

STATUS OF BIOTIC INVENTORIES IN US NATIONAL PARKS

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Abstract

It is the policy and obligation of the National Park Service to conduct baseline inventories of natural resources preserved in its 32 million hectare National Park System. We evaluated the status of natural resources information in 252 national parks and monuments: those park units that contain significant natural resources. Results show that few parks contain relatively complete systematic inventories for any major plant or animal group. Better information on species occurrence is available for vascular plants, mammals and birds than for other taxa (reptiles, amphibians and fish). Although most parks have compiled species lists for at least some taxa, the majority (> 80%) of the lists are reported to be less than 80% complete in their species, geographic, and ecological (community type) coverage. An earlier study of 40 parks in California, Arizona, Nevada and Hawaii found that information on terrestrial invertebrates, aquatic invertebrates, and non-vascular plants was generally poor or non-existent. Thus, the National Park Service presently knows little about the biological diversity in national parks. Spatially explicit data on park resources are also limited. While 43, 28 and 24% of the 252 parks surveyed had maps of vegetation, soils and geology, respectively, none of these maps appears to have been systematically

checked for accuracy after their creation. If parks are to serve as baselines to measure environmental change, there is an urgent need (1) to develop strategic plans to rank inventory needs in the National Park System; and (2) to design and conduct biological inventory programs to bring all parks to an acceptable level of resource awareness.

Keywords: biotic resources, inventory and monitoring, national parks, biodiversity.

INTRODUCTION

The National Park System provides both fully protected habitats for the long-term maintenance of biological diversity and a baseline against which to measure change (The Keystone Center Report, 1991). Increasingly, decisions affecting park resources are made without sufficient biological information (Ruggiero *et al.*, 1992). For many purposes, managers need accurate assessments of both the occurrence (or absence) of species or genotypes in parks, and the status and condition of populations. These assessments are essential to form natural resource management policies, manage the natural diversity within existing parks, and identify potential new or expanded reserves to encompass biotic diversity not now effectively protected within the park system. As the oldest and most extensive park system in the world, the US National Parks also serve as a seminal model for conservation efforts in countries where the erosion of biotic diversity is even more pressing.

Within the National Park Service, inventories of natural resources are needed to make resource manage-

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ment decisions, to identify research needs, and to design efficient and standardized protocols to monitor the effects of both within-park management policies and externally driven environmental changes. Clearly, knowing the resources in national parks is an essential element of the mandate for their protection set forth in the 1916 enabling legislation (16 USC 1). Supported by this and other legal mandates (e.g. Endangered Species Act, 1973, Amended 1982; The National Environmental Policy Act, 1979), National Park Service policy requires that the Park Service know the nature, status, and condition of natural resources and park ecosystems under National Park Service stewardship. Park Service policy states specifically that the National Park Service understand the dynamic nature of natural ecosystems and monitor natural resources to detect change and provide reference points for comparisons with other, altered environments (National Park Service Management Policies, Chapter 4, 1988).

The National Park Service began an intensive effort in 1990 to address the availability and needs for biological data with a standardized, systemwide, 'inventory of inventories' (Ruggiero *et al.*, 1992) that describes the current status of biological inventories for vascular plants, birds, mammals, reptiles, amphibians and fishes for each park. This 'Phase I' Inventory and Monitoring Program, which focuses on the 252 park units with significant natural resources, is the first step in a larger plan designed to:

- (1) determine the status, quality, and completeness of existing information on park resources;
- (2) identify priority gaps in information on natural resources, ecosystem processes, and stresses to ecosystems, and inventory those resources, processes, and stresses; and
- (3) develop systematic long-term monitoring programs to detect changes and quantify trends in resource conditions, and link the changes to their causes.

The primary objectives of this Phase I survey were (1) to provide a qualitative assessment (categorical summary) of the status of species lists for various biological groups (e.g. vascular plants, birds, etc.); (2) to inventory mapped information on vegetation, soils, geology and other natural resources; and (3) to inventory photographic series, aerial and satellite imagery, and digitally-processed, geographic information.

METHODS

For most of the park units, biological technicians spent a few days to a week in each park interviewing key research or resource management personnel and examining resource records, research libraries, map collections, and other records of biological resources. Other park surveys were completed by regional office personnel or park staff. Species occurrence records were grouped by biological group (for most parks, vascular plants, mammals, birds, reptiles, amphibians, and fishes). For

each group, the park personnel were asked to estimate the completeness of the existing records on a scale of 1 (most complete) to 6 (least complete), or 7 (no information available) in each of three categories — geographical completeness, ecological completeness, and taxonomic completeness (Table 1). The resulting database has been termed the Biological Inventory Status (BIS) database.

Geographic completeness refers to the percentage of the entire park surveyed to derive existing inventories, ecological completeness to the percentage of the total number of ecological communities included in the inventory, and taxonomic completeness to the estimated percentage of the existing species pool reliably detected, identified, and listed on existing species lists for each major biological group given above.

The sum of taxonomic + geographic + ecological completeness was used as a 'composite score' to summarize the status of knowledge on each biological group and to allow comparisons among parks and between biological groups (Table 1). A score of 3 represents an assessment that more than 95% of the species in the group have been detected in survey data covering 95% of the park's area and habitat types. In almost all cases, scores of 3 resulted when the organisms involved had received some years of study from National Park Service or university-based researchers. A score around 10 suggests that the available inventory information is about half complete. A score of 18–19 indicates that essentially no attention has been paid to that group. Additional details on methods are given in Stohlgren and Quinn (1991, 1992a). Information on the history of the inventory, references, the status of voucher specimens, and comments by park personnel on the reliability of individual pieces of data were also recorded.

Maps and imagery (aerial photographs and digital satellite images) known to park personnel were catalogued. Each map record included subject or theme date, investigator, repository, and various characteristics such as scale, classification scheme used, map form, and data structure for digital map files (Stohlgren &

Table 1. Biological Inventory Status Codes

Individual scores for taxonomic, geographic, and ecological completeness:

- 1 = Inventory probably >95% complete.
- 2 = Inventory 80% to 95% complete.
- 3 = Inventory 50% to 80% complete.
- 4 = Inventory <50% complete.
- 5 = Inventory contains good information about a few taxa, in a local area or in a few communities.
- 6 = Inventory poor to non-existent.
- 7 = Taxonomic completeness unknown.

Composite score (taxonomic+geographic+ecological completeness):

- 3 = Inventory probably >95% complete.
- 4–6 = Inventory 80% to 95% complete.
- 7–9 = Inventory 50% to 80% complete.
- 10–13 = Inventory <50% complete.
- 14–17 = Inventory contains good information about a few taxa, in a local area or in a few communities.
- 18–19 = Inventory poor to non-existent or unknown.

Quinn, 1991). For each one, recorders asked if the map had been systematically field-checked after its development. Information on imagery included type, scale, format, comprehensiveness and repository of the aerial and digital images.

The scores were reported by park staff and reflect the knowledge of individuals interviewed. No attempts were made to verify their scores. We have discovered several cases in which the existence of important park records (e.g. geological maps, published species lists) was not known to the current resource specialist in the park. For some parks, under-reporting of this kind may lead to an underestimate of the quality of inventory information. It also is likely that 'completeness' was often substantially overestimated (Stohlgren & Quinn, 1991) in parks that had received some study.

RESULTS

Status and completeness of inventories

Although most parks have species lists for at least some biological groups, about 80% of the lists are reported to be less than 80% complete in their taxonomic, geographic, and ecological (community type) coverage (Fig. 1). Fewer than 30 of the 252 parks surveyed had inventories thought to be >95% complete for any one of the biological groups. For all biological groups except vascular plants, the status of inventories most often reported by park staff was 'poor to non-existent'. Most parks had more complete information on vascular plants and birds than on other groups, but many parks had large gaps in information (i.e. high

composite scores) of even these better known groups (Fig. 1).

Very few parks reported parkwide systematic surveys (studies by specialists on the biological group in question according to a sample protocol from which relative completeness can be judged) for any of the biological groups. Some systematic vegetation surveys (e.g. Sequoia and Kings Canyon NP, Glacier NP, Yellowstone NP, and Great Smoky Mountains NP) were geographically broad surveys but certainly miss some rare habitats and taxa. The intensive marine ecosystem monitoring program at Channel Islands NP (Davis, 1989) is thought to be relatively complete taxonomically (judging from comparisons with intensively studied sites, such as marine laboratories), but is restricted geographically (spatially and in depth) (G. Davis, pers. comm.).

In 40 park units of the Western Region, the incompleteness of current lists is illustrated by the rate at which new species are added. In the Western Region (California, Arizona, Nevada, and Hawaii) alone, over 3000 plant and animal species have been added to park species lists in the past 10 years (Stohlgren & Quinn, 1991). Most of the additions have been in the best studied parks (e.g. Sequoia and Kings Canyon NP, Channel Islands NP), suggesting that many more species lie undetected in the lightly surveyed, smaller parks (Stohlgren & Quinn, 1992b).

While 43, 28 and 24% of the 252 parks surveyed had maps of vegetation, soils and geology, respectively, none of these appear to have been systematically checked for accuracy after their creation. We have discovered a number of cases of vegetation and geological

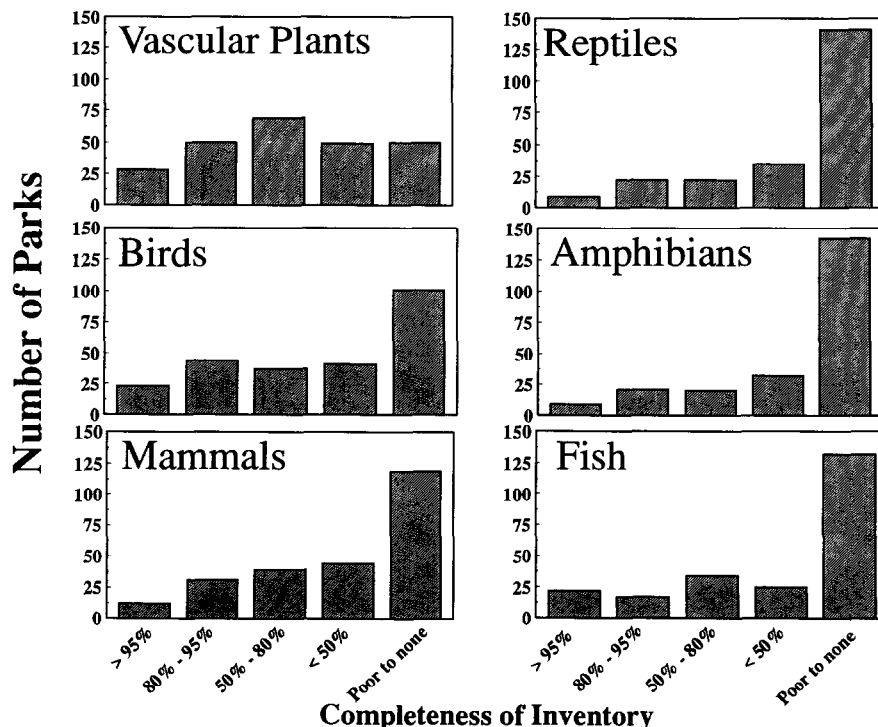


Fig. 1. Composite scores (taxonomic+geographical+ecological completeness) for vascular plants, mammals, birds, reptiles, amphibians, and fishes in natural area national park units.

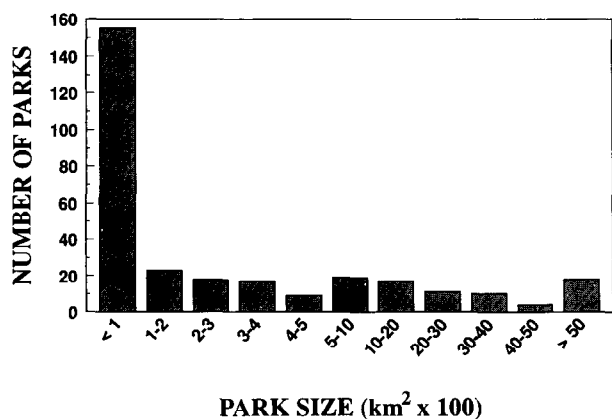


Fig. 2. Number of National Park Service natural area parks by park size (area in km²; $n = 252$ parks).

maps unknown to park resource management specialists, although most of the maps are old and of unknown validity.

Vegetation classification schemes were not standardized among parks. For example, in northern California parks, the vegetation map for Whiskey town National Recreation Area was derived from a USDA Forest Service timber type map, whereas that for Redwood NP was based on plant associations, and that of Lassen Volcanic NP primarily on dominant tree species. Soils and geological maps vary considerably in soil or stratum classification and resolution. With few exceptions, maps of natural resources in parks are not catalogued and rarely cover the entire park. Most were transferred to USGS topographic maps but were not independently geo-referenced or field-verified after their creation. Great Smoky Mountains NP recently developed a vegetation map, but accuracy checking of the map occurred in only part of the park (S. Nodvin, pers. comm.).

Relationship of park size to the status of resources information

Most natural area parks in the US National Park System are small: 56% of the park units are <100 km², 77% are <500 km² (Fig. 2). By comparing the mean composite score (MCS \pm 1 SE) of the six biological groups tested for each park with park size, we found that staff in smaller parks (<100 km²) generally reported less knowledge about biotic resources (MCS = 9.8 ± 0.4 ; $n = 130$ parks) than staff in larger parks (>100 km²; MCS = 8.5 ± 0.4 ; $n = 100$).

Staffs of small parks often lack (1) physical resources to house and maintain voucher collections; (2) computer facilities and expertise to manage large datasets (e.g. geographic information system (GIS) capabilities); and (3) readily available assistance from National Park Service or university scientists.

DISCUSSION

Several common themes appear in our 'inventory of

inventories' in the 252 national parks surveyed. First, most parks apparently lack readily available information on previous studies of park resources. In many cases, more information is available, but is unknown to the current staff. Some park areas, especially in the Pacific Northwest Region and Southern Arizona Group, have easily accessible bibliographies of past research indexed by topic, but, in general, it is difficult, even for park staff, to identify gaps in available resource information.

Historic records and voucher specimens (plants and animals) are poorly maintained in most parks. Most park herbaria are incomplete, and the data recorded for specimens are inconsistent among parks and over time within parks. Few voucher collections are systematically organized, catalogued, or checked by experts. However, the National Park Service is making a concerted effort to catalog new collections using the standardized NPS Automated National Catalog System. Even so, knowledge of bird, mammal, reptile and amphibian occurrences was usually based largely on poorly scrutinized 'wildlife observations', on general range maps not validated by field study in the parks, or on biological surveys conducted in the 1930s.

The types of data collected for various taxa vary considerably among parks. For example, we found, as had Sauvajot *et al.* (1990), that no two California parks used the same classifications for seasonality and abundance in bird occurrences, nor, in the cases where they were recorded, were the same census protocols used. Consequently, it is virtually impossible to compare objectively the status of bird populations between parks, either for setting management priorities or for conducting comparative scientific studies. More fundamental inconsistencies result from the lack of either standardized field techniques or, for many taxa, nomenclature. Even for the best studied parks (e.g. Sequoia and Kings Canyon, Channel Islands, and Glacier), each inventory team has developed its own rather different survey protocol. As a result, estimates of taxonomic completeness, population densities, rates of long-term change, etc., cannot be compared directly from park to park (Cook *et al.*, 1990; Robinson *et al.*, 1990; Sauvajot *et al.*, 1990). Similarly, even within regions, different surveys have used different taxonomic authorities. For example, nearly 7000 latin binomials are reported for vascular plants in California parks, a somewhat greater number than all the described species in the state. More than a quarter of these are apparently synonyms (Robinson *et al.*, 1990).

Inventory efforts also vary among taxa (Fig. 1). Disproportionate attention is given to some 'popular' biological groups (vascular plants, mammals, birds) or to taxa within biological groups (butterflies, trees, large mammals, etc.). Inconspicuous, or 'unpopular', groups (most invertebrates, non-vascular plants) and difficult-to-identify taxa (sedges, arachnids, fungi, etc.) have been largely ignored (Stohlgren & Quinn, 1991). Although these gaps are generally recognized, few parks have plans or programs to address unstudied groups.

Inventories in small parks

Like inventories of small organisms, biotic inventories of small parks are generally very incomplete (Fig. 2). This could reflect a history of limited funding for research and resource management activities in smaller parks, the absence of resident scientists, and smaller staffs. One reason to be concerned about the dearth of inventory information in the small parks is that they probably contain most of the National Park System's biotic diversity (see Quinn & Harrison, 1988; Stohlgren & Quinn, 1992b). For example, in the study of Newmark (1986), 22 smaller parks, with a combined area of about 28,000 km², had more than twice as many mammal species (162) as were found in the larger area of the two largest park complexes combined (73), although individual large parks had more total species than any small park. Similarly, six small national parks in northern California reported 1,951 species of vascular plants in 1,485 km², 39% more than the 1,402 species in 3,431 km² in the much better studied flora of Sequoia and Kings Canyon NP (Stohlgren & Quinn 1992b).

Ranking the knowledge gaps in parks by mean composite score is only approximate, particularly for poorly studied parks. However, such a ranking will be useful (1) to identify parks above or below a yet-to-be-defined target for inventory completeness (corresponding perhaps to a composite score of 6 on our BIS scale, representing approximately 80% completed inventories); (2) to set priorities for designing and funding inventory and monitoring programs; and (3) to assess progress toward meeting the priorities.

Completeness of inventories

Despite several excellent single-park inventory programs, overall we believe that biotic inventories in the US National Park System are substantially less complete than is needed for informed management. However, a complete inventory of species is virtually unachievable, and even moderately complete inventories of well-known organisms require a considerable scientific workforce and years of sampling. For many practical purposes, a species list might be considered 'adequately complete' when it is unlikely that any common or ecologically important species have been missed. If taken from a range of habitats, with periodic sampling, such lists are probably adequate to characterize habitat types, monitor successional changes (e.g. recovery from fire), or detect effects of extrinsically driven environmental changes such as global change (if the most susceptible species are adequately sampled). However, complete lists of common species are clearly not sufficient to identify and protect those species threatened with local or regional extinction, which, by their nature, are the ones most likely to be missed in most sampling programs.

Although developing 100%-complete species lists for all taxa is an unobtainable goal, we believe that it is important to estimate what portion of the biota has been missed. Typically, the number of species detected

in ecological surveys approximately doubles with each order of magnitude increase in the area studied, or corresponding increase in the sample size (Simberloff, 1986). As it is impractical to sample exhaustively more than a tiny fraction of the total area of any park, many of the species in all but the most conspicuous or depauperate taxa will remain undetected. However, by their very nature, the undetected species are likely to include uncommon species of particular management and legal importance. It is, of course, National Park Service policy to maintain all the components of diversity in natural area parks (National Park Service Management Policies; Chapter 4:1; 1988). Realistic estimates of the numbers and probable locations of undetected species seem essential to manage rare species and to protect the most vulnerable areas.

A variety of statistical techniques has been developed to estimate the number of rare species missed by any given level of sampling effort (e.g. Efron & Thisted, 1976; Slocumb & Dickson, 1978; Palmer, 1990; Coddington *et al.*, 1991; Soberón & Llorente, 1993). Often, calculations based on these techniques suggest that even well-designed and intensive surveys may miss as many rare species as they detect. Still, these techniques could be very useful in estimating both how much additional inventory and monitoring is necessary and the degree of uncertainty to expect in applying the results of a given level of inventory and monitoring effort to management decisions. To our knowledge, this approach has not been applied directly in any park study. These techniques may require sampling teams to record more detailed data than is usual, including the sequence in which species are detected and the number of individuals of rare species encountered.

Toward a systemwide Biological Inventory Program

The National Park Service is beginning to respond to these needs by initiating a servicewide Inventory and Monitoring Program (Ruggiero *et al.*, 1992). Likewise, the newly established National Biological Survey in the US Department of Interior has a goal to determine and monitor the status and trends of the nation's biological resources. Shared National Biological Survey and National Park Service action items are (1) to complete a basic inventory (i.e. occurrence, documentation, distribution, residence status and abundance) of vascular plants and vertebrate species of the National Park System; and (2) to develop a strategy for acquiring and managing new flora and fauna information. To this end, we suggest that a resource inventory program should strongly reflect two important objectives: (1) develop a strategic plan to rank inventory needs in the National Park System; and (2) design and conduct biological inventory programs to bring all parks up to an acceptable level of resource awareness.

1. Develop strategic plans to rank inventory needs in the National Park System

While the degree of completeness needed to assist effec-

tive resource management or support scientific study warrants discussion, we doubt that inventories that are less than about 50% complete (10 or greater on our BIS scale) for taxa of particular concern are adequate to meet the conservation mission of the National Park Service. For birds, mammals, and vascular plants, for which records are usually the best, this level of completeness appears to require one to several years of expert field investigation. Even this level of effort will require substantial increases in the funds devoted to inventory activities in most small parks, few of which have a resident scientific staff.

We believe it should be a servicewide priority to have new biological survey information be geographically referenced. In most parks surveyed, species occurrence information is not currently mapped. As a result, estimates of geographic and ecological completeness are usually unreliable, and it is difficult to identify areas of particular importance for conservation of biological diversity. To enter survey information into a GIS, geographical (spatial) coordinates must be recorded. This is now becoming more straightforward to do in the field using global positioning system (GPS) technologies. Although we encountered considerable concern about standardizing mapping and GIS hardware and software in our survey, the choice of specific storage, analysis, and presentation technology is probably inconsequential if the underlying data are standardized and spatially explicit.

At a minimum, all parks with significant natural resources also should have accurate vegetation, soils, and geology maps. To assure maximum utility in decision making, these should be current, properly geo-referenced, and of appropriate scale and resolution (which might range from kilometers for vertebrate distributions to meters or less for rare plant populations). Most existing maps do not meet these criteria. A careful reexamination of the accuracy, scale, and utility of existing maps is essential before incorporating them into a developing GIS database. Often, developing new maps from satellite imagery (e.g. Thematic Mapper, SPOT — *Système pour l'Observation de la Terre* (France)) may be more accurate and cost-effective than attempting to verify and correct information on existing inaccurate maps.

Park staffs reported that priority needs for imagery are park-, region-, and purpose-specific. For example, because Grand Canyon NP is currently developing an updated vegetation map, obtaining high-resolution aerial photography may be a higher budget priority than providing imagery for smaller, cultural resource parks. Image needs, particularly for satellite imagery, will likely expand as geographic information systems are developed in other parks. The current high cost of satellite imagery (and processing) has prevented its acquisition and use by all but the best-funded National Park Service research programs although some recent cooperative purchases may help. A change in national policies to make taxpayer-subsidized imagery available for managing public resources seems long overdue.

Most of the existing biotic inventories assessed in this study and base-level inventories recommended below are primarily species lists. Most resource managers and scientists expressed a greater need for (1) species abundance and distribution data, particularly for non-native species; (2) population trend data for rare, threatened, endangered, and non-native species, populations, and local subpopulations; (3) long-term study plots; and (4) integration of data into geographic information systems. Often, the information needed to meet these goals is not currently available, and for most species it is likely to be unattainable under current budgetary and work force constraints. Considerably more research is needed on how to detect evidence of the population changes in sensitive species to make informed management decisions.

Some needs are systemwide and must reflect common standards. Others are probably most easily done at the level of individual parks. One mechanism for focusing local priorities is to include informed scientists and outside policy makers in the scoping sessions associated with developing mandated Park Resource Management Plans.

We believe that a systemwide inventory program should follow a hierarchical design so that smaller numbers of more intensively studied parks can be used to test for uncertainties (for example, the number of unsampled rare species) in the most basic inventories expected of all parks. Perhaps the most immediate challenge to the National Park Service/National Biological Survey partners is to establish a standardized, inexpensive, and reliable protocol for baseline biotic inventory surveys in every park. A second level of investigation might consist of more detailed physical data, including local meteorology, air quality, rainfall and surface water chemistry, and hydrology, and be gathered in all parks with staff ecologists and resource managers. Higher levels could include fixed transects and monitoring plots, radio-tagging programs, analyses of invertebrates and non-vascular plants, etc., and be conducted in only the small number of parks where work force and expertise permit.

An explicitly hierarchical approach (a nested experimental design) has many advantages. The most detailed programs not only act as experimental or pilot programs to develop and test inventory protocols for parks with fewer resources, but they also provide a way to estimate the uncertainty in the results of inventories conducted at the more basic levels. For example, the rate of discovery of unrecorded species in intensive surveys provides an estimate of the completeness of 'standardized' survey techniques (Efron & Thisted, 1976; Palmer, 1990; Coddington *et al.*, 1991). As a result, we believe that any efficient systemwide biotic inventory program must incorporate both intensive (pilot parks) and expansive (all parks) research in essentially a nested experimental design.

Establishing standardized field protocols and data structures among parks and deciding priorities on the taxonomic and geographic scope of surveys will likely

benefit from consultation with the National Biological Survey at regional and national levels. The development and use of standards is integral to the mission of this newly established bureau within the Department of Interior. Adherence to published standards is necessary for making meaningful park-to-park comparisons. Other federal land management and conservation agencies have also recognized the value of standardized environmental data bases: examples include the Biodiversity Project and Environmental Monitoring Assessment Program (EMAP) initiatives in the Environmental Protection Agency, the USDA Forest Service's Forest Inventory and Analysis (FIA) Program, the US Fish and Wildlife Service's National Wetlands Inventory (The Keystone Center, 1991), the Gap Analysis Program (Scott *et al.*, 1993), and the EuroMAB Biosphere Reserve Integrated Monitoring Project. Ideally, inventory efforts ought to be coordinated among biodiversity initiatives at state and federal levels to reflect the information needs of a greater variety of end users.

Successful application of the hierarchical model described above requires a well-funded, well-staffed infrastructure. We suggest national level responsibilities include securing funding; providing guidance, leadership, and program continuity; coordinating efforts with national and international agencies conducting similar efforts; and standardizing protocols for inventories and data management. Since there are no optimum 'off-the-shelf' resource inventory protocols available to meet all management needs, and because of the experimental nature of inventory design, there should be strong research and development and quality assurance/quality control components in the program (Stohlgren, 1994).

A new concept that the National Biological Survey is developing is the National Biological Information Infrastructure (NBII). The NBII will allow users to access, manipulate, organize, and use biological data and information from federal, private, state, and local sources. The primary function of the NBII is to provide an interactive data and information network that will improve the accessibility, dissemination, and quality of information on the nation's biological resources.

Regional responsibilities for a servicewide Inventory Program include establishing 'Centers' (perhaps in partnership with the National Biological Survey and universities) to coordinate inventory and monitoring activities among parks (provide taxonomic expertise, centralize data management activities and museum collections, and coordinate Science Advisory Teams, etc.). National Park Service and National Biological Survey scientists would provide technical assistance to small parks in resource inventories, synthesize data at regional levels, and produce annual reports and scientific publications.

Park responsibilities in the servicewide Inventory Program include identifying inventory and monitoring needs in park Resource Management Plans, identifying present and future questions to be asked of the data, and cooperating in all aspects of park, regionwide, and servicewide inventory and monitoring programs.

2. Design of biological inventory programs to bring all parks up to an acceptable level of resource awareness

Guided by the information needs of users, the National Park Service, in partnership with the National Biological Survey, should establish minimum inventory standards at the park, regional, and national level to meet resource preservation needs. We recommend that the standards for species lists include (1) systematic, standardized surveys (e.g. with transect length, plot shape and size, sampling design, and minimum sample size specified) in each park for each target taxon; (2) increased training for the collection and improved curating of voucher specimens; (3) expert checking of problematic specimens for proper identification; (4) in-park personal computer-based, standardized and compatible software for easy data entry, editing, and reporting and for ease of use and for inter-agency exchange of information; (5) a central service facility for handling taxonomic synonyms and data exchange; and (6) integration of standardized field and statistical techniques to assess more accurately the 'completeness' of species lists and identify information gaps on an ongoing basis.

The structure of inventories should reflect the information needs of end users of inventory information. Complete species lists are unattainable, as are complete distribution maps and population records for all species of conservation concern. Effective inventory and monitoring protocols should be designed to obtain adequate sampling to address the most important information needs of users, including resource managers, scientists, and regional and federal environmental policy makers.

Developing and evaluating protocols for intensive studies are not simple tasks. Several different sampling designs and inventory techniques have been used in the survey of a park's resources (Fig. 3). Study designs are tailored to meet specific objectives and none of the examples used below were designed explicitly to result in near-complete species lists. The rate at which new (new-to-park) species are discovered is dependent

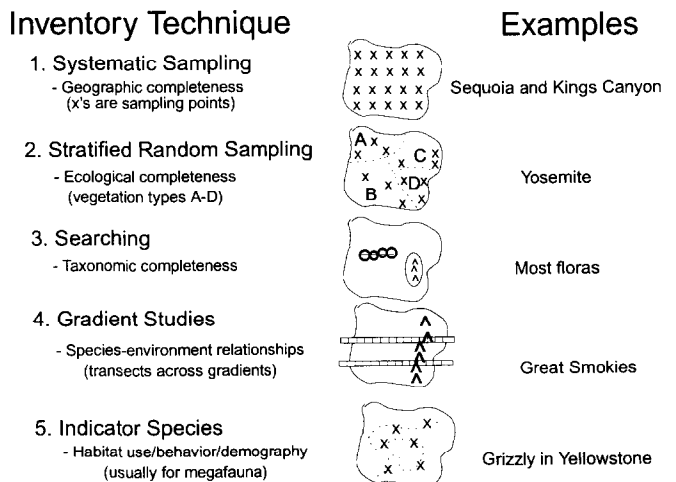


Fig. 3. Selected examples of biotic inventory designs and techniques used in national park units.

largely on the current completeness of the list, the sampling design employed, and the intensity of sampling. To be useful, specific protocols must be field-tested and carefully monitored (Palmer, 1990). We present these examples to show that various sampling designs will result in different results.

The ongoing vegetation survey in Sequoia and Kings Canyon NP is systematic (i.e. regular spacing of plots at a 1 km grid scale; Graber *et al.*, 1993). This technique is designed to produce geographically broad information. No large areas remain unsampled. However, certain habitats will be missed if they are rare, clustered, or spatially arranged in a linear or regular pattern but offset from the grid locations (Legendre & Fortin, 1989; Stohlgren, 1994).

Stratified random sampling will result in ecologically complete information if all ecological types are sampled thoroughly (e.g. the forest fuels survey in Yosemite NP; J. van Wagendonk, pers. comm.). However, because there is a priori selection of relatively homogeneous areas, heterogeneous areas (ecotones, gradients, mixed stands, etc.) are often ignored or under-represented in sampling.

Searching can result in rapid development of a species list (i.e. towards taxonomic completeness). However, searching is generally expensive, subjective, and localized so little information is gained about the representativeness of the samples or the geographic distributions of organisms. Furthermore, searching does not generally allow statistical treatment of temporal change, analysis for completeness or beta-diversity, etc.

Investigations of ecotones or vegetation transects along environmental gradients often are used to describe species distributions and species-environment relationships (Stohlgren *et al.*, 1994). However, here too, rare habitats may be missed or important resources lying off-line or perpendicular to transects may be under-represented.

Indicator species might be used to infer ecosystem integrity, resource condition, food-web connectivity, stress, habitat use, etc. However, it is difficult often to identify appropriate indicator species in light of changing resource threats and the complexity of species-environment interactions. In addition, extrapolation of results to unsampled populations, species, and communities is often tenuous.

In short, there are no off-the-shelf sampling designs and techniques for optimizing geographic+ecological+taxonomic completeness in biotic inventories. In fact, trade-offs are inevitable. Design considerations for common-use protocols include several basic questions, still debated strongly (see Fortin *et al.*, 1989; Legendre & Fortin, 1989). What plot sizes and experimental designs should be used? Which taxa should be sampled? How should population sizes be estimated? How often? What physical factors (rainfall, soil characteristics, etc.) should be measured? If vegetation, soil, or other classifications are used, which classification scheme is appropriate? How should the data be documented? How should the source and reliability of the data (for

example, staff versus visitor observation, or the experience and judgment of assistants) be evaluated? To what degree can or should protocols and databases be made compatible with those used by other agencies and conservation organizations? There is no right answer to most of these questions. We suggest that consistency, documentation, and easily followed guidelines may be more important than most of the particular choices. Clearly, no realistic inventory effort can be sufficiently complete to anticipate the information needs of all future users. We suggest consulting major users (e.g. park managers, resource specialists, regional and national decision makers, and researchers) at the design stage for anticipated questions to be asked of the data. An important component of future inventory work will be developing and testing hybrid sampling designs (Fig. 3) to address those questions.

Our results suggest that much of the work of establishing adequate resource inventories in our national parks lies ahead. The incompleteness of current biotic inventories reflects, in part, their low priority when compared with other park programs or to other agencies. In 1987, for example, the Park Service's science budget was \$15 million, or about 2.4% of the annual operating budget. This compares with \$122 million for the US Forest Service (5.6% of the annual budget) and \$53 million for the US Fish and Wildlife Service (8.7% of the annual budget; National Parks and Conservation Association, 1988; Day & Ruttan, 1991). Our hope is that increased support for inventory and monitoring for national parks will be made available by the National Biological Survey.

Coordinated, adequately detailed, planning, implementation and analysis across multiple parks will undoubtedly require much greater effort than is currently being applied. However, much of the potential effectiveness of an expanded biotic inventory program will be compromised if nomenclature, data processing, and sampling protocols are not tested and standardized. This will require a substantial increase in research and development: developing and testing inventory techniques, information and technology transfer, and a well-coordinated 'decision core'. We believe it is essential to have some parks carry on much more detailed programs than are feasible in most parks, both as pilot studies for establishing future standards, and as means of evaluating the uncertainties and risks inherent in applying incomplete ecological data to pressing problems in environmental management.

CONCLUSIONS

We believe the status of biological inventory information in many national parks reflects a history of low-priority treatment and uncertainty about the information needs of users of inventory data. Yet, the increasing national recognition of the importance of protecting biological diversity and monitoring ecological baselines and the availability of new technological tools have created opportunities to identify and map

biological resources, and coordinate analysis and planning, in a way never before possible. Doing so effectively will require explicit recognition that, because complete inventory and monitoring databases are nearly impossible to establish, priorities must be set early to address, by the most appropriate means, the specific information needs of the major database users.

Since a disproportionate share of biodiversity in national parks resides in the many smaller parks, it is essential to develop and implement acceptable baseline standards for inventory and monitoring information in all park units. The most important challenge facing the National Park Service is to intensify the partnerships with the National Biological Survey and others and obtain the resources necessary to get the job done.

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