A GEO-BASED RESOURCE INFORMATION SYSTEM WITH APPLICATIONS FOR MONITORING WILDLIFE IN SEQUOIA AND KINGS CANYON NATIONAL PARKS

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Abstract: Sequoia and Kings Canyon National Parks have begun the long-term development of a geo-based resource information system to provide comprehensive data on many classes of resources (including terrain, vegetation, and fauna) that can then be integrated and analyzed by computer using both tabular-statistical and cartographic techniques to yield powerful ecological insights. In addition to using data acquired from remote sensing and previous work, we have begun an exhaustive systematic survey of biota by establishing plots on 1 km^2 centers throughout the parks. These plots serve 3 functions. They provide necessary ground-truth for accurate implementation of remote sensing; a detailed and exhaustive sampling of organisms and their distribution; and because they are permanently marked, serve as a baseline for long-term monitoring. While natural resources in national parks are managed for long-term preservation, changes in habitat induced by pollution, fire, recreation, and island effects, for example, may nonetheless occur and must be monitored. The exhaustive inventory of wildlife and habitats produced will provide useful validation of the wildlife-habitat relationships model sponsored by California Department of Fish and Game. The first round of surveying and implementation of this program throughout the parks was begun in 1985 and will take up to a decade to complete.

Professional management relies on accurate and comprehensive information. Managing both the physical resources and the visitor services of national parks such as Sequoia and Kings Canyon has become progressively more complex as pressure on those resources and numbers of park visitors have increased. Neither the information base nor its accessibility has kept pace with these increasing demands. For these parks, as for other large natural-area parks established long ago, much of our information about natural resources was collected during the first half of this century. That database is no longer adequate to manage the parks. It lacks the technical sophistication and theoretical underpinnings of modern science, and it is a static picture of a dynamic system. In many aspects it is also plainly incomplete. A high quality baseline of natural resources information and the long-term monitoring of those resources has become imperative for the National Park Service as the ecosystems under its protection become increasingly valuable and vulnerable (Strayer et al. 1986) Secondly, while the information base supporting management has grown with time, it has become progressively more unwieldy as it has become larger and more complex. The Geo-based Resource Information System (GIS) project sets in motion a process to update the information base and to manage that information more efficiently. As resource monitoring comes to play an increasing role in the protection of Park resources and as a reference point for the nation as a whole, the GIS becomes critical to the management of multi-dimensional information (Devine and Field 1986).

Sequoia and Kings Canyon National Parks are located in the central Sierra Nevada of California. They were established in 1890, with periodic expansions through 1978. The two parks are contiguous, and form an International Biosphere Reserve of 349,811 ha. There are 1270 km of trails, and 300 km of paved roads, with 85.3% of the reserve in legal wilderness. Annual visitation recently has averaged nearly 2 million people.

The parks are bounded on the north, east, and south by Federal National Forest lands used for timber harvest, grazing, and recreation, but otherwise little modified. Lands to the west are largely private, devoted to ranching and farming, and containing villages. The eastern boundary is the crest of the Sierra Nevada. The remaining boundary is a combination of watershed, river, and artificial demarcations. Elevations in the reserve range from 400 m to 4,418 m, constituting a portion of the western slope of the Sierra Nevada which rises gently to the Pacific crest and boundary. The eastern slope of the range is a steep escarpment. Three major river systems: the Kings, Kern, and Kaweah, drain the parks. Climate is Mediterranean, with hot, dry summers and cool winters during which most precipitation falls. Above 2,000 m the bulk of this is as snow. Vegetation is extremely varied, including chaparral, oak woodland, upland hardwood forest, conifer forest, and alpine plant communities.

Present compiled records list 1,237 vascular plant species, of which 89 are alien. There are 160 regularly occurring bird species (of which 5 are alien), 78 mammals (7 alien), 24 reptiles, 11 amphibians, and 8 fishes (3 alien). The only native vertebrate known to have become extinct within the present boundaries of the reserve since its establishment is the grizzly bear (*Ursus arctos*), in 1922. Although Newmark (1985) has claimed additional extinctions since establishment of the parks (e.g. *Canis lupus*), these are species for which there is little data to support either their original presence or their subsequent disappearance. There are no reported plant extinctions. The vascular plant list is quite incomplete (at least 11 species were added from 1986 field work), while those for the vertebrate classes undoubtedly contain errors including omissions, unsupported listings based on range inferences or misidentifications, and local unrecorded extirpations.

PROJECT OBJECTIVES

The initial goal of this project is to develop a high-quality, comprehensive database describing the parks' natural and cultural resources, and to integrate this information into a computer-based system that can easily be accessed and modified over time. The classes of information presently planned for this system include, but are not restricted to, the following: (1) vascular vegetation, (2) vertebrate fauna, (3) terrain (slopes, elevations, and aspects) and hydrography, (4) bedrock geology, (5) soil taxonomy, (6) caves, (7) fire history (locations and dates of recorded fires), (8) fuel structure and loading, (9) landnet (boundaries, roads, trails, management zones), (10) archeological sites, and (11) structures (historic and contemporary).

Most - but not necessarily all - of this information will be stored as "themes". These can be visualized as map overlays registered to a common base, permitting relational syntheses and analyses among different information classes or themes. Contemporary three-dimensional map analysis and image processing requires software and computer hardware only recently developed for small systems (i.e. Cooney and Tucker 1986, Davis and McCullagh 1975). Traditional database management and statistical software will be used for numeric, two-dimensional (e.g. tabular) processing of this database. Such geographic information systems permit not only numeric but visual interpretation of multiple themes by retrieving information as images that can be viewed, manipulated, combined, and stored as new data (Smith et al. 1987).

The second goal of the project is to set in motion long-term monitoring of the resources in the system, and to institutionalize this monitoring to assure that collection, compilation, analysis, and interpretation of data continue indefinitely.

This project is distinctly different from most National Park Service research and resources management programs in several ways. Because it is not driven by any particular resource crisis, the project is scheduled to progress conservatively, with an initial data acquisition and system development period of at least five years, and a more likely period of ten years to complete resource surveys. Additionally, the project is designed to be immortal. Resources data will be acquired and integrated indefinitely through monitoring and periodic new surveys. A parallel cooperative project was initiated in Yosemite National Park in 1983. The two park units have each pioneered a different task (Yosemite, digital cartography and remote sensing, Sequoia and Kings Canyon, field data acquisition and wildlife data management) to minimize the duplication of wasteful errors during the development process.

ACQUISITION OF INFORMATION

The database generated by this project will come from three primary sources.

Existing Information

The parks presently possess vegetation maps produced at different times, to differing standards, to different scales, and for different purposes. Yet all of these have some value, particularly as historic baselines for evaluating change. Thus there will be several different vegetation type maps within the database. Other data in map form include archaeological sites, roads and buildings, historic fires, boundary changes, and the like. Wildlife information exists as individual sightings (usually with a geographic reference), museum collection records, and data from directed research projects. These various files of information will be digitized, and each stored as a theme within the GIS database.

Information From Current Field Surveys

Because no reliable or exhaustive inventory of Park biological resources presently exists, a systematic survey began as part of this project in 1985 that will eventually sample vegetation and terrestrial vertebrate fauna throughout the parks. In addition, park staff who are frequently in the field and who can reliably identify animals or plants are aggressively encouraged to complete simple species/date/place observation forms, data from which are included in the historic database. Finally, special surveys conducted by extramural organizations to classify soils, or to identify invertebrates, aquatic animals, and non-vascular plants will be encouraged, and supported as funds permit.

Remotely-sensed and Other Digital Data

Two critical elements of the GIS database are Landsat Thematic Mapper (TM) satellite-originated imagery of the parks, and Geological Survey digital cartography in the form of Digital Elevation Models (DEM) and Digital Line Graphs (DLG). At a resolution of 0.1 ha, the TM data set offers the most economical basis for a modern vegetation classification over an area the size of Sequoia and Kings Canyon National Parks. With the field survey providing detailed ground truth sampling 0.1% of the parks, remote sensing can be used successfully to extrapolate to the remainder. Geological Survey DEMs at a nominal scale of 1:24,000 and approximate resolution of 0.1 ha will be the absolute base maps against which all locations are referenced, as well as providing topography, while DLG's at the same resolution map hydrography, transportation, boundaries, named features, and structures (the digital equivalent of that provided on published quadrangles).

INCORPORATION OF INFORMATION

If existing information is in map form or can efficiently be converted to map form, mylar outline overlays will be drafted in the park and digitized by automatic scanner or digitizing tablet. Tabular or other non-map oriented data of value that contain coordinate (locational) attributes will be organized in a conventional relational database management system, and later converted to cell-image data. Data collected by field surveys will similarly be stored and later converted to image data as appropriate software and hardware come on line. NASA Landsat TM and USGS DEM/DLG data are provided as magnetic tapes. Thematic mapper imagery will be geo-referenced to DEMs and existing published 15 minute topographic quads. Initial vegetation classification will be conducted using the first three years' field data as ground-truth.

COMPUTER SYSTEM

The GIS database is expected to exceed 300 megabytes by its fifth year. Map analysis and image processing require substantial memory and mass storage when databases this large are to be manipulated. At present, the most appropriate (and minimal) data processing configuration for an isolated location such as these parks is a stand-alone super-microcomputer workstation with 32 bit CPU, at least 4 MB physical memory, virtual memory, at least 300MB disk drive, 1/2 inch tape drive, and a 1100x900x6-plane pixel color monitor. The minimally-configured computer workstation costs approximately $50,000 (in 1987 dollars). Input devices such as plotters and scanners, and hard-copy output devices such as color plotters or ink-jet printers represent additional costs. A variety of commercial GIS software exists, but generally is quite expensive and restricted in compatible hardware and applications. Public domain software is now being modified to operate on a variety of 32 bit microcomputers running under the UNIX operating system, including ELAS, developed by NASA, and GRASS, developed by the Army Corps of Engineers. An IBM PC-AT presently is used to store and manipulate non-image data files, with the image-processing workstation expected to come on line in 1988.

FIELD INVENTORY OF PARK RESOURCES

In 1985, a systematic survey of the natural resources of both parks was initiated. Sampling points were located at the intersection of 1 km Universal Transverse Mercator (UTM) grid lines. There are approximately 3,400 such sites in the parks, 136 having been sampled through 1986. However, periodic analyses of variance will refine sampling density as more sites are visited (we hope reducing it!), and use of initial sites to classify remote sensing of the parks during 1987 will provide a basis for stratification.

The resource inventory is a neighborhood description, wherein sampling radius about the coordinate point varies according to the scale and mobility of each class of organisms (Lund 1982). Thus large organisms, such as trees, and mobile organisms, such as birds, are sampled over a greater area than are herbs and amphibians, for example. No effort is made to place sampling points in homogeneous habitat, as is conventionally done with releves (Mueller-Dombois and Ellenberg 1974:46). That would bias sampling against ecotones, under-report variability of the physical and biotic environment, and undermine the value of the sampling to test existing classification schemes. While the 100 m radius neighborhood of each sampling point is described in terms of the California Natural Diversity Database Natural Communities schema (Holland 1986), and an extensive narrative description is recorded and photographs taken, site parameters are empirically enumerated, not assigned to *a priori* classes. Although some density and frequency measurements of plants are made, we consider the most important data to be simple determination of plant and animal species present at each site. Not only is such dichotomous sampling substantially cheaper and less subject to error than census measurements, with our large number of planned sample points most statistical distribution problems are overcome. Our conceptual model assumes that changes in the populations of a species will be reflected by expansion or contraction of its range, and these changes will be detected by sampling in this periphery.

Sampling Protocol

Sampling points are located using conventional maps, orthophotquads, and compass to navigate as closely as possible to 1 km UTM grid intersections (e.g. 4076.000 N, 339.000 E). This is a difficult and time-consuming exercise in unsurveyed wilderness. We hope that global positioning devices, tracking navigation satellites, will become hand-portable and affordable within the next several years, permitting plot location and relocation to within 10 m precision. Random displacement up to 99 m from the nominal site, to minimize selection bias, is accomplished by using a 2-digit random number for distance, and a 3-digit random number for compass direction. This establishes the actual center of sampling. Points are permanently marked with stainless steel rods or metal tags epoxyed to rock. Resource classes are then sampled as follows:

Trees.—Sampling radius 17.84 m generates a 0.1 ha plot. Each tree breast height (BH, 1.3 m) and above is recorded individually by species and diameter. Trees > 10 cm and < BH are tallied by species. Dead trees are

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