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Monitoring vegetation and rare plant populations in US national parks and preserves

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Summary

The lack of permanent reference points is perhaps the single most important hindrance to assessing change in species populations and natural systems. At Great Smoky Mountains National Park rare plant monitoring includes mapping of population locations, sampling of 0.1 hectare permanent plots, mapping of individuals from permanent reference points, and establishment of photo points. This monitoring is part of a continuing program to update baseline inventories, monitor changes and explore management alternatives.

Aspects of rare plant monitoring in the USA are discussed and a survey of monitoring in 33 US Biosphere Reserves is presented. Four levels of activity are outlined: (1) designation and listing of rare species and assessing priorities; (2) establishment of a record of locations from past data; (3) field verification of sites and exploration for new sites; and (4) establishment of a permanent record of populations, including permanent plot sampling and mapping of individuals. Much work is in progress and much remains to be done.

Introduction

Monitoring is essential to conservation goals: it allows detection and documentation of change. Thorough documentation of change is often necessary in legal action, in evaluating priorities for conservation resources, and for convincing natural area managers that a management change is needed. An important measure of the success of a nature preserve may be its ability to retain species and natural systems – this measure is furnished by baseline inventory and monitoring. The Unesco Biosphere Reserves program, implemented in the USA in 1974, includes directives for long-term data collection (US Department of State, 1979).

The opinions presented in this chapter are those of the authors and do not represent official US National Park Service policy.

Great Smoky Mountains National Park: A case history of preservation, change and monitoring

Great Smoky Mountains National Park, Tennessee and North Carolina, is the largest wilderness reserve in the Southern Appalachian Mountains. It extends over 209 000 hectares. It is administered by the US National Park Service and was one of the first Unesco Biosphere Reserves in the US. The diverse flora of 1600 vascular plants is associated with rugged topography over elevations from 225 to 2025 m, high annual precipitation which increases with elevation from 100 to 250 cm, and a continental warm temperate climate – 150–180 days per year are continuously above 0°C. Slopes are forested with a pattern of deciduous, broad-leaved and evergreen, coniferous vegetation (Whittaker, 1956). There is no climatic tree line, but treeless communities dominated by grasses and shrubs ('balds') occur. The region is rich in endemics and in northern plants at their southern range limit: about 10 per cent of the park's native vascular plants are on state or national rare species lists (Cooper *et al.*, 1977; Committee for Tennessee Rare Plants, 1978; Ayensu and DeFilipps, 1978; White, in press, *a*). The flora includes one strict endemic and four species nearly restricted to the park.

National park status was formalized in 1940. About 70 per cent of the land has been cleared, at one time or another, for logging or agriculture. Some uncut areas have histories of anthropogenic fire, livestock grazing, or selective cutting. The remaining land supports some of the most significant tracts of pristine forests in the eastern USA: trees reach 2 m dbh on mesic sites. Protecting remnant wilderness forest and rugged mountain scenery was foremost in the minds of conservationists advocating creation of the National Park; the biotic diversity was known, but protection of rare species was probably not a major consideration of those who fought for preservation. Indeed, national park status long antedates the current emphasis on endangered species.

The need for monitoring is well illustrated by the changes that have taken place during 40 years of protection at this park; these changes are described in Bratton and White (Chapter 39) and are caused both by people, such as visitor pressure and collecting of rarities, and by natural events such as windstorms. In essence ecological change occurs within preserves as well as outside their boundaries.

The evaluation of change is dependent upon the availability and quality of past data. The history of botanical research in the park can be divided into three periods: (1) an initial resource inventory directed by the Park Service, 1930–40; (2) a period when research was largely defined and conducted by academic institutions, though park naturalists recorded some information, 1940–70; and (3) the present period of research and monitoring, during which the Park Service is again taking a role in defining problems.

For rare species populations, the major data come from herbarium labels. During the 1930s, several thousand collections of vascular plants were made. The intensity of collecting varied within the park; the early work documented 75 per cent of the flora. Despite problems, the value of these collections is clear. Several species lists, unsubstantiated by voucher collections, survive from the 1930s; these cite species that are well out of range in the Great Smoky Mountains' flora but the reports cannot be evaluated.

As important as the collections are in documenting taxa, shortcomings are also evident; there is usually no information on population size, and location data is often vague. Most collections can only be mapped within 100 to 10 000 meters (White, in press, *b*), despite the fact that they are from a local herbarium devoted to floristics. Label data probably exhibit more precision than those at most herbaria, but problems with relocation contribute to uncertainty about species loss. *Linnaea borealis*, last seen in Tennessee in 1891, is known from 'Mountain woods, Servier County'; this describes an area of 40 000 hectares.

During the initial resource inventory in the 1930s, 1500 vegetation plots each of 0.08 hectare were established. These plots were not permanently marked, and data from individual plots were never analyzed, except as they contributed to a subjective forest typing and a vegetation map. A project has been recently initiated to analyze these data; they contain information on forest structure at the time of chestnut mortality.

During the phase of academic research, the first studies of grassy bald succession and chestnut replacement were conducted. Major research included R. H. Whittaker's studies of community pattern and production (Whittaker, 1956, 1966). Becking and Olson (1978) relocated some of Whittaker's plots and marked them for permanent reference.

Usefulness of the past data base is variable. The studies of grassy bald succession furnish our clearest example of the value of long-term, site-specific data. Maps from 1938 and 1944 of two grassy balds and photographs dating from the 1920s allowed Lindsay and Bratton (1980) to present an unambiguous view of succession in this habitat: Gregory Bald and Andrews Bald will be forested in the next 30 and 70 years, respectively, given present climatic conditions. The origin of the balds, however, continues to be unresolved due to lack of data from before 1920. The question of origin is relevant since the National Park Service is committed to management for pre-Columbian processes in wilderness areas.

In contrast to grassy bald succession, there is little information at site level on the loss of a major dominant, the chestnut, to give an indication of how it can be replaced. There are quantitative data from the 1930s vegetation survey and from a 1950s study (Woods and Shanks, 1959) but comparisons with present information lack detail on mechanisms of change and site variation in replacement. The 1930s survey did not contain adequate sampling of tree reproduction, and the 1950s study presented only summary tables.

No data from before 1970 exist on the impact of the European wild boar. Similarly, there are no past data on rare plant population decline in Cades Cove wetlands, though such decline has probably occurred because of extirpation of the beaver, 100 years of drainage manipulations, and use of floodplains for pasture and hay-making.

The changes evident in Great Smoky Mountains National Park and the lack of an unambiguous data base led to the present emphasis on monitoring and the establishment of the Uplands Field Research Laboratory. Monitoring has also been spurred on by the Unesco Biosphere Reserves Program (Herrmann and Bratton, 1977; Johnson and Bratton, 1978; Becking and Olson, 1978; US Department of State, 1979) and by endangered species legislation.

Some 300 permanent vegetation plots (50 × 20 m, 0.1 hectare) have been established within the last 3 years (Table 1); these will contribute (combined with aerial photography) to a new vegetation map for the park, but they have also been used to investigate problems of immediate concern to park managers (Bratton, 1981). Projects using the plots include investigation of wild boar impacts (for which exclosure plots have also been established), grassy bald succession, limestone vegetation patterns, impacts on historic zone management (Bratton *et al.*, in press), fire succession (Harmon, 1980), and gap phase regeneration. Recent studies of spruce fir forests (Becking and Olson, 1978; Hay *et al.*, 1978), heath balds (Becking and Olson, 1978), grassy balds (Lindsay and Bratton, 1980), and mesic hardwood forests (Becking and Olson, 1978), though based partially outside Uplands Laboratory, have all added permanently marked plots, as has the work of Golden and West (Darrel West, pers. comm.).

Table 1 An outline of monitoring at Great Smoky Mountains National Park

Vegetation monitoring – Permanently marked 0.1 hectare plots (50 × 20 m)
- Plot location: Mapped on USGS 7.5-min. quadrangles; field directions recorded from prominent landmarks with tape and compass.
- Permanent marking: Four steel rods, each a different color and bearing a different identifying tag; referenced to witness trees.
- Trees and saplings: All trees above 10 cm dbh mapped on plot; all woody stems 1–10 cm dbh recorded by 10 × 20 m subplots.
- Shrubs: Twenty-five individual 2 × 2 m quadrats sampled for cover and density (the latter in three diameter classes, 0–2, 2–6 and 6–10 mm at 5 cm above ground).
- Herbs: Twenty-five individual 1 × 1 m quadrats sampled for cover.
- Species list: A complete species tally is kept for each plot.
- Environment: Elevation, aspect, slope angle, measures of local topographic shape, slope position, kind of substrate.
- Disturbance: Indices of deer, wild boar, chestnut blight, flooding, windstorm, fire, logging, agricultural impacts.
- Miscellaneous: A convex mirror is used to superimpose 25 points on the canopy to measure canopy closure (in each 10 × 10 m plot).

Rare species monitoring
- Herbarium label data computerized.
- Field sightings (information also required on current herbarium labels): elevation, latitude, longitude, USGS map, watershed, location directions, habitat data, population size.
- Mapping of population locations.
- Assessing priorities among rare species based on listed status, geographic affinity, distribution of populations, number of populations, population size, population trends and threats.
- Permanent sampling: Mapping of individuals from reference points and in 0.1 hectare permanent plots.
- Photo points at mapped locations and in plots.

Herbarium labels and field sighting forms have been designed to maximize information recorded (White, in press, *a*). Photocopied sections of topographic maps, marked in the field, increase the precision of location data. UTM latitude and longitude can usually be recorded within a range of 10–100 m, and elevation within 10 m. Labels and sighting forms also require other information on location, habitat, vegetation and population size (Pyle *et al.*, 1979), information which is obvious in the field but soon lost if not recorded.

Rare plant monitoring, established within the last year, includes three levels of permanent records: (a) populations are mapped on topographic sheets and population size assessed; (b) permanent plots of 0.1 hectare are used for characterizing and monitoring habitats; and (c) individuals within populations are mapped from permanent reference points, and photo points are established. Except in the case of dramatic impacts, we envision resampling at 5–10 year intervals for rare populations and 10–20 year intervals for vegetation plots. Priorities in mapping of populations are established through a scale of seven weighted factors: 1 – listed status, 2 – geographic affinity, 3 – significance of park populations to distribution as a whole, 4 – number of locations, 5 – population size, 6 – population status, 7 – threats.

Monitoring schemes must be flexible. Species in the park vary widely in population size and distribution, in habitat, and in ecological strategy. No single series of categories predominate. Some species are known from many locations, but with very few individuals at each (e.g. the biennial *Adlumia fungosa*); others are abundant at a single location (e.g. *Prunus virginiana*). A few species are both rare and local (e.g. *Geum radiatum*). Some strict endemics are abundant in the park (e.g. *Cacalia rugelia*).

Some of the species are evidently weedy and prolific in reproduction and establishment (e.g. *Calamagrostis cainii*); other species are evidently conservative (e.g. *Geum radiatum*). The distribution of species relative to open habitats is notable: 32 per cent are characteristic of open habitats; 23 per cent are found in both open and forested communities; and 45 per cent are found in closed forest, though they may increase with small-scale canopy disturbance. Thus, just less than half of these species are found in virgin forests; monitoring must take into account both succession and mechanisms that maintain openness.

Aspects of rare plant monitoring in the USA

Much has been written on assessing which species of the US flora are in danger and monitoring rare plants (see in particular Ayensu, Chapter 2). Numerous projects are underway, involving a broad range of state and federal agencies, academic institutions, consulting firms and environmental groups. Much of the recent work is in progress or unpublished; some is in environmental impact statements and internal reports that are not widely circulated in the scientific community. At present there is little central focus. The National Heritage Program, a current proposal to be developed by the Heritage Conservation and Recreation Service (Department of the Interior), may eventually supply that focus (Merikangas, in press); if funded, that program will use the ecological inventory format developed by The Nature Conservancy for state Natural Heritage programs (S. Buttrick, pers. comm., see also Morse, Chapter 38). Guidelines for long-term ecological research in Biosphere Reserves have been developed (US Department of State, 1979) and may eventually serve as a national focus of biological monitoring efforts.

That work is in progress stems in part from the fact that federal legislation is so recent (1973). Moreover, plants are covered only secondarily by the Endangered Species Act and listing is still in progress as explained by Fay (Chapter 37); comparatively few plant species have been declared 'Endangered' or 'Threatened'. The Fish and Wildlife Service (Department of the Interior) was designated by the Endangered Species Act as the federal agency responsible for coordinating endangered species work. The *Endangered Species Technical Bulletin* of that agency is one of the few publications summarizing the status of lists, court cases, research and publications on endangered species. Nationally significant species are given the most attention, but local efforts have also been reported.

Programs to monitor rare plants in the US vary from informal (as when knowledgeable individuals keep watch on local populations) to formal (permanent plots and population mapping). Information recorded varies from presence/absence in a given locality to detailed demographic variables of growth, reproduction, and mortality. Four program levels can be described, progressing from less to more detail in monitoring: (1) assessment of which taxa are rare or threatened; (2) establishment of a permanent record of locations of rare taxa from herbarium surveys and published literature; (3) field verification of old sites and exploration to find new sites; and (4) creation of a permanent record of populations, including permanent plot establishment, mapping of individuals, establishment of photo points, and collection of demographic information. Some programs include aspects of all four kinds of work (e.g. that of the California Native Plant Society, in Powell, 1978); some have developed more or less along this sequence (e.g. our program at Great Smokies). The degree to which each level is expressed varies with constraints of time and money as well as the actual biological realities of rare species problems.

The Natural Heritage programs of The Nature Conservancy and state governments furnish the best example of establishment of a permanent record of baseline data on the distribution of rare taxa and are described by Morse (Chapter 38). These programs have been instituted in 20 states and in the 7 state areas of the Tennessee Valley Authority. Natural Heritage programs use a common format for ecological inventory and a system of mapping locations on standard topographic maps. This firmly establishes an easily accessed data base for environmental impact assessment and protection efforts. Heritage programs provide the best detailed information on the status of a species in a given state, and include species threatened at state level as well as at national level.

The next priority is to verify the sites on the ground through field work. This is being carried out by some Natural Heritage programs (e.g. see Lichvar and Stromberg, in press), but establishing ecological inventories of past data must come first and take precedence. Other examples of recent field projects include the work of Holland and Schramm (in press) in Death Valley, Thomas' study (in press) of population decline in *Sida hermaphrodita*, as well as numerous reports to Federal Agencies. Environmental groups like the California Native Plant Society (Powell, 1978) have developed extensive programs that span the four levels of work reviewed here. Conservationists in several other states have developed similar programs to assist the educational and research effort for rare plants.

Sampling plots and mapping populations are also under way in a few areas. Examples from Biosphere Reserves are cited in the next section; other examples include the work of S. L. Mehrhoff (pers. comm.) in which every known individual of the orchid *Isotria medeoloides* was mapped; Lowe (1977) on saguaro cactus; the permanent plot exclosures of Smith (1980); and the mapping of *Sequoiadendron giganteum* noted by Little (1975). Hastings and Turner (1965) showed clearly the value of photo points in assessing change in the Arizona desert. Easterly (1979) reported a resurvey of 154 rare taxa in oak openings in Ohio after 50 years of change. Ward (1977) reported a 20-year-decline in a population of *Gaultheria procumbens* in Indiana.

The Convention on International Trade in Endangered Species (CITES) of 1973 requires monitoring of export and import of listed species. This has inspired several monitoring programs, including one on *Panax quinquefolius* populations in North Carolina (R. Sutter, pers. comm.).

Monitoring in US preserves

To determine the amount and type of monitoring currently under way in US natural areas, the authors conducted a survey of the 33 US Biosphere Reserves (see descriptions in Risser and Cornelison, 1979). These preserves represent a wide variety of natural systems and are part of a worldwide network of natural areas designed, in part, to provide monitoring data (US Department of State, 1979).

The results of the survey are shown in Figure 1. Although 31 reserves have a checklist of vascular plants, 21 have an evaluation of whether nationally rare species are present, 18 have a list of state or locally rare species, and 4 have a published report on rare species. Thirteen reserves have some register of rare population locations, 11 have population estimates, 11 have an evaluation of threats, and 6 have population monitoring. By contrast, 25 reserves have permanent plot vegetation monitoring. Clearly, work is very much in progress; the Biosphere monitoring recommendations (US State Department, 1979) are still being implemented, and staff and funding problems for long-term data collection have not yet been fully resolved. Most US Biosphere Reserves are now progressing from inventory (level I of US State Department, 1979) and quantitative monitoring

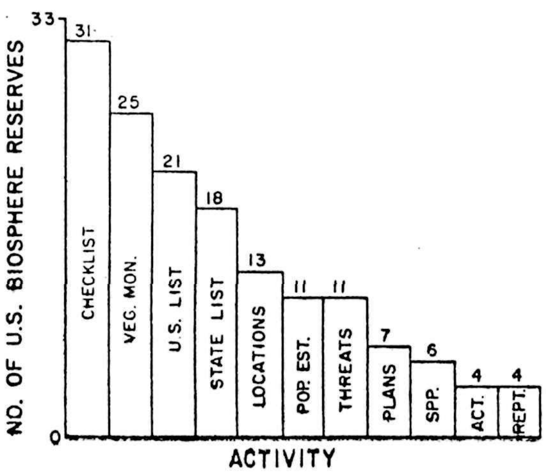

Figure 1 Results of a survey of monitoring activities in 33 US Biosphere Reserves. Work 'in progress' is tallied with completed work. Activity abbreviations are: checklist = vascular plant checklist; veg. mon. = vegetation monitoring program; US list = nationally rare species (an investigation reporting no known nationally rare species is counted as a 'list'); state list = list of state rare species; locations = mapped locations of rare species; pop. est. = estimate of population size for rare species; threats = assessments of threats to rare species; plans = management plans for rare species; spp. = monitoring of rare species populations; act. = active management for rare species; rept. = published report on rare species

(level II) to modeling and management (monitoring level III), a subject explored in Bratton and White (Chapter 39).

There is a difference in monitoring activity between reserves with a conservation mission and those with an experimental mission. All of the experimental reserves have permanent vegetation monitoring, but only half of these reserves have lists of nationally rare species. In contrast, only 66 per cent of conservation-oriented areas are engaged in vegetation monitoring, but 80 per cent have lists of nationally rare species. These differences may be due to differences in staff orientation, which is in part related to the economic objectives of some experimental areas (e.g. forest production research). Several experimental reserves had extensive schemes of permanent plots to gauge tree growth and recovery from disturbance; vegetation monitoring in conservation areas was frequently related to specific problems such as ungulate browse or visitor impacts.

Of the six reserves reporting some form of rare plant monitoring (four with a conservation mission, one with an experimental mission, and one with both kinds of mission), one was using non-quantitative annual observation (Virginia Coastal Reserve), four were using permanent plots and photo points (Everglades National Park, Channel Islands National Monument, H. J. Andrews Experimental Forest, and Great Smoky Mountains National Park), and one was using photo points exclusively (Olympic National Park). Loope (in press) reports work in the Everglades. Hawk *et al.* (1978) report on the detailed 1-hectare permanent plots used at H. J. Andrews Experimental Forest; in addition to population mapping and photo points, stream courses, boulders, and fallen logs are mapped.

A further study was undertaken of 43 national parks in the southeastern USA (see Bratton and White, Chapter 39). Most parks over 500 hectares in size, including historic areas, had had some work completed on a vascular plant collection or a checklist. Sixteen of twenty of these larger areas had a list of rare and endangered vascular plants completed or underway, based on the 1975 Smithsonian list or on state lists (see Ayensu, Chapter 2). Collections of non-vascular plants and records of endangered plant localities and population estimates are not available for most of these areas, though two of the largest parks, Great Smoky Mountains and Everglades, had published preliminary status reports on endangered plants. For areas less than 500 hectares, floristic information was scanty and few reported any rare species at all.

A discussion of monitoring issues

Biological monitoring, the periodic observation and quantitative analysis of the state of populations and natural systems, is essential (Jenkins and Bedford, 1973) – now is a time when both species and pristine habitats are being lost. Surviving natural areas are often marked by changes such as the loss of large predators, the invasion of exotic species, the spread of airborne pollutants, and direct visitor impacts. Most past data bases used to assess these changes, ; ast in our experience, allow only inference; measurements cannot be repeated. Assessments of change are needed for presentation to politicians, the general public and other scientists. Ironically, before these changes began there was no immediate need to establish baselines; now that species loss is occurring, we need that past data. Also ironic is the fact that much detail, if not actual plots, has been lost. There is now a need for certainty and site specificity.

Monitoring need not be passive; plots can be set up to test hypotheses (e.g. concerning climatic change, pollution effects, and exotic species invasions – Johnson and Bratton, 1978; Becking and Olson, 1978). Funding for science research in the USA has tended to be oriented around short-term questions involving 1–5 year periods of study. Our own monitoring was established only in conjunction with research on specific impacts and vegetation mapping. It is not clear whether monitoring could be funded where no acute problems have been recognized; it is also not clear if remeasurement of our plots will be considered part of resource management or of a science program. In the past National Science Foundation funding has also tended to work against long-term studies. The need for such studies, however, led to a trial program in the last year (Callahan, in press). The Long-Term Ecological Research (LTER) program will fund about five large scale projects this year. The title (long-term *research*, not *monitoring*) underscores the role of hypothesis testing in organizing the studies. Monitoring data can also be used to build and validate models, useful in management programs (Johnson, in press); for rare plants, autecological information can be collected and used in management.

Permanent plot establishment is not the only sampling strategy. Large independent, random samples can also document change. Several factors emphasize the need for establishing permanent reference points, however. Repeated measurement of the same plots can be used to compare change in different ecological situations. Because of the complicated nature of change in most forest stands, specific mechanisms of change can be explored on individual plots. Data unrecorded or unpublished by baseline studies can also be recovered.

For rare plant populations, large random samples would not suffice; we are often specifically interested in individual populations. For population changes, the only usual data base available is the information on herbarium labels, in the memories of collectors, or in the chance survival of photographs that can be used to assess change on specific sites.

The central issues in the establishment of a permanent plot data base are the assurance that plots can be relocated and that the measurements can be repeated. Challenges include the selection of data to be recorded (Becking and Olson, 1978; T.I.E., 1979; US Department of State, 1979), control of data quality, provision for archival storage of information (Herrmann and Bratton, 1977; Bratton, 1981) and planning for resampling. To a certain extent, data collected will depend on time and budget; data precision is usually an inverse function of cost. Archival systems must allow storage of raw data as well as summary publications. The

system must allow periodic updating – this is the reason for putting on computer the checklist and herbarium data now under way in our program.

Monitoring is important both before and after legal protection of species and habitat. Before protection, monitoring supplies precision to the conservationist's predictions and allows critical situations to be identified. After legal protection, monitoring allows us to answer perhaps the most basic of all conservation questions: how effective are our national parks, wilderness areas, wildlife refuges and other conservation areas at preserving the ecosystems and species they contain? Nearly every preserve contains species rare enough to be vulnerable to loss (Hooper, 1971; Terborg, 1974). One of the most common and significant hindrances to answering this question, and in assessing current trends, is the lack of a data base or permanent reference point from which to judge change.

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References

Ayensu, E. S. and DeFilipps, R. A. (1978). *Endangered and Threatened Plants of the United States*, Smithsonian Institution and World Wildlife Fund – US, Washington, DC.

Becking, R. W. and Olson, J. S. (1978). 'Remeasurement of permanent vegetation plots in the Great Smoky Mountains National Park, Tennessee, USA, and the implications of climatic change on vegetation', *Oak Ridge National Laboratories, Environ. Studies Div., Publ. No. 1111*, Oak Ridge, Tennessee, 94 pp.

Bratton, S. P. (1981). 'Information storage and population monitoring within Great Smoky Mountains National Park' in *Rare Plant Conservation: Geographical Data Organization* (Eds. L. E. Morse and M. S. Henifin), pp. 63–68, New York Botanical Garden.

Bratton, S. P., Mathews, R. C., Jr., and White, P. S. (in press). 'Agricultural area impacts within a natural area: Cades Cove, a case history', *Environ. Manage.*

Callahan, J. T. (in press). 'Initiating a program of long-term ecological research', in *Proceedings of the Second US–USSR Biosphere Reserve Symposium*, Everglades National Park, Homestead, Florida, March, 1980.

Committee for Tennessee Rare Plants (1978). 'Rare vascular plants of Tennessee', *J. Tenn. Acad. Sci.*, 53, 128–33.

Cooper, J. E., Robinson, S. S., and Funderberg, J. B. (Eds.) (1977). *Endangered and Threatened Plants and Animals of North Carolina*, North Carolina State Museum of Natural History, Raleigh.

Easterly, N. W. (1979). 'Rare and infrequent plant species in the oak openings of northwestern Ohio', *Ohio J. Sci.*, 79, 51–58.

Fernald, M. L. (1950). *Gray's Manual of Botany*, 8th Ed., American Book Co., New York.

Franklin, J. F. (1977). 'The Biosphere Reserve Program in the United States', *Science*, 195, 262–7.

Harmon, M. E. (1980). *The Influence of Fire and Site Factors on Vegetation Pattern and Process in the Western Great Smoky Mountains*, MSc thesis, University of Tennessee, Knoxville, 200 pp.

Hastings, J. R. and Turner, R. M. (1965). *The Changing Mile*, University of Arizona Press, Tucson, 317 pp.

Hawk, G. M., Franklin, J. F., McKee, W. A., and Brown, R. B. (1978). 'H. J. Andrews Experimental Forest reference stand system: establishment and use history. Coniferous Forest Biome', *US IBP Ecosystem Analysis Studies, Bull. No. 12*, 79 pp.

Hay, R. L., Eager, C. C., and Johnson, K. D. (1978). 'Fraser fir in the Great Smoky Mountains National Park: its demise by the balsam woolly aphid', *Rep. to the National Park Service, US Dep. of the Interior, Southeast Region, Atlanta, Georgia*, 125 pp.

Herrmann, R. and Bratton, S. P. (1977). 'Great Smoky Mountains National Park as a Biosphere Reserve: a research perspective', *US Dep. of the Interior, National Park Service, SE Regional Office, Research/Resources Manage. Rep. No. 23*, 38 pp.

Holland, J. S. and Schramm, D. R. (in press). 'Lake Mead and Death Valley rare plant studies', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, November 1979.

Hooper, M. D. (1971). 'The size and surroundings of nature reserves', in *The Scientific Management of Animal and Plant Communities for Conservation* (Eds. E. Duffey and A. S. Watt), pp. 555–61, Blackwell Scientific Publications, Oxford.

Jenkins, R. E. and Bedford, W. B. (1973). 'The use of natural areas to establish environmental baselines', *Biol. Conserv.*, 5, 168–74.

Johnson, W. C. (in press). 'Monitoring and modelling in tandem: a strategy to identify and predict successional change', in *Proceedings of the 2nd US–USSR Biosphere Reserves Symposium*, Everglades National Park, Homestead, Florida, March 1980.

Johnson, W. C. and Bratton, S. P. (1978). 'Biological monitoring in UNESCO Biosphere Reserves with special reference to the Great Smoky Mountains National Park', *Biol. Conserv.*, 13, 105–15.

Johnson, W. C., Olson, J. S., and Reichle, D. E. (1979). 'Management of experimental reserves and their relation to conservation reserves: the reserve cluster', *Nat. Resour.*, 13, 8–14.

Lawyer, J. I. (in press). 'Guide to U.S. State lists of rare and endangered plant taxa', *Mem. Torrey Bot. Club.*

Lichvar, R. and Stromberg, M. R. (in press). 'Wyoming Natural Heritage Program – inventory methodology for updating, defining, and mapping "rare" species', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, 1971.

Lindsay, M. M. and Bratton, S. P. (1980). 'The rate of woody plant invasion on two grassy balds', *Castanea*, 45, 75–87.

Little, E. L., Jr. (1975). 'Rare and local conifers in the United States', *US Dep. of Agriculture Forest Service, Conservation Res. Rep. 19*, 25 pp.

Loope, L. (in press). 'The flora of South Florida: how securely is it preserved in National Parks?', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, November 1979.

MacBryde, B. (1979). 'Plant conservation in North America: developing structure', in *Systematic Botany, Plant Utilization and Biosphere Conservation* (Ed. I. Hedberg), pp. 105–9, Almqvist and Wiksell International, Stockholm.

McKitrick, J. A., Jordan, J. R., Jr., and Thurman, J. R. (n.d.). *TVA Regional Heritage Program: A Land-Use Planning Tool for Fish and Wildlife Resource Planners*, Tennessee Valley Authority, Division of Forestry, Fisheries, and Wildlife, Norris, Tennessee, 10 pp.

Merikangas, J. B. (in press). 'Endangered species and the National Heritage Program – HCRS', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, November 1979.

Powell, W. R. (1978). 'The CNPS inventory – a progress report', *Fremontia*, 5, 28–9.

Pyle, C., White, P. S., and Bratton, S. P. (1979). 'Computerization of herbarium records at Great Smoky Mountains National Park', Rep. to the Great Smoky Mountains Natural History Association', *Int. Rep. Uplands Field Res. Laboratory*, Gatlinburg, Tennessee, 24 pp.

Risser, P. G. and Cornelison, K. D. (1979). 'Man and the Biosphere: US Information Synthesis Project, MAB-8, Biosphere Reserves', *Oklahoma Biol. Surv.*, Norman, Oklahoma, 109 pp.

Smith, C. W. (1980). 'Proposed native ecosystem restoration program for Halapé, Keuhou, and Apua Point, Hawaii Volcanoes National Park', *Cooperative National Park Studies Unit, Tech. Rep. 28, University of Hawaii*, Manoa, Honolulu, Hawaii, 35 pp.

Steenbergh, W. F. and Lowe, C. H. (1977). 'Ecology of the saguaro, II. Reproduction, germination, establishment, growth, and survival of the young plant', *US Dep. of the Interior, National Park Service Scientific Monogr. Series No. 8*, Government Printing Office, Washington, DC, 242 pp.

Terborg, J. (1974). 'Preservation of natural diversity. The problem of extinction prone species', *Biol. Sci.*, 24, 715–22.

Thomas, L. K., Jr. (in press). 'The decline and extinction of a rare plant species, Virginia Mallow (*Sida hemaphrodita* (L.) Rusby), on National Park Service areas', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, November 1979.

T.I.E. (1979). *Long-term Ecological Research: Concept, Statement, and Measurement Needs*, National Science Foundation, Washington, DC, 27 pp.

US Department of State (1979). *Long-term Ecological Monitoring in Biosphere Reserves*, National Committee for Man and the Biosphere, Washington, DC, 31 pp.

Ward, D. B. (1977). '*Gaultheria procumbens* at Pine Hills, Indiana – Its measured decline, 1951–1971', *Proc. Indiana Acad. Sci.*, 86, 131–9.

White, P. S. (in press, *a*). 'Rare plant monitoring in Great Smoky Mountains National Park', in *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, November 1979.

White, P. S. (in press, *b*). 'Herbarium computerization at Great Smoky Mountains National Park', *Proceedings of the 2nd Conference on Scientific Research in the National Parks*, San Francisco, California, November 1979.

Whittaker, R. H. (1956). 'Vegetation of the Great Smoky Mountains', *Ecol. Monogr.*, 26, 1–80.

Whittaker, R. H. (1966). 'Forest dimensions and production in the Great Smoky Mountains', *Ecology*, 47, 103–21.

Woods, F. W. and Shanks, R. E. (1959). 'Natural replacement of chestnut by other species in the Great Smoky Mountains National Park', *Ecology*, 40, 349–61.

Note

Plant names in this chapter follow Fernald (1950), except for *Geum radiatum* A. Gray, *Cacalia rugelia* (A. Gray) T. M. Barkley & Cronquist, *Calamagrostis cainii* Hitchc. and *Sequoiadendron giganteum* (Lindl.) Buchh.