego Multiple Species Conservation Program (MSCP). This integration of data was used to demonstrate how management and monitoring information from different sources is accessed and displayed in a Web site (http://www.sandiego.gov/mscp/index.shtml).

- Refuge (GAP) was designed for the purpose of studying biodiversity in Wyoming's National Wildlife Refuges. This DSS is designed to emulate the US. Fish and Wildlife Service's (USFWS) Land Acquisition Priority System for significant community biodiversity targets. The decision support tool is also designed to report on biodiversity elements for specific areas (http://www.wygisc.uwyo.edu/wbn/refuge/).

- A DSS is being used for ecoregional conservation planning. The DSS developed for this purpose incorporates spatial design criteria into the site selection process for areas of conservation importance within a particular ecoregion (http://www.biogeog.ucsb.edu/projects/tnc/toolbox.html).

- NatureServe Vista is a DSS that uses GIS scenario modeling to answer socio-economic and biological concerns (http://www.natureserve.org/prodServices/dss.jsp).

- The National Park Service in collaboration with USGS has developed a number of DSS to address various park specific natural resource management and assessment needs. For example, a DSS has been developed for the St. Croix National Scenic Riverway (http://www.umesc.usgs.gov/management/dss/5004778_st_croix.html). A variety of spatial DSS were developed to support the contaminant assessment process, nutrient load and estuarine response, and landscape scale conservation and easement planning at Acadia National Park (http://www.umesc.usgs.gov/management/dss/5004778_cap_acadia.html; http://www.umesc.usgs.gov/management/dss/anp_nutrient.html; and http://www.umesc.usgs.gov/management/dss/anp_easement.html). A list of USGS decision support systems are found at http://www.umesc.usgs.gov/dss.html.

- Conservation Assessment and Prioritization System (CAPS) is a DSS designed to assess the biodiversity value of specific locations based on natural community-specific models and prioritize lands for conservation action based on their assessed biodiversity value in combination with other data relevant to their prioritization (McGarigal 2002). CAPS was used to assess biodiversity in Massachusetts (http://www.umass.edu/landeco/research/caps/caps.html, http://www.umass.edu/landeco/research/caps/applications/route11.pdf).

- Ecosystem Management Decision Support (EMDS) is a DSS designed to perform ecological assessments at any geographic scale. The system integrates GIS as well as knowledge-based reasoning and decision modeling technologies in a Windows environment to provide decision support for a substantial portion of the adaptive management process of ecosystem management. (http://www.fsl.orst.edu/emds/).

- NetWeaver is a DSS tool for building and evaluating knowledge networks for any situation. Key features of the system include a highly intuitive graphical user interface, object-based networks of logical propositions, and fuzzy logic. As a knowledge engineering tool, NetWeaver can be used to help identify conceptual model structure and data needs, formalize relationships between and among logical entities and disciplines, and develop analytical models for use in assessments of ecological states. GeoNetWeaver utilizes GIS support tools to map models developed by NetWeaver. NetWeaver can be used as a stand alone DSS or integrated with other systems as a knowledge base. NetWeaver now serves as an important component of the Ecosystem Management Decision Support System (EMDS) (http://www.fsl.orst.edu/emds) which has been deployed by the U.S. Forest Service in various locations around the country (http://rules-of-thumb.com/NetWeaver/, http://mona.psu.edu/NetWeaver/index.html).

- The USGS has developed two decision support tools for conservation planning. The first, Geographic Information System Tools for Conservation Planning (http://www.umesc.usgs.gov/management/dss/gis_tools_for_conservation_planning.html), works in a vector environment within Environmental Systems Research Institute's (http://www.esri.com) ArcView program. The second, *LINK*: ArcGIS Tools for Conservation Planning (http://www.umesc.usgs.gov/management/dss/bird_conservation_tools_link.html), is a DSS used for conservation planning within particular regions (http://www.umesc.usgs.gov/dss.html).

Decision Support Systems were reviewed for their potential use in forest biodiversity and management by the National Commission on Science for Sustainable Forestry (Gordon et al. 2004, http://ncseonline.org/NCSSF/DSS/Documents/) and by the Commonwealth Integration Technical Working Group (Malafant and Davey 1996, http://www.complexia.com.au/Documents/DSS/M&D.html). In addition, Wright (2002) reviewed the modeling programs NetWeaver, C-Map, and Microsoft Office Visio. In that review NetWeaver received the highest rating based on its ability to address complex concepts such as biodiversity and sustainability.

Recommendations

The National Park Service is one agency that has conducted biodiversity inventories at many of their parks. These inventories were designed to include several sampling techniques to maximize species and specimen catch but sometimes lack statistical rigor such as sufficient sampling replication over time and space. In order to address conservation and resource management challenges, data collected from these inventories need to be synthesized and analyzed. Due to the nature of the data, designing a Decision Support System (DSS) is the best approach.

In the past, modeling of complex ecological systems was approached using mathematical methods that required excessive simplification. As a result, significant compromises with ecological reality often occurred. Integrative computer-based systems such as DSS are the enabling technology for biodiversity and ecosystem management. In particular, knowledge-based reasoning methodologies provide a means for using complex knowledge bases for biodiversity management purposes.

DSS are particularly relevant to biodiversity because the topic is conceptually broad and complex, involving at least several abstract concepts (e.g., health, sustainability, ecosystem resilience, and ecosystem stability) and its assessment depends on numerous interdependent states and processes (Saunders et al. 1990; Reynolds et al. 1996). DSS representations can be used as logical frameworks within which results from many specific analytical models are integrated to yield assessments of more abstract topics such as biodiversity (Coulson et al. 1996).

A DSS that integrates databases, knowledge bases, GIS analysis and mapping capabilities, conceptual, analytical, and scenario models, statistical analysis, and image processing and visualization software is the best approach to analyze National Park Service inventory data for managing biodiversity. The system would need to be customized and designed to solve complex problems and to attempt to produce workable solutions for resource managers and researchers working in national parks. DSS that offer the most flexibility and versatility for integrating and analyzing multi-taxa biodiversity inventories include framework applications that are not pre-designed for a specific purpose such as NetWeaver. However, whatever DSS system is selected its framework should be used for all national parks and designed, customized, and modified to fit each individual park's data and management needs.

The first step in using a DSS to analyze biodiversity inventory data at national parks is to make sure the data is clean, accurate, and has localities for each record. The next step, is for the DSS designer to meet individually with park resource managers, researchers, and planners to build biodiversity models based on a particular taxon. For example, for mammals, one may want to consider species diversity, species richness, species evenness, and presence or absence of specialists as indicators of biodiversity. Next, the DSS designer and model programmer feed geo-referenced data sets into taxon-specific models. Areas that differ in their value of biodiversity for a particular taxon can then be mapped. Individual park experts can review the model and map to determine if it best reflects their questions and goals of biodiversity at their park. Once taxon-specific models are approved, the individual taxonomic models can be integrated and biodiversity based on multi-taxa can be assessed and mapped. The DSS designer reviews the multi-taxa biodiversity map to determine if it reflects the goals of the park experts. If necessary, the model is adjusted to better meet park experts' opinions and knowledge of biodiversity at a particular park. This biodiversity assessment and mapping process is repetitive and can be modified at any step and time. The amount of time it takes to develop a DSS depends on the availability of the DSS designer, model programmer, and park experts.

Literature Cited

Anon. 2002. Digital Libraries: Metadata Resources. www.ifla.org.

Anon. 2000. Management Policies 2001. U.S. Department of Interior. National Park Service NPS D14116/December 2000.

Baldi, A. 1999. Biodiversity in Hungary: Advantages and limitations of taxonomically complete faunal inventories. Natural Areas Journal 19(1):73-78.

Bassett, S. 2001. Combining species richness and visual preference models for the San Pedro River Basin Arizona, U.S.A. and Sonora, Mexico. Harvard Design School. http://www.gsd.harvard.edu/academic/fellowships/prizes/gisprize/ay00-01/bassett/.

Beattie, A. J., J. D. Majer, and I. Oliver. 1993. Rapid Biodiversity Assessment: A review. Pages 4-14 in Rapid Biodiversity Assessment: Proceedings of the Biodiversity Assessment Workshop 1993. Research Unit for Biodiversity and Bioresources, Macquuarie University, Sydney.

Bedward, M. 1999. CODA: Conservation Options and Decisions Analysis. A software package for nature conservation planning. http://members.ozemail.com.au/~mbedward/coda/overview.html.

Brower, J. E., J. H. Zar, and C. N. von Ende. 1998. Field and Laboratory Methods for General Ecology. Fourth Edition. Boston, MA: WCB/McGraw-Hill.

Brunner, R. D., and T. W. Clark. 1997. A practice-based approach to ecosystem management. Conservation Biology 11(1):48-58.

Chazdon, R. L., R. K. Colwell, J. S. Denslow, and M. R. Guariguata. 1998. Statistical Methods for estimating species richness of woody regeneration in primary and secondary rain forests of NE Costa Rica. Pages 285-309 in F. Dallmeier, and J. A. Comiskey, editors. Forest Biodiversity Research, Monitoring, and Modeling: Conceptual Background and Old World Case Studies. Paris: Parthenon Publishing.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D-Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6:665-691.

Colwell, R. K. 2004. Estimates: Statistical estimation of species richness and shared species from samples. Version 5. User's Guide and application published at: http://viceroy.eeb.uconn.edu/estimates.

Colwell R. K, and J. A. Coddington. 1994. Estimating terrestrial biodiversity through extrapolation. Philosophical Transactions of the Royal Society 345:101-18.

Coulson, R. N., W. Daugherity, E. J. Rykiel, H. Saarenmaa, and M. Saunders. 1996. The pragmatism of ecosystem management: Planning, problem solving and decision making with knowledge based systems. Proc. Eco-Informa96: Global Networks for Environmental Information. Lake Vista, FL. Nov. 4-7, 1996. pp 575-580.

Coyle, F. A., 1981. Effects of clearcutting on the spider community of a southern Appalachian forest. J. Arachnol. 9:285-298.

Crump, M. L., and N. J. Scott. 1994. Standard techniques for inventorying and monitoring 2. Visual encounter surveys. Pages 84-92 in R. H. Hyer, M. A. Donnelly, R. W. McDiarmid, L. C. Hayek, and M. S. Foster, editors. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Smithsonian Institution Press, Washington, DC.

Dallmeier, F. 1996. Biodiversity inventories and monitoring: essential elements for integrating conservation principles with resource development projects. *Biodiversity in Managed Landscapes: Theory and Practice*. Szaro R. B. and D. W. Johnston, Eds. Oxford University Press. New York, NY. pp 221-236

Dangerfield, J. M., and A. J. Pik. 1999. The educational value of an All Taxa Biodiversity Inventory. Journal of Biological Education 33(2):76-83.

Debinski, D. M., and P. F. Brussard. 1994. Using biodiversity data to assess species-habitat relationships in Glacial National Park, Montana. Ecological Applications 4:833-843.

Debinski, D. M., and P. S. Humphrey. 1997. An integrated approach to biological diversity assessment. Natural Areas Journal 17(4):355-65.

Dennis, J. G., and M. A. Ruggiero. 1996. 10. Biodiversity inventory: Building an inventory at scales from local to global. Pages 149-156 in R. C. Szaro and D. W. Johnston, editors. Biodiversity in Managed Landscapes: Theory and Practice. New York: Oxford University Press.

Diefenbach, D. R., and C. G. Mahan. 2002. Vegetation inventorying and monitoring at Shenandoah National Park: Setting objectives and priorities. USDI NPS Final Report.

Fuller, R. M., G. B. Groom, S. Mugisha, P. Ipulet, D. Pomeroy, A. Katende, R. Baily, and R. Ogutu-Ohwayo. 1998. The integration of field survey and remote sensing for biodiversity assessment: A case study in the tropical forests and wetlands of Sango Bay, Uganda. Biological Conservation 86(3):379-91.

Gibbs, J. P. 1998. Integrating monitoring objectives with sound sampling design: a pilot review of selected monitoring programs at Shenandoah National Park. USDI NPS Final Report.

Gordon, S. N., K. N. Johnson, K. M. Reynolds, P. Crist, and N. Brown. 2004. Decision support systems for forest biodiversity: Evaluation of current systems and future needs. Final Report – Project A10. National Commission on Science and Sustainable forestry. http://ncseonline.org/ncssf/dss/Documents/index.htm.

Gotelli, N. J. and G. L. Entsminger. 2004. EcoSim: Null models software for ecology. Version 7.Acquired Intelligence Inc. & Kesey-Bear. Jericho, VT 05465. http://garyentsminger.com/ecosim.htm.

Gotelli, N. J., and G. R. Graves. 1996. Null Models in Ecology. Washington, D. C.: Smithsonian Institution Press. 368 pp.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8(1):27-38.

Grumbine, R. E. 1997. Reflection on "What is Ecosystem Management?" Conservation Biology 11(1):41-47.

Hairston, N. G., Sr. 1987. Community ecology and salamander guilds. Cambridge University Press, New York, NY.

Hassinger, J., R. J. Hill, G. L. Storm, and R. H. Yahner. 1998. Inventory and Monitoring of Biotic Resources in Pennsylvania. Current Ecological and Landscapes Topics – Pennsylvania Biological Survey. 220 pp.

Haufler, J. B., C. A. Mehl, and G. L. Roloff. 1996. Using a coarse-filter approach with species assessment for ecosystem management. Wildlife Society Bulletin 24:200-208.

Hone, J. 1991. Analysis of animal survey data. In:C. R. Margules, and M. P. Austin, editors. Nature Conservation: Cost Effective Biological Surveys and Data Analysis. pp 42-46. CSIRO, Australia.

Janzen, D. H., and W. Hallwach. 1994. All Taxa Biodiversity Inventory (ATBI) of Terrestrial Systems. A Generic Protocol for Preparing Wildland Biodiversity for Non-damaging Use. 132 pages. Report of National Science Foundation Workshop, April 16-18, 1993, in Philadelphia. National Science Foundation, Washington, DC.

Janzen, D. H. 1997. Wildland Biodiversity Management in the Tropics. Pages 411-431 in Reaka-Kudla, M. L., D. E. Wilson, and E. O. Wilson, editors. Biodiversity II: Understanding and Protecting Our Biological Resources. Joseph Henry Press. Washington, DC.

Johnson, P., and B. Lachman. 2001. Biodiversity Management Area Selection Model (BMAS) http://ncseonline.org/NCSSF/DSS/Documents/NatureServe/BMAS.doc.

Johnson, P., and B. Lachman. 2001. Ecosystem Management Decision Support (EMDS) http://ncseonline.org/NCSSF/DSS/Documents/NatureServe/EMDS.doc.

Johnson, P., and B. Lachman. 2001. Multiple Species Conservation Program (MSCP) http://ncseonline.org/NCSSF/DSS/Documents/NatureServe/MSCP.doc.

Johnson, P., and B. Lachman. 2001. Refuge (GAP). http://ncseonline.org/NCSSF/DSS/Documents/NatureServe/RefugeGAP.doc.

Johnson, P., and B. Lachman. 2001. Sites. http://ncseonline.org/NCSSF/DSS/Documents/NatureServe/Sites.doc.

Kerr, J. T., A. Sugar, and L. Packer. 2000. Indicator taxa, rapid biodiversity assessment, and nestedness in an endangered ecosystem. Conservation Biology 14(6):1726-1734.

Kim, K. C. 1993. Biodiversity, conservation, and inventory: Why insects matter. Biodiversity and Conservation 2:191-214.

Kim, K. C. 2001. Biodiversity, Our Living World: Your Life Depends on It. College of Agricultural Sciences, Cooperative Extension and Center for BioDiversity Research. Environmental Resources Research Institute, University Park, PA 16802. 18 pp.

Kosztarab, M., and C. W. Schaefer, editors. 1990. Systematics of the North American Insects and Arachnids: Status and Needs. Information Series 90-1 (ISSN 07423-7425), Virginia Agricultural Experiment Station, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0461. 247 pp.

LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. 1995. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, DC. 530 pp.

Lawton, J. H., D. E. Bignell, B. Bolton, G. F. Bloemers, P. Eggleton, P. M, Hammond, M. Hodda, R. D. Holts, T. B. Larsen, N. A. Mawdsley, N. E. Stork, D. S. Srivastava, and A. D.Watt. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature,* 391, 72-76.

Lemons, J. 1994. The role of science in preserving biodiversity in national parks. Pages 183-198 in S. K. Majumdar et al., Biological Diversity: Problems and Challenges. Pennsylvania Academy of Sciences.

Ludwig, J. A., and J. F. Reynolds. 1988. Statistical Ecology: A primer on methods and computing. John Wiley & Sons, NY.

Mac, M. J., P. A. Opler, C. E. Puckett Haecker, and P. D. Doran. 1998. Status and trends of the national biological resources. 2 vol. U.S. Department of Interior, U.S. Geological Survey. Reston, VA. Vol. 1 1-436pp; Vol. 2:437-964.

Magurran, A. E. 1998. Ecological Diversity and its Measurement. Croom-Helm, London.

Mahan, C. G., K. Sullivan, K. C. Kim, R. Yahner, M. Abrams, C. Snyder, D. Lemarie, J. Young, D. Smith, R. Ross, and R. Bennett. 1998. Ecosystem Profile Assessment of Biodiversity: Sampling Protocols and Procedures. U.S. Department of Interior, National Park Service, Final Report, The Pennsylvania State University, Environmental Resources Research Institute Publication No. ER9806.

Malafant, K. W. J., and S. M. Davey. 1996. Review of information technologies for consideration in comprehensive resource assessments of forests. Report to Commonwealth Integration Technical Working Group on Comprehensive Regional Assessments, February.

Margules, C. R., and M. P. Austin. 1991. Nature conservation: Cost effective biological surveysand data analysis. CSIRO, Canberra.

McFadden, M. W., J. K. Parker and M. C. Saunders. 1999. NetWeaver: A new tool for developing results frameworks, integrating performance data and testing development hypotheses. The Heron Group Report Series. HG-99-102. http://www.herongroupllc.com/docs/report102.pdf.

McGarigal, K. 2002. CAPS – Conservation Assessment and Prioritization System: An Interactive Decision-Support System. Landscape Ecology Program. University of Massachusetts, Amherst, MA. http://www.umass.edu/landeco/research/caps/caps.html.

Meffe, G. M., and C. R. Carroll. 1994. Principles of conservation biology. Sinauer Associates, Inc., Sunderland, MA.

Moran, V. C., and T. R. E. Southwood. 1982. The guild composition of arthropod communities in trees. J. Anim. Ecol. 51:289-306.

National Park Service. 2000. Management Policies 2001. U.S. Department of the Interior, National Park Service. 137 pp.

NPS (National Park Service). 2000. Natural Resource Inventory and Monitoring in National Parks. NPS Inventory and Monitoring Informational Brochure. 10 pp. http://www.nature.nps.gov/im/brochure/imbroch.htm.

NatureServe Biodiversity Data Model. http://www.natureserve.org/prodSeravices/biodatamodel.jsp.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. 2000. Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications 10:1706-1721.

Oliver, I., and A. J. Beattie. 1996a. Designing a cost-effective invertebrate survey: A test of methods for rapid assessment of biodiversity. Ecological Applications 6(2):594-607.

Oliver, I, and A. J. Beattie. 1996b. Invertebrate morphospecies as surrogates for species: A case study. Conservation Biology 10(1):99-109.

Olsen, Doug. 2003. DSS for the St. Croix National Scenic Riverway. Upper Midwest Environmental Sciences Center, USGS. http://www.umesc.usgs.gov/management/dss/5004778_st_crois.html.

Pimm, S. L. 1991. The Balance of Nature?: Ecological issues in the Conservation of Species and Communities. The University of Chicago Press, Chicago, IL.

Platt, H. M., and P. J. D Lambshead. 1985. Neutral model analysis of patterns of benthic species diversity. Marine Ecology - Progress Series 24:75-81.

Ratsirarson, H., H. G. Robertson, M. D. Picker and S. van Noort. 2002. Indigenous forests versus exotic eucalypt and pine plantations: a comparison of leaf-litter invertebrate communities. African Entomology 10(1): 93-99.

Reynolds, K., M. Saunders, R. Olsen, D. Schmoldt, M. Foster, D. Latham, B. Miller, J. Steffenson, L. Bednar, and P. Cunningham. 1996. Knowledge-based information management in decision support for ecosystem management in the Pacific Northwest US. Artif. Intel. Appl. In: Nat. Resource Mngt. 10(2):9-22.

Roloff, G. J., G. F. Wilhere, T. Quinn, and S. Kohlman. 2001. An overview of models and their role in wildlife management. Pages 512-536 in D. H. Johnson and T. A. O'Neil, editors. Wildlife-habitat relationships in Oregon and Washington. Oregon State University Press, Corvallis, OR.

Salwasser, H., J. A. Caplan, C. W. Cartwright, A. T. Doyle, W. B. Kessler, B. G. Marcot, and L. Stritch. 1996. 35. Conserving biological diversity through ecosystem management. Pages 548-573 in R. C. Szaro and D. W. Johnston, editors. Biodiversity in Managed Landscapes: Theory and Practice. Oxford University Press, NY.

Sanders H. L. 1968. Marine benthic diversity: a comparative study. American Naturalist 102:243-82.

Saunders, M. C., R. N. Coulson, and J. Folse. 1990. Applications of artificial intelligence in agriculture and natural resource management. In: A. Kent and J. Williams, editors. Encyclopedia of Computer Science and Technology Vol. 25 (10) 1-14. Marcel Dekker Inc., NY.

SAS Institute. 1985. SAS User's Guide: Basic, Version 5ed. SAS Institute, Cary, NC.

Scott, J. M., F. Davies, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, D'Erchia, T. C. Edwards, Jr., J. Ulliman, and G. Wright. 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildlife Monographs 123.

Severinghaus, W. D. 1981. Guild theory developed as a mechanism for assessing environmental impact. Environ. Management 5:187-190.

Sharkey, M. J. 2001. The all taxa biological inventory of the Great Smokey Mountains National Park. Florida Entomologist 84(4):556-64.

Simberloff,, D. 1981. Community effects of introduced species. Pages 53-81 *in* H. Nitecki, editor. Biotic crises in ecological and evolutionary time. Academic Press, New York, NY.

Simberloff, D. 2001. Biological invasions: How are they affecting us, and what can we do about them? Western North American Naturalist 61:308-315.

Solbrig, O.T. 1991. The origin and function of biodiversity. *Environment*, **33**, 16-20 and 34-38.

Southwood T. R. E. 1978. Ecological Methods. London: Chapman and Hall. 524 pp.

SPSS for Windows 9.0. 1998. SPSS Inc., Chicago, IL.

Stohlgren, T. J., and J. F. Quinn. 1992. An assessment of biotic inventories in Western U.S. National Parks. Natural Areas Journal 12(3):145-154.

Stohlgren, T. J., J. F. Quinn, M. Ruggiero, and G. S. Waggoner. 1995. Status of biotic inventories in U.S. National parks. Biological Conservation 71:97-106.

Stork, N., and J. Davies. 1996. Biodiversity inventories. Pages 1-34 in Biodiversity Assessment. A Guide to Good Practice. Field Manual 1. Data and Specimen Collection of Plants, Fungi and Microorganisms. Volume 2: Collecting Biodiversity Data 1. HMSO, London.

Stork, N. E. and M. J. Samways 1995. Inventorying and monitoring. In Heywood, V. H. (Ed.) *Global Biodiversity Assessment*. Cambridge, Cambridge University Press. 453-542.

Tiebout, H. M., III. 2003. An Inventory of the Herptofauna of Valley Forge National Historic Park. Technical Report NPS/PHSO/NRTR-03/088. National Park Service. Philadelphia, PA.

Trueman, J. W. H., and P. S. Cranston. 1997. Prospects for the rapid assessment of terrestrial invertebrate biodiversity. Memoirs of the Museum of Victoria 56(2):349-54.

UNEP. 1993. Guidelines for Country Studies on Biological Diversity, UNEP, October 1993. A guidance document designed to aid countries in the evaluating their overall biological resources and biodiversity.

US Forest Service. 2002. Conceptual Modeling Tools. Local Unit Criteria and Indicators Development Project (LUCID). Inventory and Monitoring Institute (IMI) Report No. 4. USDA USFS (IMI). http://www.fs.fed.us/institute/lucid/.

USGS/DOI (U. S. Geological Survey, Department of Interior). 2001. BioBlitz: A tool for biodiversity exploration, education, and investigation. Bio-Blitz Home Page, USGS <http://www.im.nbs.gov/blitz.html(6/5/01).

Vanclay, J. K. 1996. Towards more rigorous assessment of biodiversity. Pages 211-232 in: P. Bachman et al., editors. Assessment of Biodiversity for Improved Forest Planning. Kluwer, Netherlands.

Wheeler, Q. D. 1995. Systematics, the scientific basis for inventories of biodiversity. Biodiversity Conservation 4:476-489.

Wheeler, Q. D., and J. Cracraft. 1995. Taxonomic preparedness: Are we ready to meet the biodiversity challenge? Pages 435-446 in Reaka-Kudla, M. L., D. E. Wilson, and E. O. Wilson, editors. Biodiversity II: Understanding and Protecting Our Biological Resources. Joseph Henry Press, Washington, DC.

Woodley, S. 1992. A scheme for ecological monitoring in national parks and protected area. Environment 23:51-73.

WRI, IUCN, UNEP. 1992. *Global Biodiversity Strategy. Guidelines for Action to Save, Study and Use Earth's Biotic Wealth Sustainably and Equitably*. World Resource Institute (WRI), The World Conservation Union (IUCN), United Nations Environment Programme (UNEP).

Wright, P. A. 2002. Monitoring for Forest Management Unit Scale Sustainability: The Local Unit Criteria and Indicators Development (LUCID) Test. USDA FS IMI Report No. 4. 228 pp.

Zorn, P., W. Stephenson, and P. Gregory. 2000. An ecosystem management program and assessment process for Ontario National Parks. Conservation Biology 15(2):353-3.

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-19 May 2005

National Park Service
U.S. Department of the Interior

Northeast Region
Natural Resource Stewardship and Science
200 Chestnut Street
Philadelphia, Pennsylvania 19106-2878

http://www.nps.gov/nero/science/