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Geographic Information Systems

Jan W. van Wagtendonk
Editor

Colorado State University
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Co•Sponsored by

The U. S. National Park Service and The George Wright Society

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The Fourth Conference on Research in the National Parks and Equivalent Reserves

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The Conferences on Research in The National Parks and Equivalent Reserves

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WESTERN ARCHEOLOGICAL AND CONSERVATION CENTER COMPUTERIZED ARCHEOLOGICAL DATA BANK

Susan J. Wells[1]
Western Archeological and Conservation Center
National Park Service
Tucson, Arizona

The Western Archeological and Conservation Center (WACC), located in Tucson, Arizona, serves National Parks in the Western Region. The center houses the Division of Archeology and the Museum Collections Repository. The Division of Archeology conducts archeological clearance projects as well as inventory surveys. Project and site records are on file at the center. The manual data management system begun in 1978 is gradually being computerized.

Archeological site records, project records and maps are the three major components of the WACC Archeological Data Bank. The Data Bank also lists pertinent archive material, reports, clearances, photographs and artifact collections. In February, 1985 we began designing computer programs for entering site and project information. We are using dBASE III data base management software on an IBM XT computer with one floppy disk drive, a 10 megabyte hard disk, a 30 megabyte hard disk and streaming tape backup.

The computerized data is used to produce standard paper forms that can be filed along with older records. These manual files are used with the base maps to provide quick access to site and project information. The computerized data can also be used to produce tables that summarize site and project information, and to generate the site records used to apply for site numbers from the appropriate state agency. Project and site files are organized by individual parks. For large parks with many archeological sites, the site file may be further subdivided by park unit.

USGS Topographic maps for each park are kept in large map folders. Project boundaries and site locations are plotted on clear mylar sheets attached to each map. When a request for archeological clearance is received, the base maps are checked for previous projects or known archeological sites located in the new project area. This prevents duplication of survey effort and destruction of previously recorded archeological sites.

Using dBASE III, menu-driven programs have been designed for entry of archeological site and project data. These menus display a series of options that can be chosen by pressing the corresponding number (see below).

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[1] Western Archeological and Conservation Center, National Park Service, Tucson, Arizona

The information displayed on the computer screen is in the same format as the printed WACC Site Records and Data Control Cards to allow data entry from forms filled out by hand. Options available from the menu include adding new records to the file, editing records previously entered, printing site and project records, printing blank forms, and browsing the file.

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**********  MAIN MENU FOR WACC SITEFILE  **********

1)  ENTER NEW SITE RECORDS TO SITEFILE

2)  EDIT OR CHANGE SITE RECORDS IN SITEFILE

3)  PRINT SITE RECORDS

4)  PRINT BLANK SITE FORMS

5)  EXIT TO dBASE DOT PROMPT

6)  BROWSE

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The site data can be used to generate the forms required by the Arizona State Museum for the assignment of Arizona Site Numbers. The site card is printed on 5 by 8 inch continuous card stock. The use of two different type faces makes the site information easy to see. Only the site maps have to be added by hand. This method of producing site cards saves considerable work and time for both the archeologist and clerk-typist. In the past these cards had to be hand typed from field records.

Using the dBASE III report function, lists of site and project information can be generated from the data in the site and project files. Tables created from data entered in the computerized data bank system save time and effort such as the tables that will be used in the Tonto National Monument National Register Nomination. One of the most tedious jobs involved in the manual data bank system was updating indexes to site and project data. These lists can now be updated by computer.

All project and site records for five parks have been entered:

Pinnacles National Monument	28 sites	11 projects
Saguaro National Monument	332 sites	51 projects
Walnut Canyon National Monument	242 sites	26 projects
Tonto National Monument	65 sites	4 projects
Tuzigoot National Monument	13 sites	[projects to be entered]

In addition, site records for 15 Lake Mead sites and over 200 Petrified Forest sites have been entered. The menu driven system has been found easy to use by the archeologists who surveyed Walnut Canyon and Tonto National Monument. Their comments have been used to further improve the system.

The format of the NPS CULTURAL SITES INVENTORY (CSI) has not been completed, but the WACC site file was designed to be compatible with the national CSI. The CSI data fall into 8 categories:

Location

Site Designations

Links to Other NPS Cultural Resource Data Bases

General Site Description

Significance

Extent of Investigation

Conditions

Management Strategy

The CSI has been designed so that information can be standardized with a limited number of choices for each data field; this system will lend itself to coded data. For sites already entered in the WACC computerized site file, location information and site designations will be identical in both systems. Other data can be translated from present entries to the standard CSI codes. The remaining data can be added to the existing site file. Eventually the CSI data fields can be incorporated into the WACC data entry programs.

The process of entering all site and project data into the computerized system will be slow unless funding is available to support this endeavor. When funds permit, archeological site data from new projects will be entered as part of those projects. New project data are entered as clearances are issued by this office. Grand Canyon and Yosemite have taken the initiative to develop their own computer site files. However, there is still a tremendous backlog of site and project information that must be entered into the computer data bank. There are approximately 8,000 to 10,000 recorded sites in Western Region Parks, not counting the sites at Yosemite and Grand Canyon. Some parks have few recorded archeological resources while others have hundreds of known sites.

Although in its early stages, the WACC computerized data bank has proven itself. The production of charts and tables for National Register Nominations and project reports has been enormously useful. By using the site data to print facsimile state site records we have reduced our workload and surpassed the current capabilities of several other computerized site systems in operation in Arizona. Use of an integrated Geographic Information System package with mapping capabilities is planned but the first priority is to get the site and project data computerized. We look forward to refining the system and having a data bank useful to both archeologists and land managers in the National Park system.

A GEOGRAPHIC INFORMATION SYSTEM APPROACH TO VEGETATION AND FUEL MAPPING IN THE NORTH CASCADES

James K. Agee and Ralph R. Root[1]

ABSTRACT

Landsat multispectral scanner based forest cover type and fuel type classifications were developed for the North Cascades National Park Service Complex in north-central Washington, U.S.A. Over 400 reconnaissance-level plots were established. Detrended correspondence analysis (DECORANA) was used to ordinate the data. Temperature and available moisture were identified as primary environmental gradients. Two-way indicator species analysis (TWINSPAN) was used to classify the data, resulting in eighteen plant cover types and four inert cover types (water, ice/snow, bareground/rock, shadow). The forest cover types include ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), whitebark pine-subalpine larch (*Pinus albicaulis*-*Larix lyallii*), mountain hemlock (*Tsuga mertensiana*), Pacific silver fir (*Abies amabilis*), western hemlock (*Tsuga heterophylla*) and hardwood forest. The coniferous forest types, with the exception of ponderosa pine, have both open and closed canopy components and include a variety of plant associations. Four non-forest plant cover types were also identified: high shrub, lowland grass, subalpine herb, and heather meadow. Closest-fit National Fire-Danger Rating System and Northern Forest Fire Laboratory fuel models were assigned to each cover type, and site-specific fuel models were developed for each cover type. The project results were successfully integrated into a geographic information system and used to create a cover type map for the park complex which was 85 percent accurate.

INTRODUCTION

The North Cascades National Park Service Complex (Figure 1) is a 300,000 ha area in north-central Washington comprised of North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan National Recreation Area (hereafter called the "park

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[1] National Park Service, Cooperative Park Studies Unit College of Forest Resources, University of Washington, Seattle, Washington, U.S.A. 98195 and National Park Service Geographic Information Systems Field Unit P.O. Box 25287, Denver, Colorado 80225

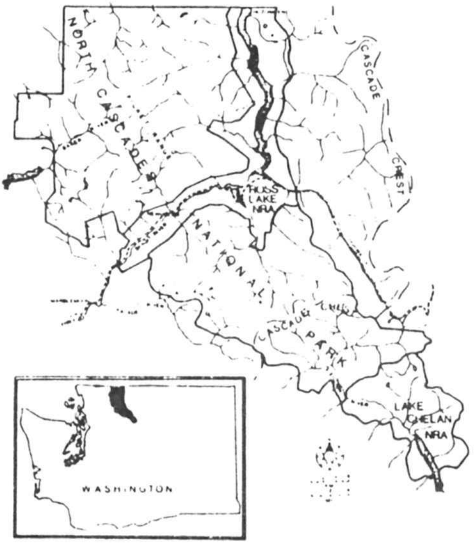

Figure 1. Location of the North Cascades National Park Service Complex in Washington.

complex"). The park complex is approximately 100 km long and 50 km wide; elevations range from less than 100 m to over 2700 m, and annual precipitation ranges from about 50 cm to well over 350 cm. It includes lowland forests on the moist west side of the Cascades, a range of higher elevation forests that span the crest of the range, and lowland forests on the drier east side. Within the park complex, the Cascade Range is so wide that some areas west of the crest of the range experience a rainshadow effect from mountains even further to the west. Numerous species and communities more characteristic of interior (east of the Cascade crest) than coastal forest areas are found in the rainshadow area (Franklin and Dyrness 1973).

The objective of this study was to describe and map the major plant cover types and fuel types of the park complex. The only prior vegetation map was a 1936 commercial forest map completed while the area was managed by the Forest Service. The vegetation and fuel maps created as a result of the present study are part of a geographic information system for the park complex (Agee _et al_. 1985).

METHODS

Landsat multispectral scanner (MSS) data were used in conjunction with other data sources (elevation, slope, aspect, and precipitation) in a geographic information system approach to derive the landcover/fuel type descriptions (Figure 2). Five initial themes were prepared as predictors to derive three additional themes: vegetation cover type and two fire planning/behavior fuel types. The MSS theme was obtained from two Landsat scenes, one each recorded in 1978 and 1979 (Root et al. 1985). The 38 spectral classes commonly identified on both Landsat scenes were lumped into nine broad spectral type groups: "dark conifer", "light conifer", "dark deciduous/mixed", "light deciduous/mixed", "herbaceous", bareground/rock, snow/ice, water, and shadow. The first five groups were hypothesized to represent very generalized vegetation types, while the latter four groups were easily separated and identified from their spectral signatures.

Annual precipitation isohyets were digitized from a state precipitation map. This map was prepared with data from stations around the park complex, and represents more a generalized index to relative precipitation than a precise map of actual average annual precipitation. The isohyets were digitized and entered into the geographic information system as vector (polygon) data. The terrain data (elevation,

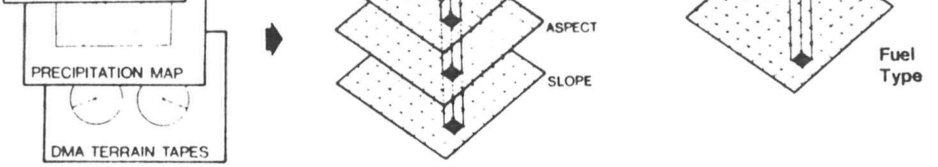

Figure 2. Conceptual scheme of a geographic information system.

aspect, and slope) were derived from Defense Mapping Agency tapes. From these tapes, elevation, aspect, and slope are interpolated from digitized contour lines. Elevation was recorded in 100 ft (30 m) classes, aspect in one of nine classes, and slope in 5 % intervals up to 65 % plus a 65-100 % and >100 % class.

All data were georeferenced to the Universal Transverse Mercator (UTM) grid, resampled to a 50 meter square cell size, and stored as raster (cell-based) themes of the geographic information system. Before any field work began, five themes of the geographic information system were in place: MSS group, annual precipitation class, slope class, aspect class, and elevation class.

The purpose of the field data collection was to refine the MSS groups to more specific plant cover types and to associate fuel types with each cover type. A total of 425 sample plots was established over the 300,000-ha park complex. Sampling was done with reconnaissance level plots located over a wide variety of vegetation and terrain types. Elevation, aspect, and slope were measured by altimeter, compass, and clinometer. A dimensioned plot of varying size (100-400 sq m) was used to determine tree density of each species by height class (0-3m, 3-10m, and >10m). The height and cover class of the dominant layer of each species was recorded. The overall cover of vegetation was recorded in one of six classes: 1 (0-5%), 2 (5-25%), 3 (25-50%), 4 (50-75%), 5 (75-95%), 6 (95-100%). Specific tree measurements were collected using dimensioned and non-dimensioned plots. Non-dimensional plots were used to record tree basal area by species using a prism, and cover class of dominant shrubs and herbs.

Annual precipitation class (in 50 cm intervals) was later recorded for each plot from the statewide precipitation map. The closest-fit fuel models determined from a key for National Fire-Danger Rating System (NFDRS) and the Northern Forest Fire Laboratory (NFFL) were recorded, as well as site-specific fuel information needed to create unique fuel models through the BEHAVE system (Burgan and Rothermel 1984).

Ordination analysis was done to associate the floristic data with important environmental gradients. Detrended correspondence analysis (DECORANA (Hill 1979a)) was chosen as the ordination technique. An importance value was derived for each species in each sample, consisting of cover class alone (expressed on the same scale of 1-6 used for plot recording) for shrubs and herbs, and for trees the average of relative density (expressed on the 1-6 scale) and cover class (expressed on the 1-6 scale). Rare species were downweighted by the program using a predefined option.

A polythetic divisive method (TWINSPAN (Hill 1979b)), was used to classify the data. Cover types were derived by aggregating community types defined by the classification analysis.

A set of rules was formulated that would predict a specific vegetation cover type given the available information in the existing themes of the geographic information system. For each cover type defined by the classification analysis, data from the sample plots in that cover type were summarized: MSS group, elevation, aspect, slope, and annual precipitation. The result was a set of variables that defined the environmental domain of each cover type. However, the environmental data for each cover type sometimes overlapped slightly with that of another cover type, as reflected by plot data. Other environmental domains were not represented by any of the cover type data sets. If the vegetation of the park complex is viewed as a set of rumpled blankets on a bed, some environmental domains had two blankets and others were not covered at all. Uncovered domains were assigned a cover type by "stretching" the domains of the nearest two cover types, as defined by the plot data. Domains that included two cover types were subjectively assigned one cover type by splitting the overlap domain. These judgments were made based on field notes; where no field notes existed, a consensus from the field crew was reached.

These decisions were incorporated into ecological models that predicted cover type from any combination of the predictor variables. The models were written in a branching form of BASIC called DBAS, and applied to the existing themes of the geographic information system in the computer. The result was a new theme for cover type which incorporated the plant cover types with the inert cover types.

Maps of the cover type theme were printed out at scales of 1:100,000 and 1:24,000. Field checking was designed with an 800 plot sample. The total sample number was defined on economic criteria. Plots were allocated proportional to area covered within the park complex on the initial cover type map. Plots were uniformly distributed across the range of each cover type to provide wide geographic coverage for the field review. Minor adjustments to the initial cover type map were made, after field checking, by eliminating four cover types that together covered less than 1.5% of the park complex. Accuracy was determined by the proportion of mapped points within cover types that were identified in the field as the same cover type.

The most common NFDRS and NFFL fuel models within each cover type were assigned as best-fit models. Using field data from each cover type, site-specific fuel models were constructed for each cover type and fire behavior runs were made with the BEHAVE system. These results were compared to the predicted fire behavior of up to two most commonly associated NFFL fuel models for the plots in that cover type. No actual fire behavior observations were available to provide field verification of the fire behavior results.

RESULTS

Vegetation Ordination

Both species and sample ordinations are computed in the DECORANA (DCA) ordination, with the sample scores being weighted means of the species scores within the sample. The species found at low elevations tended to be at the left of axis 1 of the species ordination (Figure 3), whereas species found at high elevation were to the right. This elevational (temperature) gradient was substantiated by regressing sample scores onto sample plot elevation for axis 1 (r-squared = 0.71), indicating that elevation was strongly and linearly related to the axis 1 scores.

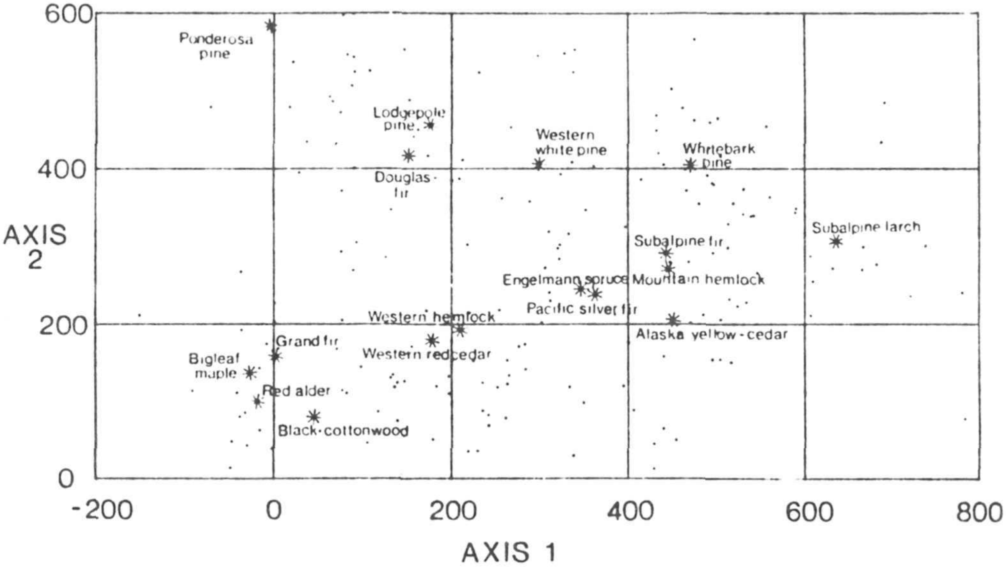

Figure 3. Ordination of common tree species on axis 1 (temperature) and axis 2 (moisture).

The drought tolerances of northwestern tree species have been summarized by Minore (1979) and increasing drought resistance is associated with higher axis 2 scores within limited axis 1 ranges. Species associated with moist environments have lower axis 2 scores whereas species characteristic of drier environments have higher axis 2 scores. A typical east Cascades dry elevation gradient is illustrated by the upper leg of the triangular distribution of points in Figure 3: ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*) and subalpine larch (*Larix lyallii*). A moist westside Cascade gradient is illustrated by the lower leg of the triangle: western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*), Pacific silver fir (*Abies amabilis*), Alaska yellow-cedar (*Chamaecyparis nootkatensis*), and mountain hemlock (*Tsuga mertensiana*).

Temperature has been described as the primary gradient differentiating major forest types in the Oregon Cascades, with moisture expressing itself as a differentiating factor within the lower elevation forest types (Zobel *et al*. 1976). These two gradients have also been identified by del Moral and Watson (1978) as primary gradients affecting forest vegetation in the central Washington Cascades. These same gradients are important for the North Cascades area, and substantiated the use of available GIS themes to predict cover types. Elevation can be used as a predictor of temperature while precipitation, aspect, and slope can be used as predictors of the moisture gradient.

Vegetation Classification

The dendrogram (Figure 4) shows an early division into three major groups, which are then further subdivided. The first group (at left) is composed of the dry, lowland forest, shrub, and grass types plus the deciduous shrub and forest types. The second group (middle) includes the westside lowland and montane forests. The third group (right) contains the subalpine to alpine vegetation types. This suggests that floristically the subalpine types, whether dry or moist, are more closely related to one another than to their associated lowland types. This relation is consistent with the ordination results which indicated that moisture is a less important discriminating factor at high elevation.

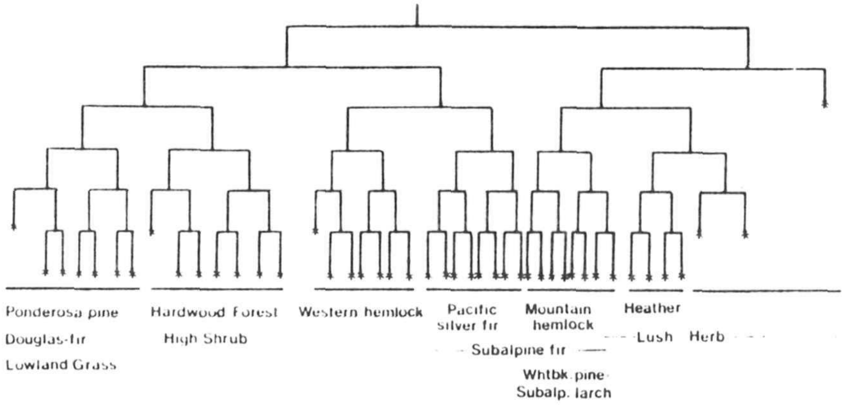

Figure 4. Clustering of vegetation plots with major cover types shown.

Cover Type Prediction

The cover types were defined such that area coverage would be capable of prediction using MSS groups and associated precipitation and terrain data. The initial classification recognized 22 cover types. There were 8 coniferous forest types each with an open and closed canopy component: ponderosa pine, Douglas-fir, grand fir (Abies grandis), subalpine fir, whitebark pine/subalpine larch, mountain hemlock, Pacific silver fir, and western hemlock. Six other plant cover types were identified: hardwood forest, high shrub, lowland grass, fescue meadow, lush herbaceous, and heather meadow.

Some cover types (<1.5% of the area) were absorbed into other cover types after statistics derived from the cover type theme revealed they covered little area or field checking showed they were not consistently identified. The closed canopy ponderosa pine type and both open and closed canopy grand fir type were absorbed into the Douglas-fir cover type; Douglas-fir was a substantial component of each of the eliminated types. The fescue meadow and lush herb meadow were combined into a subalpine herb cover type.

The field-checked cover type classification had an overall accuracy of 84.3%. Some of the discrepancy is due to difficulty in the field distinguishing the precise cutoff between open and closed canopy stands of a given type; if those misclasses are ignored, overall accuracy of the classification increases to 88%. This project successfully linked indirect and direct ordination techniques; limited copies of the vegetation map are available from the first author (Agee _et al_. 1985).

Cover Type Descriptions

Vegetation covers about 75% of the land surface within the park complex and over the wider area covered by the park special map (Table 1). Ponderosa pine is the driest and lowest elevation cover type, found primarily in the dry, southeastern portion of the park complex. Ponderosa pine is codominant with Douglas-fir on rocky sites where canopy closure will likely never occur.

The Douglas-fir cover type is widespread at low to mid-elevation on slightly moister sites than the ponderosa pine type. A majority of tree basal area and cover are in Douglas-fir; common shrubs are _Pachistima myrsinites_, _Arctostaphylos uva-ursi_, and _Ceanothus velutinus_. This type also includes most of the lodgepole pine stands in the park complex.

The subalpine fir cover type is higher elevation forest in the drier environments of the park; its moist counterpart to the west is the mountain hemlock cover type. The open portion includes subalpine meadows that are being invaded by coniferous trees due to the 1920-40 regional drought that reduced snow loads and increased growing season length (Franklin _et al_. 1971). At lower elevation it is typically bounded by the Douglas-fir cover type.

The whitebark pine/subalpine larch cover type is a higher elevation and sometimes drier variant of the subalpine fir cover type. The closed canopy component is essentially a subalpine fir type with minimal coverage of either whitebark pine or subalpine larch. Dissimilar habitat requirements of the larch and pine results in a complementary rather than competitive relationship between the two species in these marginal forest environments (Arno and Habeck 1972). South-facing slopes are heavier to whitebark pine whereas north-facing slopes have more subalpine larch.

Further to the west, in more moist subalpine environments, is the mountain hemlock cover type. The open canopy portion of this type is often in a treeline environment. Pacific silver fir is also well represented in the understory of the mountain hemlock cover type, suggesting a codominance of these two species in the type over time.

Table 1. Areas covered by each cover type within the park complex and over the area covered by the park special map. Data were generated from the geographic information system.

Cover Type	In Park Complex			In Special Map	
	Hectares	% of Veg.	% of Land	Ha.	% of Land
Ponderosa pine (Open Canopy only)	**493**	**0.2**	**0.2**	**2772**	**0.3**
Douglas-fir	**39321**	**19.2**	**14.3**	**123430**	**14.5**
Closed canopy	26798	13.1	9.7	86468	10.2
Open canopy	12523	6.1	4.6	36962	4.3
Subalpine fir	**28177**	**13.8**	**10.2**	**122172**	**14.3**
Closed canopy	17105	8.4	6.2	85401	10.0
Open canopy	11072	5.4	4.0	36771	4.3
Whitebark pine/ Subalpine larch	**3922**	**1.9**	**1.4**	**30457**	**3.6**
Closed canopy	2034	1.0	0.7	16998	2.0
Open canopy	1888	0.9	0.7	13459	1.6
Mountain hemlock	**18444**	**9.1**	**6.7**	**43067**	**5.0**
Closed canopy	11381	5.6	4.1	28424	3.3
Open canopy	7063	3.5	2.6	14643	1.7
Pacific silver fir	**33830**	**16.5**	**12.3**	**81769**	**9.6**
Closed canopy	24546	12.0	8.9	63343	7.4
Open canopy	9284	4.5	3.4	18426	2.2
Western hemlock	**34031**	**16.7**	**12.4**	**116788**	**13.7**
Closed canopy	24128	11.8	8.8	76779	9.0
Open canopy	9903	4.9	3.6	40009	4.7
Hardwood forest	**998**	**0.5**	**0.4**	**10019**	**1.2**
High shrub	**13399**	**6.6**	**4.9**	**38830**	**4.5**
Lowland grass	**4269**	**2.1**	**1.6**	**13747**	**1.6**
Lush herb	**25498**	**12.5**	**9.3**	**69378**	**8.2**
Heather meadow	**1671**	**0.8**	**0.6**	**4259**	**0.5**
All other (rock, snow, ice, bare ground, water, shadow)	**71086**	**--**	**25.8**	**194345**	**22.8**
Total	**275139**	**100**	**100**	**851040**	**100**

At lower elevation on the westside, the Pacific silver fir cover type has the highest average basal area (67 sq m/ha for the closed canopy portion) of all the types. This cover type is also found as a valley bottom type in the drier eastern valleys of the park complex; occasional Engelmann spruce and Douglas-fir are found associated with this cover type in those locations.

The lowest elevation coniferous forest type on the west side of the park complex is the western hemlock cover type. In the area of the park complex, it is represented by relatively high elevation or dry western hemlock forests. Douglas-fir is a seral codominant in the closed canopy portion of the type, and is clearly dominant in the open canopy portion of the type.

The hardwood cover type is defined on the basis of overstory dominance by deciduous trees, and comprises a wide variety of tree species and sites. Most commonly, this type occurs at low elevation where disturbance, primarily by flooding, has occurred within the past 50 to 80 years. This type appears largely seral to the other low elevation coniferous forest types.

The non-coniferous cover types were very generally defined. High shrub was usually alder (Alnus spp.) or willow (Salix spp.) thickets along avalanche tracks. The lowland grass type was herbaceous-dominated vegetation below 1300 m elevation, such as recent clearcuts, fields, and gravel bars. The subalpine herb type was comprised of the fescue meadow and lush herbaceous types, both high elevation herb communities which were combined into a single type in the final classification. The heather meadow type was found at high elevation on gentle slopes with late snowmelt. These types comprised over 16% of the total land base of the park complex, substantiating the ecological and esthetic significance of nonforest vegetation in the region.

Fuel Models

When plot data were sorted by cover type, fuel model information was also sorted. The most common NFFL and NFDRS fuel models within each cover type were selected as the best-fit models for that type (Table 2). Where two models within either system had roughly equivalent representation, both were listed to represent the variation in the cover type. The most common models across the park complex were NFDRS Model H and NFFL Model 8 (Table 2). Over 70% of the park vegetation keys out to one of these models or to a two-

Table 2. Best-fit fuel models for cover types.

Cover Type	N	NFDRS MODELS	NFFL MODELS
Douglas-fir (C)	44	H	8
Subalpine fir (C)	6	H	8
Whtbk. pine/Sub.Larch (C)	0*	H	8
Mountain hemlock (C)	25	H/G	8
Pacific silver fir (C)	43	H/G	8
Western hemlock (C)	83	H/G	8
Hardwood forest	17	R	9
High shrub	42	O	4/5
Lowland herb	11	L	1
Subalpine herb	26	L	1
Heather shrub	16	S/L	1/5
Ponderosa pine (O)	0*	C	8/1
Douglas-fir (O)	36	H/G	8/5
Subalpine fir (O)	20	F/Q	8/5
Whtbk. pine/Sub. Larch (O)	21	H/Q	8/1
Mountain hemlock (O)	20	H/F	8/5
Pacific silver fir (O)	5	H	8/5
Western hemlock (O)	17	H/Q	8/5

C= closed canopy type
O= open canopy type

*No field plots were established in 1983 in these types, so nearest fit models were subjectively assigned to these types. Ponderosa pine is a C rather than a U model because fuels other than pine needles will carry the fire.

fuel model (Rothermel 1983) where one of these models is the dominant type. These models fit short-needled conifer stands with sparse understory and scattered large fuel. The closed canopy forest cover types commonly keyed to models H and 8; open canopy conifer stands fit the two-fuel model concept better.

Site-specific fire behavior prediction was done using the BEHAVE system. The BEHAVE output suggests that in most cases the existing NFFL models are sufficient to predict fire behavior in the cover types of the park complex. This was determined by visually comparing rate of spread, flame length, and fireline intensity of the site specific model along with the closest-fit NFFL models for a range of weather conditions (Figure 5). Variation around average values was quite high, indicating considerable variation in potential fire behavior within a cover type. Monitoring of prescribed fires in the park complex will be necessary to validate these predictions.

DISCUSSION AND CONCLUSION

The North Cascades vegetation and fuels project was designed to be integrated with a geographic information system (GIS) being developed for the park complex, so that cover types could be identified using themes of the GIS: classified MSS data and digitized information on annual precipitation, slope, aspect, and elevation. The ordination results suggested that elevation could be used as a predictor of the temperature gradient and precipitation, aspect, and slope as predictors of the moisture gradient. The classification results provided logical groupings of plots from which ranges of elevation, precipitation, slope, and aspect of each cover type could be summarized. Using plot information within each cover type, a series of predictive cover type models was developed so that each 50 by 50 m cell within the park complex and surrounding area was eventually assigned a forest, non-forest, or rock, snow/ice, or water cover type in the final classification with relatively high accuracy. Fuel models assigned to each cover type appear to correspond fairly well with potential fire behavior estimated from site-specific information within each cover type.

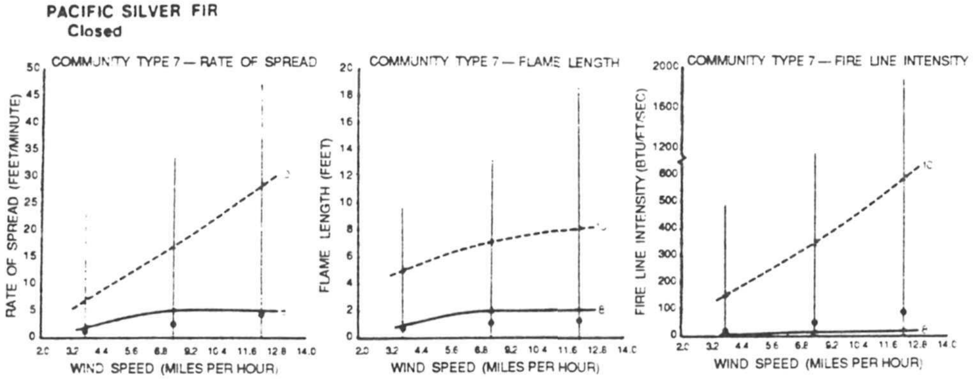

Figure 5. Comparative fire behavior between NFFL models and site-specific BEHAVE models for the closed canopy Pacific silver fir type. NFFL model 8 is a closer fit than NFFL model 10, but will underpredict fireline intensity at high windspeeds.

The North Cascades National Park Service Complex contains a wide array of forest cover types typical of the region, missing only good representation of the ponderosa pine type. Because of its preserve nature, it will remain a significant natural laboratory into the future. The forest cover type and fuel type classification will serve as a base for many future ecological studies. Together with the other themes of the geographic information system, they provide a powerful resources management tool for North Cascades National Park Service Complex.

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DEVELOPING A GEOGRAPHIC INFORMATION SYSTEM FOR THE SIERRA NEVADA NATIONAL PARKS

Jan W. van Wagtendonk[1] and David M. Graber[2]

When Yosemite and Sequoia National Parks were established in 1890, enabling legislation for both parks specified that all "timber, mineral deposits, natural curiosities or wonders in the area be preserved from injury and retained in their natural condition." Similar language was used when Kings Canyon National Park was designated in 1940. Since their establishment, many changes have occurred in the natural and cultural resources of each park. Past policies dealing with fire suppression, wildlife management, visitor use, and park facilities may have significantly altered the natural and cultural resources of the Sierra Nevada national parks. The importance and extent of these changes have not been effectively evaluated because adequate resource information and a comprehensive system for managing it have been lacking. The lack of such a system has precluded timely retrieval and analysis of resource information necessary for sound decisions.

With this problem in mind, researchers in the Sierra Nevada parks have initiated a resource inventory information and management system. In the past, resource information was scattered in files and publications, and on maps of varying scale and accuracy. If the information could be found at all, its compilation and analysis was difficult in most cases and impossible in others. Syntheses were thwarted by different systems for measuring ecological parameters.

The advent of relatively inexpensive supermicrocomputers, high-resolution graphics, and large mass-storage devices has made the use of computers to perform resource information storage, management, retrieval and analysis a practical technology. The objective of our project has been to develop resource inventories and computerized geographic information systems (GIS) for the national parks of the Sierra Nevada. Such systems will enable managers to make informed decisions affecting cultural and natural resources, set in place the basis for long-term monitoring of park resources, and allow researchers to explore spatial relationships of varied resources in ways never before possible. Our approach has been to develop in tandem field inventory methods at Sequoia and Kings Canyon National Parks and a computer information system at Yosemite. Eventually, complete systems will be operating in both park units.

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1. Yosemite National Park, El Portal, CA 95318; 2. Sequoia and Kings Canyon National Parks, Three Rivers, CA 93271

GIS CONSIDERATIONS

The development of a geographic information system, particularly if there are many kinds of resource "themes" included, is complex and expensive. We had to determine the purposes of our systems before either information collection or system integration had begun. What uses were going to be made of the GIS? What classes of data ("themes") were available and what must be collected? What level of detail would be required? How much money could be allocated for the system? The answers to these and other questions determine the kind of system that should be developed as well as the software and hardware that are appropriate.

Planned Uses

One of the primary purposes of our systems will be to calculate what changes have occurred in vegetation during the past 50 years. We will be looking for changes in relative abundances and size-classes for both overstory and understory species, as well as for changes in geographic distribution. Another use will be to evaluate natural and cultural resource values that may be adversely or beneficially affected by prescribed or wilderness fires. Modeling of fires burning in non-uniform fuels and over complex terrain will be necessary for this purpose. Another function will be to estimate habitat for wildlife species, especially sensitive or problem species such as bighorn sheep, black bears, great gray owls, and peregrine falcons. Resource information, actual wildlife observations, and predictive models will be used.

The search for undiscovered archeological sites in unsurveyed areas will be guided by extrapolating associations of known sites with environmental factors to areas with similar factors. And finally, planning for new trails, roads, and visitor facilities can be guided by combining detailed information about such characteristics as slope, soil type, sensitive plant and animal species, and archeological remains on potential sites. Instead of merely comparing several arbitrarily selected alternatives, linear programming can be used to seek the locations best satisfying the preferences and constraints of park planners from the entire spectrum of possibilities.

Data Themes

The kinds of uses we've described require the inclusion of specific data themes in the GIS. For example, evaluation of vegetation change over time will require data on past vegetation as well as current vegetation in directly comparable formats. For both park units, fortunately, detailed vegetation information was collected during the 1930s. We could not afford to replicate this effort today, but fortunately satellite imagery and topographic data are available to largely accomplish this task. Field data--so called "ground truth"--will be required to verify vegetation classifications based upon such remote sensing.

Fire behavior analysis will rely on fuel models and fuel data collected in the field. These will be combined with topographic and weather data to model fire spread. Themes describing other resources will be needed to assess fire's potential effects on them. Included would be roads, structures, wildlife habitats, sensitive species, and archeological and historic sites. Themes needed for the wildlife habitat delineation are vegetation, hydrography, topography, and recorded wildlife observations. Predictions of archeological sites will require data on known sites and on environmental variables such as vegetation, geology, topography, and hydrography. Of course, resources may be selected for inclusion simply because long-term monitoring requires a baseline or beginning point, and the GIS is an ideal vehicle for managing such data.

Resolution and Scale

The specific application and precision of source data determine the resolution and scale to be used in the system. Unlike paper maps, however, scale can be dynamically adjusted by the computer depending upon available graphics, land area to be examined, and resolution of the source data. If a very detailed analysis of a small area (an archeological site of less than one hectare, perhaps) is desired, a resolution of one meter might be appropriate. If the source were a paper map, an input scale of 1:100 would have the accuracy necessary for such an application. On the other hand, a parkwide survey of archeological sites might better be depicted at a resolution of 30 meters. Map data could be entered into the system from standard U.S. Geological Survey topographic quad maps of 1:24,000 or 1:62,500 scale. It is important to remember that the system can be no more accurate than the data that are entered. Conversely, increased resolution requires not only more precision, but also more data storage. Most of the maps used to enter data for Yosemite, Sequoia, and Kings Canyon were at a scale of 1:62,500, although some themes were at 1:125,100. When the new 1:24,000 scale Geological Survey map series becomes available for the parks (offering not only higher resolution but better accuracy and precision), it will be used for most subsequent themes. Digital data such as satellite imagery and elevation models come in a variety of resolutions (i.e. sampling densities). A resolution of 30 meters was chosen for the remote sensing and topographic themes, as this is the native resolution of Digital Elevation Model (DEM) and Landsat Thematic Mapper (TM) data and is feasible for parks of our size. Although the elevation data from the Defense Mapping Agency (DMA) are available at only a 100-meter resolution, they can be resampled to 30 meters. Obviously, this does not increase the accuracy of the data.

Software Selection

As is the case with any software selection, planned application is the most important consideration. There are many computer assisted design (CAD) systems available which perform satisfactory computer mapping for small areas at large scales. However, CAD systems are generally restricted to computer cartography, and do not do map analysis nor do they work with raster (cell) data. For areas larger than 100,000 ha such as the Sierra Nevada parks, software specifically designed for GIS applications is necessary. Increasingly sophisticated GIS packages are available commercially and from the public domain.

Some GIS packages can deal with data in either a cell (raster) format or as points, lines, or polygons (vector); others are restricted to one or the other. Processing time is less with raster data, while storage requirements are less for vector data. We have acquired or developed data of both types, and a combined or dual system is thus preferable. A final consideration must be whether or not the selected software restricts you to a particular brand of hardware.

Hardware Requirements

The data bases for the parks are very large. The need to store 4 million cells of information (8 megabytes) per data theme and the need for as many as ten data themes to be resident at some times requires a large storage device. A large address space in the CPU, virtual memory, and available working disk storage are needed to hold even a few themes simultaneously. To move data in and out of memory and through the processor at sufficient speed to create a truly interactive environment requires a large word size, fast clock rates, and a high-speed bus. To display themes with enough detail to distinguish the colors related to the different categories of data typically requires a display screen of 1 million picture elements (pixels) with at least 256 displayable colors. In order to interchange data within the National Park Service and with other agencies, universities, and contractors, a high density, standard format tape drive is necessary.

The hardware system that we selected would be required to support a full UNIX implementat. UNIX is rapidly maturing as the standard operating system for scientific and technical workstations; it offers a large software base and is used on many different kinds of computers.

SYSTEM CONFIGURATION

The above considerations have led to the following decisions concerning data themes, software, and hardware.

Data Themes

The themes initially developed for the Yosemite GIS, and under development for the Sequoia and Kings Canyon GIS, were those required for the applications that had been identified, as well as some others derived from data that were readily available (Table 1). In many cases the listed themes include multiple data layers separating different subclasses within a general theme (e.g. standing vs. flowing water; perennial vs. seasonal streams) or different sampling periods (e.g. 1930s vegetation vs. 1980s vegetation). Many data layers are linked to complex tabular databases (e.g. archeological sites, historic fires).

Table 1. Themes under development or planned for the Yosemite, Sequoia and Kings Canyon geographic information systems.

Theme	Description
Vascular vegetation	Distribution and enumeration
Vertebrate fauna	Distribution and enumeration
Terrain	Elevation, slope, aspect
Hydrography	Standing and flowing water
Surficial geology	Classification map
Soil taxa	Classification map, fourth order
Weather	Long-term data for several sites
Caves	Distribution and description
Fire history	Mapping and classification
Fuel	Distribution and enumeration
Transportation	Roads and trails
Boundaries	Political, management
Archeology	Distribution and description
Structures	Mapping, historic and contemporary
Place names	Mapping, historic and contemporary

Vegetation change in Yosemite will be evaluated partly based on data derived from a survey done in the 1930s, including a vegetation map, photo points, and data sheets from plots used during the survey. These will be used in an attempt to relocate plots. Current vegetation for all parks will be classified using imagery from the Thematic Mapper aboard

LANDSAT-5. Those data will be complemented in Yosemite by a recent vegetation type map developed by the park and DMA elevation data. The DMA data will be replaced by the more accurate Digital Elevation Model (DEM) data in all parks as they become available from the U. S. Geological Survey. Slope and aspect themes are derived from elevation. The Survey also is developing Digital Line Graph (DLG) data for such themes as roads, trails, structures, political boundaries, and hydrography. In Sequoia and Kings Canyon National Parks, the Geological Survey's place names database will serve as the starting point for a theme recording the positions of all significant place names, historic as well as contemporary. A long-standing program by the Geological Survey to map surficial geology for Yosemite, and a parallel program in Sequoia and Kings Canyon, have produced source material suitable for digitization. Maps drawn by park personnel have been used for historic and wilderness boundaries, fire management zones, fire history, fuel models, trails, campsites, archeological sites, and sensitive plants.

Software

The National Park Service supports three public domain GIS software packages through its GIS Division in Denver, Colorado. Image processing and limited data base manipulations are done with ELAS, which was developed and is supported by NASA. Since this in-house capability already existed, it was used to process our LANDSAT imagery and the topographic data. The U. S. Fish and Wildlife Service originally developed SAGIS, and it is now being enhanced and supported by the Park Service. We have used it to develop all of the vector-based (map-originated) themes and to do some preliminary analyses. Linkages between ELAS and SAGIS have been written so that data may be exchanged. The development of GRASS by the Army Corps of Engineers has provided a raster-based system with vector capabilities, and map analysis functions. Each of these software packages runs or is being converted to run under the UNIX operating system. Both GRASS and a menu-driven version of SAGIS will be used in the Sierra Nevada parks. An active users group of public agencies, universities, and others continues to develop and support GRASS, adding new capabilities such as more powerful map analysis and graphics capabilities.

Hardware

We limited the search for hardware to systems based upon 32-bit processors, since this architecture is appropriate for large data bases and is required to run most complex GIS software. At the time (1985) that Yosemite selected its system, 32-bit processors and the UNIX operating system were available only in scientific-engineering workstations based on the Motorola 68010/68020, such as those offered by Apollo, SUN, and MASSCOMP. Reviewing the software we expected to use and the size of our databases, Yosemite established the following minimum criteria for its system: The CPU had to have demand-paged virtual memory in hardware, 100 Megabytes per process, and a clock speed of at least 10 MHz. We specified four megabytes of RAM. External mass storage had to be available in amounts of at least 380 Megabytes formatted, on a high speed bus. A color monitor of one million pixels and 256 simultaneous displayable colors had to be available. The bus structure had to support tri-density tape drives (for data interchange), color ink-jet printers, and digitizing tablets. Based on these requirements, the following system was purchased by Yosemite in 1986:

System unit	MASSCOMP MC5520 with 4 Mb memory and the Motorola 68020 microprocessor ($24,726)
Mass storage	MASSCOMP 387 Mb hard disk ($16,929)
Tape drive	MASSCOMP 1/2" 9-track tape drive 6250/1600 BPI ($19,730)
Monitor	MASSCOMP Aurora GA1000 graphics processor, 910x1152x12 bit screen ($18,160)
Printer	Advanced Color Technology ACT-II colorgraphics ink jet printer ($5,722)
Digitizer	ALTEK 22"x22" digitizing tablet ($2,545)

At the time of the initial purchase of the system unit and the monitor, approval for GIS equipment had to come from the Department of the Interior. The National Park Service Washington Office can now approve those purchases. Sequoia and Kings Canyon have yet to purchase a hardware system, and have been compiling data on an IBM PC-AT in the interim.

DATA PREPARATION

Data, regardless of its source, must be prepared for entry into a GIS. Typically this is the most expensive and time-consuming aspect of developing a computerized resource data base. Once data are entered, however, the cost of maintaining and updating themes is minimal compared to hand methods.

Mapped Data

Much of the data that will be entered originates from maps. While it may seem that mapped data could be digitized directly by automatic scanning, problems of mixed scales, lack of a coordinate grid, clutter, and dimensional imprecision make it impractical to do so. The first step must be to select a base map of suitable scale and accuracy for portraying the mapped information. The standard 15' U.S. Geological Survey map series was chosen initially for the Sierra Nevada parks since it was the most accurate available at the time (this series is now being replaced by the new 7.5' series), most mapped data have been recorded on that base, and accuracy was adequate for most uses.

A stable-base, 7-mil, right-reading, frosted mylar of each quadrangle was purchased from the Geological Survey. These cost approximately $45 apiece and consist of a composite of lettering, Universal Transverse Mercator (UTM) grid, revisions, contours, hydrography, boundaries, transportation, and land net. Registration tics were placed near the four corners of each base map with a triple zero black India ink pen. The next step was to overlay the base map with a sheet of 4-mil frosted mylar, frosted side up. Registration tics were then transferred, and the sheet titled with the theme, quadrangle, and park names. Each theme was then transferred to the mylars by placing the paper map with the resource data under the base map and the clear sheet. Since these sheets usually were to be scanned, only lines were transferred, one theme to each mylar. Themes not scanned were digitized by hand. This process is often more practical for simple themes with just a few categories and was used to enter structures, roads, hydrography, and political boundaries from the base maps. The final step was to assign names or codes to each of the categories depicted on each map.

Published and Recorded Data

Publications and reports are another source of valuable resource information. If the data are associated with some geographic coordinate system, they can be entered directly into a computer data base or transferred to a base map for entry. Historic wildlife observations are an example of this kind of data. In order for these data to be useful, their level of reliability, accuracy, and precision must be recorded--always a good practice. Our fire history themes were derived from fire records dating back to 1930. These were reviewed and the point of ignition and areal extent of each fire plotted on quadrangles. The quality of the information varied from year to year. Knowledge of topography, vegetation, and burning patterns was used to estimate parameters when information was lacking.

Digital Data

Some classes of baseline information in computer-readable format, with coverage for all of most of the United States, is available from agencies for entry into a GIS. For instance, DMA, DEM, and DLG tapes can be read directly into GRASS and processed to produce themes. Attribute data can be added to such themes using a data base management system if additional information is desired. Digital data from satellites (e.g. Landsat Multi-spectral Scanner and Thematic Mapper scenes, and SPOT scenes) can also be processed by GRASS, although, in our case, this processing was done by the GIS Division in Denver using ELAS. It is necessary to register such remote sensing data to base map coordinates, and then to classify the different spectral signatures. For us this process will continue over a number of years, as additional field data and new analyses refine and validate vegetation and land cover classifications.

FIELD INVENTORIES

Because no high-quality inventories of biological resources in the parks exist, we have initiated systematic surveys to sample vegetation and terrestrial fauna throughout the parks. These surveys have three purposes: Establishing baseline information; providing ground truth for the classification of remotely-sensed imagery; and initiating long-term monitoring of sensitive park resources.

Basic Inventories

Natural and cultural features of the parks will be surveyed systematically by visiting sites at the intersections of one kilometer UTM grid lines. Inventories at each site will radiate from the coordinate point, with the sampling radii determined by the scale and mobility of each class of subject. Thus large classes, such as trees, and mobile classes, such as birds, are sampled over a greater area than are herbs or amphibians. At each sampling point, data will be collected on vegetation, animal species, fuels, archeological sites, soils, and terrain.

These plots will serve primarily to give an accurate and detailed enumeration and distribution of the plants and animals in the parks. They will also serve as baselines for long-term monitoring, and for ground-truthing satellite images. This work was initiated 1985 in Sequoia and Kings Canyon National Parks where over 3,400 potential plots have been identified at the nominal sampling density of 0.1 percent of land area. Periodic analyses of variance from sampled plots will refine (and, we hope, reduce) this sampling density over time.

Classification Plots

In order to classify and validate the Thematic Mapper data for Yosemite, it was necessary to establish plots in the field. This was done first by using the ELAS program to perform "untrained classification" of the raw multi-band TM spectral data, using clustering algorithms to reduce the data to a single value for each pixel and assign common values to common land cover classes. Next the images and corresponding color infrared photographs were searched for areas of homogenous signature and cover. Over 200 plots were established for this purpose in 1984 and vegetation and fuels data collected on them. These data were analyzed using detrended correspondence analysis to determine similar groupings of species which might be considered vegetation types. Additional plots will be established in these vegetation types to verify and test the classification. During this sampling phase, the procedures initiated at Sequoia and Kings Canyon will be used.

APPLICATIONS AND RESULTS

Although the geographic information systems for the Sierra Nevada parks are still in their developmental stage, some preliminary applications and results have occurred. These have ranged from simple to complex analyses of resource information and the addition of new species and sites.

New Additions

During the first few years of the resource inventory, several plant and animal species previously unknown from Sequoia and Kings Canyon have been discovered, including six species of grasses and both alien and native species. The distribution of many other species has been amended as a result of the inventory, especially for small terrestrial vertebrates where data have been very scant. Scores of previously unrecorded archeological sites have also been found, including many in areas where past theory had presumed no native American occupation.

Fire Occurrence

SAGIS was used to analyze Yosemite's historic fires in relation to vegetation and topography. The topographic data were derived on ELAS and transferred to SAGIS. This analysis found that fire occurrence and size varied significantly between different vegetation types and elevation zones but were not affected by aspect class. Fire size increased between 12-year periods before and after a wilderness fire management plan was implemented in 1972. The GIS was able to produce these results in a fraction of the time necessary for hand methods.

Lake Surveys

The Sierra Nevada parks are currently reassessing their fishery management programs. In order to keep track of which lakes had or had not been stocked in Yosemite, it was necessary to inventory the lakes by size class. Since hydrographic data were on SAGIS, it was used for the analysis. A straightforward listing indicated that there were a total of 1,359 lakes in Yosemite. Of these, 749 were less than one acre in size, 261 between one and 2.41 acres, and 349 larger than 2.41 acres. A hand tabulation would have been very time consuming and costly. Lake information added by a subsequent survey will become a part of the data base and will be available for further analysis by the system.

Future Applications

Although some of the originally-planned applications are still awaiting necessary data, others will be implemented in the immediate future. A current great gray owl study in Yosemite has collected the data necessary to evaluate potential owl habitat. A combination of meadow size, surrounding forest composition, and elevation will suggest where field crews can best optimize search time for new breeding pairs. This process will be used during the 1988 field season. In order to monitor the effects of prescribed fires over the long term, park managers have decided to monitor selected index areas. The index areas will be selected randomly from all areas planned to be burned, after stratification by fuel model, vegetation type and slope class. GRASS will be used to help delineate the population for selection and extrapolate findings to the remainder of the parks.

VEGETATION MAPPING AND GIS FOR THE CAPE HATTERAS NATIONAL SEASHORE

Hugh A. Devine[1], Beau McCaffray[2] and Kent Turner[3]

ABSTRACT

A vegetation map for the Cape Hatteras National Seashore was developed and tested from an air photo data base. This map was then placed into a computerized geographic information system for subsequent use in natural resource planning. In addition, roads, streams, and ownership boundaries were added to the computer system. The paper focuses on the vegetative data collection technique, its validation, and the use of the geographic information system in Eastern Barrier Island Management.

INTRODUCTION

In 1984 a conference sponsored by the National Park Service was called to define strategies for developing wildfire management plans for the barrier island parks in the eastern United States (Foley and Bratton 1984).

The major concern of the conference was to facilitate the initiation of research focused on problems in the development of these plans. One of the research issues, expressed by six of the eight parks represented at the meeting, was the lack of vegetation maps. Vegetation classification maps have been repeatedly demonstrated to be a key information need for the development of fire management plans (Deeming and Brown 1975, Getter 1976, Trabaud 1977). Cape Hatteras National Seashore (CHNS), a barrier island park off the coast of North Carolina, was one of the parks without a vegetation map.

The College of Forest Resources at North Carolina State University has been involved with vegetation management and computerized mapping systems applied to forest management for a number of years. As a part of that program a research

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[1] Recreation Resources Administration, North Carolina State University, Raleigh, NC 27695-8004.

[2] Recreation Resources Administration, North Carolina State University, Raleigh, NC 27695-8004.

[3] Cape Hatteras National Seashore, Manteo, NC 27954.

project was initiated through the Cooperative Park Studies Unit at the university to develop a vegetation map for Cape Hatteras and to place this map along with several other map themes (e.g. ownership) into a GIS. The research focused on constructing a classification procedure for vegetation that could be used for natural resource planning. In addition, several new sub-processes for capturing, storage, and retrieval of the necessary map data were developed. A statistical verification technique for the vegetation maps was also constructed and implemented. This paper presents the results of the research effort by first defining the specific map and information products produced, then discussing the approaches employed to generate the products, and finally describing the GIS potential for barrier island resource management.

OBJECTIVES

The project had three major objectives. These were:

1. Construct a vegetation map for the CHNS.
2. Develop and implement a verification procedure for exploring the accuracy of the vegetation map.
3. Develop a computerized GIS, including vegetation, infrastructure, and selected natural features, to assist in resource management on Cape Hatteras.

APPROACH AND RESULTS

Each of the objectives required a unique set of procedures for implementation. Therefore a separate methodological explanation is presented for the vegetation mapping, the accuracy tests, and the GIS construction. The project was centered on the vegetation maps. Coverage included the entire Seashore, with the exception of the Buxton Woods, Bodie Island, Fort Raleigh, and Wright Brothers Memorial developed areas. In addition, some areas outside the National Park Service boundary were mapped where it was appropriate for resource management.

Map Construction

The primary step in the mapping effort was the organization of appropriate base map and air-photo information into a common format. Base maps were developed on the United States Geological Survey (USGS) 7.5 minute topographic series. A complete set of USGS maps was available for Cape Hatteras, and all other data were referenced to this source. The actual vegetation information was developed from a set of 1:24,000 color infra-red aerial photographs taken in 1982 by the North Carolina Department of Transportation. The air photo data were transferred to the USGS base maps via a zoom transfer scope. The vegetation classes used in the project were defined by Mr. Kent Turner, the Natural Resource Specialist on CHNS, in consultation with Mr. John Sheperd, Fire Management specialist with the North Carolina Division of Forest Resources. Mr. Sheperd's assistance was employed because an initial application of the vegetation map was the development of a wildfire management plan for the seashore.

Fifteen vegetation classifications were used. They are described as follows:

1. Bare Sand. Generally devoid of vegetation (0 - 15 percent cover), pioneer species include Cakile edentula (sea rocket), Euphorbia polygonifolia (dune spurge) and Uniola paniculata (sea oats). The few plants that are able to colonize the berm are often grouped around piles of debris and are usually temporary depending on the frequency of storms.

2. Dune Grassland. Forming almost a continuous band along the margin of the inner berm, grasses usually dominate this community affording as much as 90 percent cover. Sea oats and Spartina patens (saltmeadow hay) dominate dune grassland though sea rocket and Iva imbricata (seashore elder) are found on the more exposed dunes. In the protected areas, Solidago sempvirens (seaside goldenrod) is common.

3. Shrub Savanna <1/3. The map shows two categories of shrub savanna which will be distinguished on the basis of percent cover. Shrub Savanna <1/3 is a combination of closed grassland and a shrub savanna with less than 1/3 of the cover in shrub savanna. Infrequently flooded closed grasslands (a common occurrence on CHNS due to the artificial dunes blocking overwash) initially invaded by Baccharis halimifolia (silverling), Myrical cerifera (wax myrtle) and scrub Juniperus virginianan (eastern red cedar) develop into shrub savannas. However, high salt marsh areas will also support this classification.

4. Shrub Thicket. Shrub thickets are commonly found on protected flats and stabilized dunes. Dominated by wax myrtle and silverling in the wetter areas, dryer areas are characterized by Ilex vomitoria (yaupon), Quercus virginiana (live oak), eastern red cedar and a tangle of vines such as Smilax spp. Shrub thickets form when shrubs coalesce and shade out grasses and forbs.

5. Reeds. On CHNS these communities of Phragmites are often found in thin bands, intervening between the soundside

edge of maritime forest or shrub thicket communities and the high marshes. Fimbristylis spadicea (fimbristylis), Spartina cynosuroides (giant cord grass) and Typha spp, (cat-tail) are common in these areas.

6. Juncus High Marsh. This community is almost pure Juncus roemerianus (black needle rush). A very few scattered shrubs such as silverling and wax myrtle may also be present.

7. Patens High Marsh. Spartina patens (saltmeadow hay) dominates this high marsh. As with the Juncus High Marsh, a few shrubs might be present as well, including Distichlis spicata (salt grass) and Borrichia frutescens (sea ox-eye).

8. Shrub Savanna >1/3. This shrub savanna community features shrub cover on one-third to two-thirds of the area. The same species found in Shrub Savanna <1/3 are also found here. However, less grasses and forbs are present.

9. Pinus Maritime Forest. This type is dominated by Pinus taeda (loblolly pine), with some hardwoods such as Quercus laurifolia (laurel oak). Larger wax myrtle shrub-trees make up the understory.

10. Broadleaf Evergreen Maritime Forest. Quercus Virginiana (live oak) and Persea borbonia (red bay) make up the majority of the canopy of these small forests.

11. Low Marsh. These areas are almost exclusively dominated by Spartina alterniflora (salt marsh cordgrass) and Salicornia spp (glasswort).

12. Developed Land. Where the density of homes is too great to show them individually, an area is defined as developed land. Piers, trailer parks, private campgrounds, complexes of motel/hotels are labeled as this type.

13. Water. Ponds and relatively unvegetated fresh marsh areas, as well as significant pools in dune slacks, are designated as water.

14. Freshwater Marsh. These areas are dune slack marshes which are dominated by grasses, rushes and sedges. Salt meadow hay, Pannicum spp., and Hydrocotyle (water pennywort) are the major plants. Species diversity in these areas is a function of water table fluctuation and exposure to salt spray. Old interdune swales surrounded by shrub thicket or maritime forest are a common location for freshwater marshes. The marshes are dominated by Juncus spp., Typha spp. and Cladium jamicense (sawgrass marsh) with the dune slack species present as well. Sagittaria latifolia (arrowhead), Ipomea

sagittata (morning glory) and Kosteletzkya virginica (marsh mallow) are common in these zones.

15. Salt Panne. Essentially devoid of vegetation, the communities contain Salicornia spp. but it only covers about ten percent of the area. It is not unusual for low soundside Salt Panne areas to become an arm of the sound during periods of high water. Only Ocracoke supports this community on CHNS.

Seashore infrastructure (drainage ditches, roads, piers, historical structures, developed areas, etc.) and CHNS boundaries were also added to the vegetation map from the air photos and National Park Service cadastral survey maps.

VERIFICATION PROCEDURE

The large number of cover types to be mapped from the photos made it necessary to derive a measure of how accurately the photos were interpreted. Although field trips were frequently made to correlate interpreted classes with ground truth, a statistical evaluation of the final cover type identification was developed to provide an indication of map accuracy as well as to improve subsequent photo interpretation.

A stratified sampling design that had been initially tested on an earlier mapping project of Ocracoke Island (McCaffray 1983) was modified and repeated for this project. Two strata, boundary and interior, were created under the hypothesis that interior sample points could be identified with greater accuracy as to vegetation cover type than could boundary points. Boundary points were defined as points falling within 75 feet of a vegetation cover type boundary line on the photo. All other points were interior. Sample size was calculated based on maximizing statistical accuracy (as measured by standard error) subject to cost/time constraints. For this project, a sample size of 80 points, yielding an estimated standard error of four percent, was the maximum number of samples that could be budgeted. When compared with the acreage totals of the map reports from the GIS, the distribution of the 80 sample points provides a reasonable representation of the common cover types found on CHNS (Table 1). The 80 points were allocated to the two strata based on the proportion of the total CHNS area in each stratum and its standard deviation. The statistical procedure for both the sample size calculation and the sample point to strata allocation are described in Cochran (1977).

Table 1: Comparison of Sample Point Distribution and GIS Mapped Acreage

Cover Type	Points	Acreage
Shrub Savanna <1/3	21 (26%)	2590 (17%)
Dune Grassland	15 (19%)	3096 (20%)
Shrub Thicket	9 (11%)	1048 (7%)
Bare Sand	8 (10%)	2589 (17%)
Juncus romerianus	8 (10%)	1209 (8%)
Other cover types	19 (24%)	4743 (31%)
TOTAL	80 (100%)	15277 (100%)

Forty-three interior and 37 boundary points were selected for sampling. The location of these points was determined by randomly selecting cell intersections from a grid overlay of the seashore. The intersections were then transferred to the photo base and the vegetation map. National Park Service personnel next located and visited each of the sample points noting the vegetation class at the point. These field point classifications were then compared with the photo interpreted classes.

Upon completion of the field checks, comparisons were made between the photo interpreted and field observed classifications. Overall, the photo interpretation accuracy was 70 percent, with 56 of the 80 points correctly identified. Interior points were correctly identified 74 percent of the time while 65 percent of the boundary points were accurately predicted.

Over three-quarters (61) of all sample points fell into 5 of the 15 cover types. This is consistent with the acreage estimates from the GIS and implies the dominance of the Bare Sand, Dune Grassland, Shrub Savanna <1/3 cover, Shrub Thicket and Juncus romerianus High Marsh cover types on CHNS. Difficulties with classification occurred primarily in two classes. First, there were seven points (five interior and two boundary) interpreted as Shrub Savanna <1/3 that were Dune Grassland upon field inspection. This indicates that there can be some problem in distinguishing between these classes with the infra-red photography. Three potential explanations are postulated for these errors. First, the small young pioneer shrubs may have only recently invaded a grassland community and much of the grassland still remains. Second, some dune slack areas, in which surface water resides throughout most of the winter, may be misinterpreted for the darker shrub patterns. Finally, during the winter it is common for Juncus Romerianus to be blown or washed over into matts that take on different visual properties from the standing needle rush.

The second major class of error was the three boundary points misclassified as Shrub Savanna <1/3 when in fact they were Bare Sand. These errors are of no particular concern as the dynamic nature of barrier island vegetation accounts for a movement of sand boundaries over the two year period between the photos and the field work. A complete description of the sampling procedure and results is given elsewhere (Devine and McCaffray 1985).

Given these results, photo interpretation of cover types appears to be a reasonably accurate method of mapping barrier island vegetation. Multi-seasonal and different types of photos (black and white or color) would increase accuracy. When the problems in interpreting Shrub Savanna are resolved, accuracy rates should improve. The true test of the accuracy of these maps will come in their sustained management use.

GIS PROCEDURE

The use of a Geographic Information System to store the vegetation map was not originally a major concern of the project. However, as the mapping developed the GIS became the central activity of the effort. It was determined early on in the project that the impact of the vegetation map on actual seashore resource management would be greatly compromised if no mechanism for on-going updates of the map were developed. Further, the establishment of an updatable vegetation map would provide the base upon which all other resource map layers could be drafted and new projects evaluated (e.g. wildlife planning, exotic plant species control, beach erosion studies etc.). Therefore, the establishment of the vegetation based GIS becomes a coequal objective of the project and an integral part of the vegetation effort.

The description of the GIS activity here is limited to the details of the actual activity on the CHNS vegetation project. No general description of GIS technology is presented. As noted above, the mapping procedure began with the photo interpretation of vegetation classes. The interpreted vegetation class boundaries were hand copied onto the paper topographic maps via a zoom transfer scope. The interpretation procedure, including two field trips to the CHNS and the transfer work, was completed without major difficulty in about six man weeks. The CHNS boundaries were then transcribed onto the topographic source via the same zoom technology in about two man days. At this point the maps (11 topographic sheets) were ready for entry into the GIS.

The "STRINGS" package (version 2.1) produced by GeoBased Systems Incorporated was selected as the GIS into which the maps would be entered. This system was chosen because it was available at the University and it was the system in use by the state of North Carolina in its own GIS program. Use of the same package allows the easy transfer of map data between the North Carolina statewide program and the CHNS. The digitizing of the vegetation and ownership boundaries was a very time consuming task taking over four man months to complete. At project end it was calculated that it required five minutes per polygon to digitize these two layers. That is, five minutes was required to initially trace each closed area (e.g. shrub thicket path) into the system and correct any tracing errors. Difficulties arose in the digitizing process with editing the very small polygons which characterized the transition zones between vegetation classes and with the large number of polygons contained on each sheet (over 500 on some maps).

Once the map was digitized and edited, two other production GIS problems arose. First, the GIS files were constructed by topographic map sheet which, as noted above, could contain a large number of small polygons. This meant that any GIS function performed on these files took a long time to complete. This became very inconvenient, as even activities as simple as producing a color shaded plot of the map could take as long as two hours. The problem was alleviated with the construction of a series of arbitrary map sub-sheets. Each sub-sheet covered about one quarter of the topographic sheet and generated approximately a five-fold reduction in GIS processing time.

The second major problem with the GIS was the difficulty encountered in the routine handling of point symbol data. The problem, which is likely a function of the "STRINGS" package, centered on the inability of the software to plot symbols to scale when the entire map scale was changed. This resulted in very large plots of symbols (e.g. mileposts) on relatively small maps. No truly effective remedy was found to correct this annoyance.

The benefits of going to the GIS were significant and somewhat unexpected. First, the use of a GIS to store the data made corrections to the map relatively inexpensive and quick. Boundary changes were implemented and new plots generated in less than one hour. Second, the production of the GIS boundary layer complete with the seashore infrastructure provided an easily accessed map source for storage of other resource management information such as sea turtle nests, dune movements, and beach access points. A third benefit of the GIS effort is its use in the sampling accuracy for the vegetation map itself. The GIS provided the estimates of vegetation coverage that were used in the sample size calculation and provided a permanent record of sample point locations. The fourth benefit resulted from the use of the GIS to develop acreage estimates of vegetation by survey plot for an ecological analysis that was not a part of the original project. There were ten of these approximately 20 acre plots and the GIS provided the vegetation estimates in less than one man day. It was estimated that it would have taken at least a week to develop these estimates by conventional methods. A final benefit has been the use of the GIS to develop a preliminary wildfire fuel map for use in fire management on CHNS. The vegetation classes were simply recoded into fuel categories and the resultant map then edited to form the base for the wildfire management analysis. This procedure is described in detail in the project report (Devine and McCaffray 1985).

The major challenge in constructing the GIS vegetation product was to develop a transfer technique for use of the map and the GIS in "on the ground" management. It was determined early in the project that it was unlikely that the human and monetary resources necessary to operate a GIS on the CHNS were going to be available in the near future. Therefore, a mechanism that would allow the use of updated, inexpensively produced paper maps for seashore personnel was needed. The first attempt at such a product was the construction of a series of "windowed" maps based on the sub-topographic sheets identified earlier. These maps were produced at the common 1:24,000 scale of the original topographic maps and were plotted on notebook size sheets that were subsequently assembled into book form for field use. This effort proved quite successful as park resource records began to be maintained in these notebooks. An example sheet is presented in Figure 1. However, the continuing support for updating and adding to the original effort was not forthcoming so a second procedure is now under development. The original GIS files have been moved to a less expensive (i.e. approximately $1,000), easier to use (i.e. requiring no significant training of personnel) map display system in anticipation of installing such a system at CHNS itself. The results of that effort are yet to be determined.

CONCLUSIONS

Each of the three study objectives was realized throughout the course of the project. The vegetative maps were effectively produced from the field work and the Department of Transportation photos. These maps have been successfully applied to subsequent management and research activities on the seashore. A GIS data base was developed and stored at the University and has been employed to produce the field handbook for resource management. In addition, implementation procedures for an operating GIS are underway.

FURTHER STUDY

Several steps remain to attain the full promise of this project. First, different photographic techniques should be investigated to see if the classification problems with this effort can be resolved. Second, the development of a relatively simple micro-computer based map display system would greatly improve the usefulness of the GIS product. Preliminary investigations into the transfer of the CHNS data base to such a system have shown encouraging results and an extension of this effort would allow the seashore managers to produce map materials and perform map based analyses in their own offices without significant training. However, substantive research in the file management and analyses features of the software needs to be performed for this type of benefit to be realized.

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Fire Management Planning In Acadia National Park Using A Geographic Information System

Steven L. Garman, William A. Patterson III,
and John T. Finn[1]

ABSTRACT

We used SAGIS- one of the National Park Service's geographic information system (GIS) software packages - to aid in the fire management planning process for the Isle au Haut unit of Acadia National Park, Maine. Specifically, we needed to assess relative fire danger (defined here to be a combined assessment of fire hazard, fire behavior, and fire risk) which we put into a spatial context. Fire hazard and behavior relate to characteristics of the fuel complex, its position on the landscape, and in the case of behavior- weather; in the Northeast fire risk relates to intensity and nature of human use of an area. The geographic data base consisted of natural resource information including slope, aspect, and vegetation cover type. To analyze fire danger on Isle au Haut, vegetation cover types were grouped according to four National Fire Danger Rating System fuel models (H, E/R, Q, and L). Topographic information was grouped according to two slope classes (level and steep) and two aspect classes (mesic and hydric) and all possible combinations of fuel model and topography classes were derived. Human use areas such as campgrounds, roads, and developed areas were overlayed on the fuel model-topography information along with the park boundary. Maps were generated using the graphic capabilities of SAGIS which allows variable color and line pattern selections and facilitates emphasis of fire danger. Critical areas of high fire danger were defined to be fuel model H or Q on dry aspects and steep slopes adjacent to human use areas. Fuel model-topography area statistics for both park and private lands were generated. These results will generate specific recommendations for prioritized fuel-load reduction. Presentation of the fire management plan to park personnel and the general public will be facilitated by the visual representation of fire danger made possible by SAGIS. The digitial data base created for this study is permanent and will be available to future natural resource research and management efforts.

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[1] Dept. of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA 01003

INTRODUCTION

Acadia National Park spans several islands off the coast of eastern Maine. Most of the park is located on Mt. Desert Island and was donated to the federal government between 1916 and 1919 through the efforts of George Dorr and by J. D. Rockefeller, Jr. In 1919, Lafayette National Park was officially established. The name was later changed to Acadia. About half of Mt. Desert Island is national park land (12,245 ha). Other island parcels and a unit on the Schoodic Peninsula east of the island have been acquired raising the total park acreage to 14,285 ha. This first national park east of the Mississippi and the only national park in the Northeast was created to preserve the scenic coastal Acadian landscape which is characterized by spruce-fir and aspen-birch uplands, cedar and sphagnum/heath lowlands and rocky coastal shorelines.

Establishment of the park protected the landscape from development but not from disturbances such as fire. In 1947, 28 years after the creation of the park, a human-caused fire burned approximately 25 percent of Mt. Desert Island, including 29 percent of the park. Adherence to a fire suppression philosophy during the first half of the 1900's and the relative absence of natural fires in the moist Northeast resulted in heavy accumulations of fuel (plant material) on the island. This, coupled with the driest month recorded in Maine, caused the 1947 fire to burn out of control for nearly 10 days in late October. In many areas, organic soils were burned down to bare rock.

Today, there is a concern that the fuel loads throughout Acadia are again reaching levels capable of supporting a conflagration. The historic occurrence of large fires at long intervals combined with the fact that fire management planning is mandated by National Park Service policies (Guideline NPS-18, 23 August 1979) gave rise to the present fire management study at Acadia. Baseline inventories of fuel loads in representative forest cover types were completed in 1980 (Patterson et al. 1983), and these led to preliminary fire management recommendations (Patterson et al. 1985).

Further analysis was needed to delineate areas of greatest fire danger. Fire danger for an area, as used here, is a combined assessment of fire hazard, fire behavior, and fire risk (each as defined by Chandler et al. 1983) that results in a qualitative measure of the potential for a fire to occur and the perceived difficulty of control. Such an analysis facilitates pinpointing areas on the landscape of greatest fire management concern. This information will guide recommendations on where to concentrate fuel reduction efforts and is especially useful given the limited resources available for this function at Acadia. Recommendations are to be included in the fire management plan for Acadia National Park (Drake and Patterson, in preparation).

Fire hazard for an area is the fuel complex, defined by volume, arrangement, and location, that determines ease of ignition and suppression difficulty. Fuel complex attributes partly determine the burning properties of a fire (fire behavior) which, in turn, determine the ease of ignition and suppression. Suppression difficulty is also related to ease of physical access.

The physics of fire behavior (the manner in which fire reacts to fuel, weather, and topography) have been extensively studied, resulting in the development of behavior simulation models (Rothermel 1972, Albini 1976, Cohen and Deeming 1985) that are available as computer programs such as AFFIRMS (Helfman et al. 1980) and BEHAVE (Andrews 1986) or in graphic (or nomogram) form (Albini 1976, Burgan et al. 1977). Model input parameters include fuel properties (amount, size, surface-area-to-volume ratios, fuel bed depth, moisture content, etc.), weather information (wind speed, relative humidity, days since rain, etc.), and climate and slope class (ordinal values representing general climate conditions and percent slope, respectively). The fire behavior models evaluate complex interactions among fuel properties, weather, and topography and determine the reaction intensity of a fire (amount of energy per unit area per unit time), a spread rate component (rate at which the flaming front moves), an energy release component (a function of the reaction intensity and the residence time of the flaming front), and a burning index (which is numerically equivalent to 10 times the predicted flame height in feet and is a measure of fire intensity). These outputs are used to predict the severity of fire behavior with respect to difficulty of control. Fire behavior analysis integrates the volume and arrangement components of fire hazard with weather conditions.

Some important generalizations can be made concerning the relationship between model input parameters and fire behavior response. The amount of fuels by diameter size class significantly affects fire behavior. Simulation models use four standardized size classes for dead and downed woody fuels, (including litter and duff) because the amount of time required for internal moisture content to equilibrate with ambient levels varies with particle diameter. Live shrubs and herbaceous plants are assigned to two separate live fuel classes (for explanation of fuel size classes see Deeming et al. 1977). In general, increasing amounts of fuels of all size classes increase the potential energy output of a fire. As moisture content increases, the amount of heat energy necessary to ignite fuels increases, thus decreasing the intensity and rate of spread of a fire. As slope and wind speed increase, a larger area of fuels up slope (or up wind) from the flaming front is simultaneously heated through increased exposure to flames and, convection and/or radiant energy. This increases the spread rate of a fire.

To faciliate analysis of potential fire behavior using the derived algorithms, 20 predefined input data matricies (commonly known as National Fire Danger Rating System (NFDRS) fuel models) have been defined (Deeming et al. 1977) and collectively represent a broad spectrum of fuel conditions found throughout the United States. Fire managers of public lands (such as national parks and national forests) evaluate the potential for fire daily during the fire season (approximately mid spring- late fall) using either automated systems (e.g. AFFIRMS) or published nomograms that allow selection of a specific NFDRS fuel model to represent fuel loads and that require real-time measures of moisture and windspeeds. Daily assessment of the severity of a fire, if one was to occur, enables a fire manager to prescribe precautionary actions accordingly.

We were interested in fire behavior across the landscape as a whole rather than at any one point in time or space. Measures of fuel in vegetation cover types of Acadia were available (Patterson et al. 1985). Cover types can be assigned to NFDRS fuel models and, holding fuel moisture content and wind speed constant, fire behavior can be simulated and relative severity assessed. However, the rugged topography of Acadia warranted additional consideration of aspect and slope due to their potential influence on fuel moisture content and fire spread rates, respectively. We assumed that fuels on northern aspects have relatively greater moisture content than fuels on southern aspects, thus decreasing the severity of fire behavior. Also, steeper slopes encourage faster spread rates and thus increase the severity of fire compared to more moderate slopes. For our purposes, we felt that fire behavior could be expressed as a function of the interaction between vegetation cover types and topography. Using this approach, analysis of fire behavior would use actual fuel load measures with representation of relative moisture and slope differences.

Fire risk is the chance of a fire starting, as affected by the nature of causative agencies. Unlike the landscapes of the western United States, lightning strikes are rarely an important ignition source in the Northeast. Most fires at Acadia are due to human negligence (Patterson et al. 1985). We considered the likelihood of a fire start on a parcel of land to be a function of its juxtaposition to campgrounds, roads, and developed areas (i.e. proximity to areas of human use).

Defining fire hazard (based on fire behavior and accessiblity) and fire risk as landscape features that can be referenced by a cartesian coordinate system (e.g. Universal Transverse Mercator (UTM) system) enabled us to approach fire danger analysis using spatial analysis techniques; that is, the mapping and analysis of vegetation cover types over topography, transportation networks, and human settlements. Manually drawing, overlaying, and measuring areas of the desired combinations of the spatial information would have been a tedious effort. We sought a relatively human-error-free method that would graph or plot overlays of designated resource information and would provide area statistics. The use of a geographic information system (GIS) software package for our spatial analysis was deemed essential.

A GIS is a computer-based methodology for manipulating digital information referenced by a coordinate system (Gray and Maizel 1985). Essentially, it is a set of computer programs that accepts and analyzes information represented by (primarily) X and Y values. Development and application of GIS's began about two decades ago and initially were associated with military applications (Marble et al. 1984). GIS applications have since grown to include a wide range of disciplines. Dangermond (1984) provides a concise review of the advantages of using an automated geographic data analysis system. In short, a GIS allows the blending together of layers of information from different sources and of different scales and offers the ability to perform a range of spatial area analyses; from simple area calculations to the more complex viewshed analyses. It is a very versatile mechanism for relatively quick and repeated data analysis. As an automated system, storage and retrieval of geographic data sets can also be automated.

New information can easily be added to existing data sets, and, with a minimal amount of time and effort, combined and analyzed with data previously collected. The automation and versatility of a GIS encourages an integrated flow from data collection and spatial analysis through decision making (Dangermond 1984).

A very important function of a GIS is the production of maps. Spatially referenced information can be illustrated using an array of color and line patterns to emphasize specific details. Also, once a GIS data base is created it is permanently available for future redrafting using different visual patterns to represent different attributes of the data set or for representing information at different scales.

OBJECTIVE

Our objective was to use a GIS as a spatial analysis tool for the delineation, quantification, and presentation of fire danger to aid in the fire management planning process. In our analysis we viewed relative fire danger of landscape parcels as a function of their fuel loading, topographic position, accessibility, and proximity to human use areas. Specific issues to address were: 1) Where are the areas of greatest fire hazard on Isle au Haut, 2) How large are these areas, and 3) How are they distributed in relation to roads, developed areas, and the park boundary?

The fire management planning effort for Acadia National Park is in progress. Initial fire management planning efforts have focused on the island of Isle au Haut, because it is geographically isolated from the rest of the park, because its vegetation is comprised largely of older red and white spruce (<u>Picea rubens</u> <u>and P. glauca</u>) forests, and because fire protection capabilities of the National Park Service and the local town of Isle au Haut are limited. Also, previous analysis classified Acadia National Park on Isle au Haut as a separate Fire Management Area (FMA) (Patterson, unpublished 1983). This designation is used to signify that fire management on the island should, because of its size and isolation, be considered separate from the Mt. Desert and Schoodic Peninsula FMAs.

STUDY AREA

Isle au Haut is a 2785 ha island located in the Gulf of Maine, 24 km southwest of Mt. Desert Island (Fig. 1). It lies between 44° 00′ and 44° 05′ N. latitude, and 68° 38′ W. longitude. Park lands

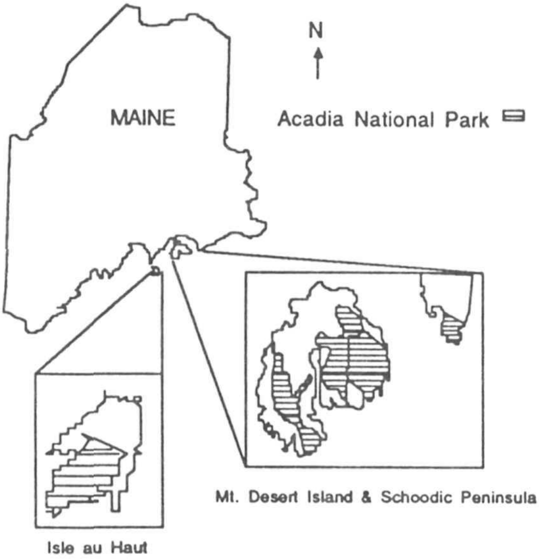

Figure 1. Geographic setting of Acadia National Park.

comprise two parcels totaling 1312 ha. Vegetation is predominantly mature spruce forest. Elevation ranges from sea level to 165 m. A ridge bisects the island along its north-south axis. The resident island population ranges from 40-50 people during the winter to as many as 200 during the summer. There is an unimproved road that circles the island and provides access to most areas along the shore. The island is accessible from the mainland only by boat or seaplane.

METHODS

We obtained SAGIS, one of the National Park Service's GIS software packages, from the National Park Service Geographic Information Systems Field Unit in Denver, Colorado, and installed it on the University of Massachusetts CYBER 175 mainframe computer. The SAGIS package is a series of individual computer programs that, collectively, enable one to perform data entry and editing, spatial analyses, and map production. It accepts polygonal information with the capability to convert to a rastor (cellular) format, thus making it a hybrid (polygonal-rastor) system. SAGIS will also accept point and line information. A graphics terminal configured for Tektronix 401X or 410X series is essential to realize the full capabilities of SAGIS. However, we did not have Tektronix monitors available at the time of our analysis but found the monochrome VISUAL 550 graphics

Table 1. Natural resource themes used in fire management planning for the Isle au Haut Unit of Acadia National Park.

Theme/ Classes	Origin	Original Map Scale
Island Boundary/ Island Boundary	USGS Orthophotoquad, Deer Isle (SW&SE), ME	1:24,000
Park/ Park Boundary	USGS Acadia National Park and Vicinity topographic map	1:50,000
Campground/ Campground	NPS Isle au Haut trail map	1:30,720
Slope/ 0-3%, 4-8%, 9-15%, 16-25%, 26-35%	USGS DMA elevation data	1:250,000
Aspect/ North, Northeast, East, Southeast, South, Southwest, West, Northwest, Flat	USGS DMA elevation data	1:250,000
Vegetation/ Spruce-fir, Cedar, Bl. Spruce, Mixed Conifer, Mixed Hardwood-Conifer, Pitch Pine, Northern Hardwood, Red Oak, Aspen-Birch, Alder, Shrub-Bog, Red Maple, Moss-Sedge, Field, Heath, Rock, Developed	Cover types derived from aerial photo's and transferred to USGS Orthophotoquad, Deer Isle (SW&SE), ME	1:24,000
Inland Water/ Pond	USGS Orthophotoquad, Deer Isle (SW&SE), ME	1:24,000
Road/ Main Road, Auxiliary Roads	USGS Orthophotoquad, Deer Isle (SW&SE), ME	1:24,000

terminal to be adequate. We had several graphic output media to select from. For quality plot production we used the University of Massachusetts Computing Center's CALCOMP pen plotter.

Information layers or themes required for our analysis were derived from a variety of sources of different scales (Table 1). A theme has at least one if not more classes which represent certain categories; the theme is general (i.e. vegetation), the class is specific (i.e. spruce-fir). The National Park Service's GIS Field Unit photointerpreted vegetation cover types from high altitude color infrared photos in 1981. Cover types were field checked and transferred in poygonal format to the Deer Isle (SW&SE) USGS orthophotoquads. Seventeen cover types, (including a developed type) were delineated. Fuel loadings of representative stands of the most important cover types were determined by Patterson et al. (1983). The island boundary, a pond, and roads were also delineated on the orthophotoquads. These themes were digitized in polygonal form (except for the roads) from the orthophotoquads using a SUMMAGRAPH digitizing tablet connected to an IBM AT micro and driven by a software program written by University of Massachusetts Computing Center personnel. The park boundary and campground were digitized in polygonal form from other sources of varied scales. Roads, the campground, and the developed cover class represented the human use areas in our analysis. All digitized information was geographically referenced via the UTM coordinate system. Harvard University's Laboratory for Computer Graphics was contracted for the transformation of DMA (Defense Mapping Agency) information into five slope and nine aspect classes in UTM-referenced polygonal format. Percent slope groupings were arbitrarily defined, with at least two groups for the steeper slopes and with lesser percent slopes (<15 percent) more finely divided. The aspect and slope themes were to represent relative moisture and slope, respectively, in the assessment of relative fire danger.

All polygonal data were transformed into an internal SAGIS format. Error checking and georegistration (making sure that all data are geographically aligned) were performed using SAGIS modules. Since some of the spatial analyses required rastor formatted information, polygonal data were rastorized using SAGIS modules. The complete data set used in this analysis included both polygonal and rastor forms of all classes.

Digitizing, checking for errors, and georegistering are time consumptive and, admittedly, not very exciting. It took 34 man-hours to perform the in-house digitizing. The error checking and georegistering process took up to three times as long. In general, the benefit of using a GIS is the ease with which the actual spatial analyses and mapping can be perfomed. Also, once created and stored, the digital data bases are forever available; the long-term benefits make up for the short-term costs!

ANALYSIS

Once in SAGIS format, the digital information was easily manipulated using an array of SAGIS analysis and graphic modules. To illustrate position on the landscape, natural resource themes were individually mapped with the park boundary superimposed (or overlayed). The maps aided in visually perceiving the extent of each theme class in and outside of the park. Area statistics were generated for combinations of

Table 2. Description of NFDRS fuel model theme classes derived from topological combinations of vegetation cover classes for the Isle au Haut Unit of Acadia National Park.

NFDRS Fuel Model	Relative Fire Control Difficulty	Cover Class Composition
Q	High	Pitch Pine
H	Medium to High	Spruce-Fir, Cedar, Black Spruce, Mixed Conifer, Mixed Hardwood-Conifer
E/R	Medium	Aspen-Birch, Northern Hardwood, Red Oak, Red Maple
L	Low	Alder, Shrub-Bog, Field, Heath, Moss-Sedge, Urban
Null	-	Rock

themes and for both park and private lands.

Vegetation cover type data were grouped according to NFDRS fuel model types (Deeming et al. 1977) based on fuel characteristics (amount of fuel by size class and mean fuel bed depth) (from Patterson et al. 1983). Cover types were grouped using the Boolean command of SAGIS which enables the combination of classes to form new classes that can be cataloged under an existing or new theme. The combined classes remain unchanged. The derived NFDRS fuel model classes collectively formed the NFDRS fuel model theme (Table 2). Cover types were grouped into fuel models to facilitate recognition of relative severity of fire behavior. Holding all other parameters constant, the potential fire behavior attributes for each fuel model were assessed quantitatively from simulation runs and intuitively from previous field experience.

Pitch pine (Pinus rigida) was the only cover type assigned to fuel model Q. Fuel model Q is used to describe a fuel array that contains relatively large amounts of fine and heavy fuels. Fuel model Q is also defined to have a relatively large fuel bed depth (1m). Downed woody fuels in Isle au Haut pitch pine stands are not deep, but, dense thickets of highly flammable huckleberry (Gaylussacia baccata) growing to heights of 1 to 1.5 m are common beneath pitch pine. Q -type fuels can potentially support hot, fast moving fires. Fuel model H is used to describe a fuel array derived from healthy short-needle conifers. This model describes a fuel load not quite as heavy as model Q, however under drought conditions a fire in this fuel type burns quite hot making it difficult to control. The vegetation types that contained spruce and cedar were assigned to this fuel model. Fuel model E/R was a combination of two models which represent hardwood (deciduous) fuel loadings during winter (fuel model E) and summer (fuel model R). All vegetation cover types containing hardwood tree species were assigned to this fuel model. Fuel model E/R is less of a fire threat than Q or H. Fuel model L is used for fuel arrays comprised of perennial grasses. L-type fuels represent the least fire threat of all the fuel models used on Isle au Haut. Grassy areas can readily ignite (during dry periods in the spring and fall), however such fires are usually not as hot as forest fires and are easily suppressed. Also, few fields are found on Isle au Haut and those that do exist are easily accessible. Fields, bogs, and developed areas were assigned to this model (developed areas on Isle au Haut are small clusters of summer cottages and homes with large grassy yards). The rock cover type made up the Null fuel class. The fuel models were mapped with the park boundary overlayed, and area statistics of fuel model type by ownership class were generated.

To add the influence of slope and aspect to fire hazard, topography classes were to be overlayed on the fuel model classes. The outcome from all possible combinations of five fuel models, nine aspects, and five slopes on one map would have been unwieldy given the four-color constraint of our plotter. We grouped slope information into two new classes: level (0-3 percent and 4-8 percent), and steep (9-15 percent, 16-25 percent, and 26-35 percent). Aspect was grouped into two new classes: hydric (north to southeast), and mesic (south to northwest and flat). These groupings were performed using the SAGIS Boolean command.

All possible combinations of the four fuel models (excluding the Null fuel model) and the two slope and aspect themes were derived using the Boolean command. This resulted in the creation of 16 new classes. All classes of this fuel model-topography theme were illustrated as one map with the park boundary, roads, campground, water, and developed areas overlayed. Area statistics were generated for fuel model-topography classes in the park and on private lands (Table 3).

RESULTS AND DISCUSSION

The fuel model-topography map illustrated the interaction between fuel types and landscape features

Table 3. Cross-tabulation of fuel model-topography classes with land ownership type on Isle au Haut. The first entry in each triad is the number of hectares of the fuel model-topography class in the land ownership type, the second the percent of class found in the land ownership type (sums to 100% within rows), the third the percent of land ownership type comprised of the particular class (sums to 100% in columns Park and Nonpark).

Fuel Model-Topography Class (fuel model/ aspect*/slope**)	Park (ha) (%)1 (%)2	Nonpark (ha) (%)3 (%)4	Total (ha)
H/MESIC/LEVEL	505.3	347.8	853.1
	59.2	40.8	100.0
	38.5	23.6	-
H/MESIC/STEEP ***	221.6	166.5	388.1
	57.1	42.9	100.0
	16.9	11.3	-
H/HYDRIC/LEVEL	243.4	300.2	543.6
	44.8	55.2	100.0
	18.6	20.4	-
H/HYDRIC/STEEP	132.1	221.2	353.3
	37.4	62.6	100.0
	10.1	15.0	-
O/MESIC/LEVEL	3.4	8.0	11.4
	29.9	70.1	100.0
	.3	.5	-
O/MESIC/STEEP ***	5.4	10.3	15.7
	34.4	65.6	100.0
	.4	.7	-
O/HYDRIC/LEVEL	3.9	2.9	6.8
	57.7	42.3	100.0
	.3	.2	-
O/HYDRIC/STEEP	3.6	22.1	25.7
	14.0	86.0	100.0
	.3	1.5	-
ER/MESIC/LEVEL	44.3	55.3	99.6
	44.5	55.5	100.0
	3.4	3.8	-
ER/MESIC/STEEP	27.2	14.7	41.9
	65.0	35.0	100.0
	2.1	1.0	-
ER/HYDRIC/LEVEL	19.0	74.9	93.8
	20.2	79.8	100.0
	1.4	5.1	-
ER/HYDRIC/STEEP	26.5	40.1	66.6
	39.8	60.2	100.0
	2.0	2.7	-
L/MESIC/LEVEL	11.3	48.1	59.4
	19.1	80.9	100.0
	.9	3.3	-
L/MESIC/STEEP	.1	6.2	6.4
	1.9	98.1	100.0
	.0	.4	-
L/HYDRIC/LEVEL	5.2	23.8	29.0
	18.0	82.0	100.0
	.4	1.6	-
L/HYDRIC/STEEP	1.1	25.1	26.1
	4.0	96.0	100.0
	.1	1.7	-
NULL	58.8	77.3	136.1
	43.2	56.8	100.0
	4.5	5.2	-
POND****	.0	28.7	28.7
	.0	100.0	100.0
	.0	2.0	-
GRAND TOTAL	1312.2	1473.0	2785.2
	47.1	52.9	100.0
	100.0	100.0	-

* Aspect Code: MESIC = South + Southwest + West + Northwest + Flat
HYDRIC = North + Northeast + East + Southwest

** Slope Code: Level = 0-8% Steep = 9-35%

*** Represent relatively greater fire danger.

**** Included for correct nonpark acreage total and percent values.

1- % class in park 2- % park in class 3- % class in nonpark 4- % nonpark in class and aided in analysis of fire danger across the landscape. The SAGIS system, like most GISs, allows the operator to design color and pattern schemes of output maps. Choosing colors to represent the intensity of each fuel model (blue for Q, red for H, green for E/R, and black for L and Null) and line patterns to represent steepness of the grade (45^{o} diagonal for hydric and -45^{o} diagonal for mesic) aided in the interpretation of the maps. Based on predicted severity of fire behavior, areas of Q and H-type fuels are of greatest concern. These fuels in inaccessible areas on steep slopes and dry aspects represent a great fire hazard and were termed "hot spots". Fire risk, however, is greatest where these fuels are in proximity to human use areas, especially on the steeper slopes and drier aspects. Hot spots account for 17 percent (227 ha) of the park area, and 12 percent (176 ha) of the nonpark area. The remainder of the park and island is primarily occupied by H-type fuels (Table 3). The hot spot areas were easily visible on the final map which also showed the surrounding fuel types and their topographic position.

Aided by the final map, we visually grouped hot spots into eight areas (based on the contiguous nature of individual polygons) and evaluated their proximity to potential ignition sources, thus ranking their fire danger (Fig. 2). Four areas are adjacent to the park's boundary and two are very close to the campground. The road that circumscribes the island traverses through large sections of several parcels, and developed areas are close to two parcels. For management purposes, the eight areas were grouped into three major areas of special concern (areas 1-6, 7, and 8 in Fig. 2).

Prioritized fuel load reduction recommendations will be generated from analysis of the GIS-produced maps and statistics. The management plan will pinpoint on the ground the location of suggested management actions, and, from analysis of the area statistics, the cost/benefit of management efforts can be assessed.

To be effective, the fire management plan must be accepted and implemented by the park. The graphic output from the GIS analysis can be used to help justify, in an illustrated form, management recommendations when presenting the plan to park personnel. In turn, resource managers can use these visual aids to advocate fire management actions, (e.g. manual fuel removal or prescribed burning) to the general public.

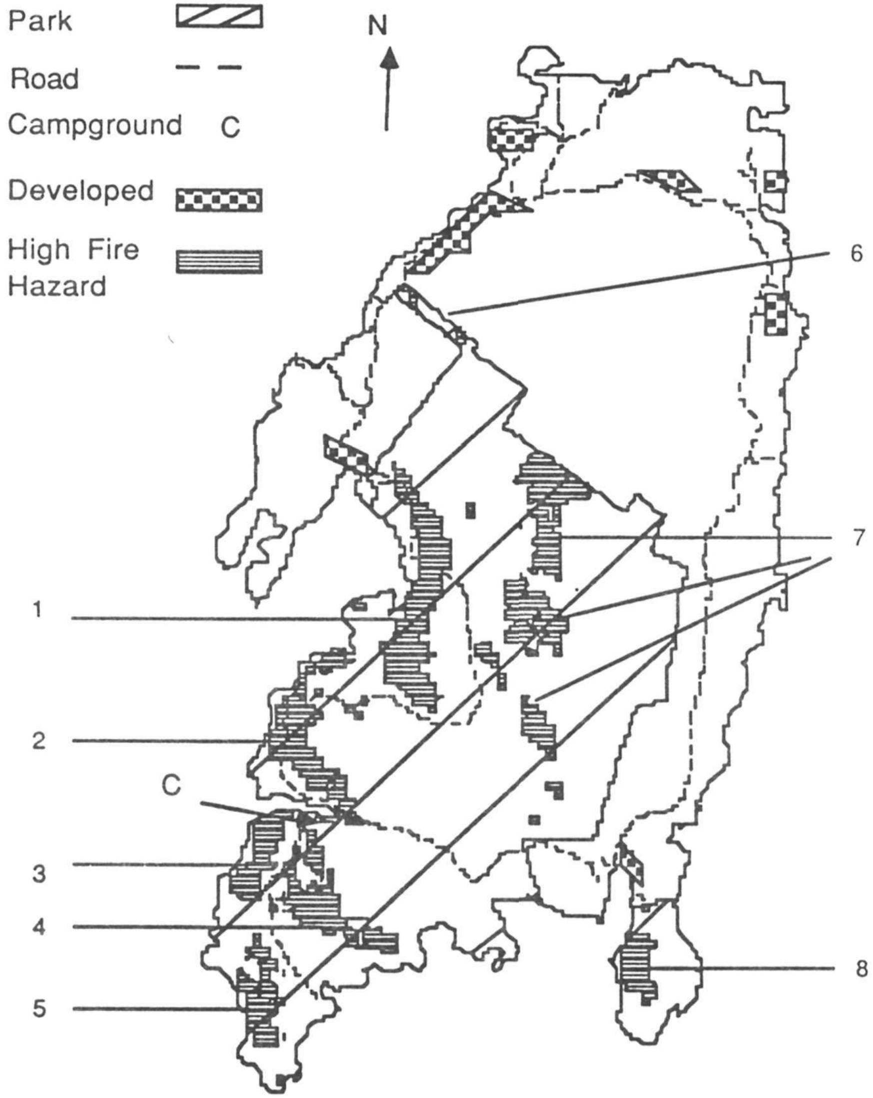

Figure 2. Delineation of high fire hazard and proximity to human use areas in Acadia National Park on Isle au Haut. Nos. 1-8 designate general groups (see text).

GIS data bases for Acadia National Park on Mt. Desert Island are being created. Analyses similar to those for Isle au Haut will be performed.

CONCLUSIONS

We performed very simple spatial analyses to assist in the fire management planning process for the Isle au Haut Unit of Acadia National Park. Combining multiple layers of natural resource information, available from different sources and scales, into one map and automatically generating area statistics has greatly facilitated the fire management planning process. More information has been analyzed in a shorter time period than could have been accomplished by manual means. Using a GIS enables one to arrange and analyze spatially referenced natural resource information in a variety of ways. Also, a digitized natural resource data base with broader applications results from this process. This information is permanently stored and is an essential source of information for future management and research applications. Creating digitized data bases of our national parks' resources is consistent with today's emphasis in long-term ecological research and monitoring. A GIS is a valuable tool for natural resource management decision making in national parks.

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