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Gap Analysis: A Geographic Approach for Assessing National Biological Diversity

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Abstract

The global concern with reduction in biodiversity has generated responses in the United States, such as the Endangered Species Act (ESA). Although the ESA has had some effect, the species-by-species approach presents a problem because it does not consider the broad ecological principles of biodiversity including the need for balance between different species and their combined influence on a given habitat. There is an implicit assumption that national parks, wildlife sanctuaries, and other protected areas provide for conservation needs. However, these areas have not necessarily been delineated on the basis of animal habitat zones or ecologically significant units. Gap Analysis is an evaluation method providing a systematic approach for assessing the protection afforded biodiversity in a given area. It uses geographic information systems to identify "gaps" in biodiversity protection that may be filled by the establishment of new preserves or changes in land-use practices. Gap Analysis has three primary layers: (1) distribution of vegetation types delineated from satellite imagery, (2) land ownership, and (3) distribution of terrestrial vertebrates as predicted from vegetation cover using habitat preference models. Vegetation classification procedures using satellite image or aerial photograph analysis are linked to wildlife / habitat databases. Gap Analysis includes seral as well as climax vegetation, and classes must be compatible with those used in neighboring states. The examples of these procedures for the Utah Gap Analysis are given with some reference to Gap Analysis in other states. The overall approach provides a logical base for evaluating and protecting national biological diversity.

INTRODUCTION

The rapid loss of biodiversity remains mankind's greatest threat. Traditionally, approaches to stem this loss have concentrated at the species level and are brought to bear only when a species is brought to the edge of extirpation or extinction. Within the United States, the primary means of stemming this loss is the Endangered Species Act (ESA). Recent reports have criticized the ESA for several reasons, including a backlog of unaddressed listing petitions, a failure to develop and implement recovery plans in a timely fashion, and a lack of adequate funding to meet objectives (GAO 1992). A primary cause of these problems is that the act focuses on individual species. Effort expended on this species-by-species approach is inefficient, expensive, and biased toward "charismatic megafauna" having broad public appeal (Pitelka 1981, Hutto et al. 1987, Scott et al. 1987, Noss 1991). Last ditch efforts also lead to economic conflict because they fail to provide a reasonable planning framework for economic interests.

Maintenance of biodiversity is the concept around which new concerns about biological conservation are centered. Definitions of biodiversity vary but generally include recognition of diversity at genetic, species, and ecosystem levels (Wilson 1988). Calls for the maintenance of biodiversity are an explicit recognition that biological loss occurs at all levels and that attempts to maintain this diversity-conservation effort must be applied to all levels, not just to endangered species (Noss 1991, Scott et al. 1991).

Historically, most national parks and other areas that implicitly are thought to protect biodiversity are selected for reasons other than biological. Although a variety of conservation methods for evaluating the conservation worth of areas has been suggested, few have attempted to provide a cost-effective means for evaluating biodiversity at the scale of the ecoregion. Here we describe a rapid conservation evaluation method for assessing the current status of biodiversity at large spatial scales. Called Gap Analysis, this evaluation method provides a systematic approach for evaluating the protection afforded biodiversity in given areas. It uses geographic information systems (GIS) to identify "gaps" in biodiversity protection that may be filled by the establishment of new preserves or changes in land-use practices (Scott et al. 1993).

Gap Analysis consists of three primary data layers. These are (1) the distribution of actual vegetation types delineated from satellite imagery, (2) land ownership, and (3) distributions of terrestrial vertebrates as predicted from the distribution of vegetation. Within the GIS, overlays of animal distribution and ownership can be used to estimate the relative amount of protection afforded vertebrate animals. Gap Analysis functions as a first-pass approach for organizing biological information. Depending on the nature of the issue, the database can be used to springboard into other, more detailed studies and is meant to be used as a proactive rather than reactive management tool.

VEGETATION CLASSIFICATION AND MAPPING

Numerous vegetation classification systems exist and are used in the United States, e.g., UNESCO, (Driscoll et al. 1984; Brown et al. 1980; Kuchler 1964). Classification schemes represent attempts to group vegetation into classes based on factors such as structure, taxonomy, or evolutionary history. Vegetation acts as an indicator of the physical and biological attributes of an area and has been used as a surrogate for ecosystems in conservation evaluations (Specht 1975, Austin 1991). Mapping of vegetation is a reflection of physical and biological attributes of a site and is the basis for most management.

Methods of mapping vegetation vary (Kuchler and Zonneveld 1988), and selection of a specific mapping method is largely goal-specific. Although several different mapping methods have been tried for Gap Analysis, all methods shared the following properties: (1) vegetation classes must be discriminated from satellite imagery or aerial photographs; (2) mapped classes must be linked with existing wildlife/habitat-relation databases; (3) classes must encompass seral as well as climax vegetation; and (4) classes developed in one state must be complementary with neighboring states (Scott et al. 1993).

Vegetation maps used in Gap Analysis quantify the extent, representation, and distribution of vegetation classes in the study area. Further uses of the map may include analyses of the amount and extent of fragmentation, identification of linkages and corridors (Noss 1991) between management areas, and use as a modeling tool for projecting probable pathways of future vegetation. Because the goal of Gap Analysis is to assess the current status of vegetation, plant-indicator species are used to identify the habitat type, usually at the series level (Driscoll et al. 1984). A national, hierarchically based classification scheme has been developed for the Western states (Bougeron et al. 1992) and is being expanded for the remainder of the United States. The need for a consistent classification scheme cannot be overemphasized; failure to develop such a scheme limits the ability of Gap Analysis to resolve biodiversity conflicts at large spatial scales.

A pilot project in Idaho synthesized a vegetation map from existing local, regional, and state vegetation maps. Based on lessons learned, a second project in Oregon added visual photo-interpretation of satellite imagery to locate boundaries of vegetation classes. Later, states such as California, Utah, and Nevada began mapping vegetation by a combination of digital classification of satellite data, visual photo-interpretation of satellite imagery, and reference to existing maps and other ancillary data. This approach has become the standard for all subsequent programs (Scott et al. 1993).

Vegetation mapping in Utah relied heavily on digital analysis of satellite data (Ramsey et al. 1992). Ancillary data used to model vegetation in Utah included digital elevation data, hydrology, an existing vegetation map, and training points collected from a variety of outside collaborators. From this a total of twenty-four cover types and three land-use types were mapped (Table 1). Based on preliminary data, map accuracy for Utah was estimated at 76 percent.

LAND OWNERSHIP

Land ownership categories are based on private and public lands. On public lands, knowledge of the administering agency is important because of different mandates and policies. The administering agency provides a strong clue to the kinds of management activities likely to occur on the land and their resultant effect on biodiversity. For example, Forest Service lands are managed under a multiple-use scenario that allows for a wide range of activities ranging from resource extraction to wilderness areas. Private lands, with few exceptions, are not managed for the preservation of native species but for human activity and needs, e.g., agriculture.

To obtain an estimate of the protection afforded biodiversity on the wide spectrum of ownerships, land ownership was assigned one of four management status classes (Scott et al. 1993). Class 1 includes areas with active management plans that, through management, maintain or mimic natural disturbances. Most national parks, Nature Conservancy preserves, and some U.S. Fish and Wildlife refuges are included in this class. Management Status 2 areas are generally managed for natural values but receive use that may degrade the quality of natural communities. This class includes most wilderness areas. Most nondesignated public lands, including USDA Forest Service, Bureau of Land Management, and state parklands, fall into Class 3. These are multiple-use lands. Class 4, private or public lands without permanent conservation easements, are managed principally for human activity. Urban, residential, and agricultural lands are included in this class.

WILDLIFE-HABITAT RELATIONS MODELLING

Biologists have long used knowledge of an animal's habitat to predict its presence or absence. Traditional approaches to mapping animal distribution include (1) dot distribution maps; (2) grid-based maps; (3) hybrid dot distribution and range maps; and (4) range maps (Scott et al. 1993). These methods rely only on the location or observation of specimens and include no information on the ecological conditions, e.g., vegetation, that favor presence of the animal. Using vegetation as a surrogate to map presence or absence of animals has limitations but also provides enhancement over traditional mapping. Because the process does not rely only on known locality records, unsampled areas can be included in predicted models. Coupling known locations with those predicted from vegetation can lead to exceedingly refined maps of species distribution. Given sufficient samples, the distributions can be mapped as a series of probability estimates.

Several factors complicate the use of vegetation to predict species presence and absence (Scott et al. 1993). Birds, for example, respond more to vegetation structure than to floristics (Miller 1951, Cody 1985). Because Gap Analysis vegetation mapping relies principally on floristics rather than structure, bird distribution maps may contain error. Gap Analysis assumes that this error is reduced by defining vegetation classes with the structural characteristics necessary to the bird.

A second complicating issue is differences in habitat breadth. Some species, like coyotes (*Canis latrans*), are generalists in their habitat. Others are restricted to a single habitat type. If an animal is associated with a single type and that type can be mapped, Gap Analysis provides an excellent predictor of range. If the type cannot be mapped or is contained in another class, predicted range can be far from actual. Moreover, our ability to map habitat classes often exceeds the natural history information available for a species. For example, Holland (1986) recognizes 375 plant communities in California. Many of the vegetation units differ only in the ratio of dominant to associate plant species. Although of interest to botanists, these differences may or may not be of importance to animals. Thus, Mayer and Laudenslayer (1988) cross-walked the 375 plant communities into fifty-three wildlife-habitat classes.

Although the number of plant communities can be high, natural history data linking animals to specific

Table 1. Cover types and descriptions identified in the Utah vegetation base map. Description refers to series; cover type can be a compilation of >1 series.

Cover Type	Description
Alpine	Grass-*carex*; grass-forb-low shrub
Subalpine	
Spruce-fir	Engelmann spruce; subalpine fir
Lodgepole pine	Lodgepole pine
Montane lodgepole pine	Lodgepole pine; Douglas fir
Lodgepole pine woodlands	Lodgepole pine; subalpine fir; aspen; sagebrush
Montane fir	Douglas fir
Ponderosa pine	Ponderosa pine; Douglas fir; lodgepole pine; sagebrush; grass
Aspen	Aspen
Limber pine	Limber pine; bitterbrush
Bristlecone pine	Bristlecone pine
Pinyon-juniper	Pinyon pine; juniper; sagebrush; grass
Mountain brush	Maple; oakbrush; serviceberry; snowbrush; bitterbrush; mahogany
Tall sage	Sagebrush
Tall sage with trees	Sagebrush; all pines; all true firs; Douglas fir; aspen
Low sage with trees	Sagebrush; pinyon pine; juniper
Salt desert shrub	Shadscale; *Atriplex*; greasewood; grass; winterfat; saltgrass; horsebrush; pickleweed
Creosote-bursage	Creosote brush; bursage
Blackbrush	Blackbrush
Grassland	Grass
Marsh	Cattail
Canyon shrub riparian	Birch; alder
Cottonwood riparian	Cottonwood
Willow riparian	Willow
Mountain forb	Groundsel; mulesears; bluebell
Agriculture	
Urban-industrial	
Sand dunes	
Barren	
Open water	
Streams-rivers	

communities are sparse for most species, requiring that mapped habitats be grouped into categories that correspond to the known information about a species. For example, the best information on a bird species may be that it is associated with coniferous forests. Given that at least seven mapped classes in Utah contain conifers, the potential distribution for that species is exceedingly general.

Data on natural history of plants and animals are collected in a variety of formats of which the state natural heritage programs are the best example. These databases, called Vertebrate Characterization Abstracts (VCA), contain state-specific information on the ecological relationships of every vertebrate species in the state. Unfortunately, information in the database is often fragmentary and may reflect particular interests of the state program rather than a more systematic approach to a database. In contrast Utah has a more detailed data set based on the Multi-State Fish and Wildlife Information Systems (MSFWIS) database. Although similar in concept to VCAs, the MSFWIS contains more tabular information better suited to geographic distributions (Table 2).

Linking known ecological relationships with the vegetation map provides a spatial component to range mapping. Within Gap Analysis, two sets of information are needed to model animal distributions. These are the digital vegetation map and the wildlife-habitat association data linking particular species to mapped vegetation classes. This simple linkage provides a description of the predicted spatial location for each animal species in the database. Once identified the maps go through an additional screening to further refine the predicted distribution. This involves comparing the predicted distribution to more refined spatial data. One such source of information is county-of-occurrence maps, a frequently available data source, especially for birds.

Predicted distributions fail for several reasons. Reptiles, for example, are poorly predicted by vegetation (Scott et al. 1993), probably because reptiles respond more to climate than vegetation per se. Second, species associated with hydrologic regimes are grossly overestimated unless hydrology is incorporated as a linear string. Fossorial rodents, such as pocket gophers and ground squirrels, are also overestimated, presumably because Gap Analysis vegetation maps do not integrate soil characteristics very well. Last, rare species having localized distributions are also overestimated. Nonetheless, species range predictions from Gap Analysis exceed the resolution of existing range maps.

DISCUSSION

Gap Analysis is a method of identifying gaps in the protection of biodiversity at state, regional, and national scales. Although designed to identify "gaps" in the protective network, the data collected for Gap Analysis can serve numerous other purposes. In one sense, the data represent the first systematic compilation of data on biodiversity that transcends political boundaries. As such, the data are a useful starting point for other efforts designed to protect biodiversity. Some important applications include the ability to note temporal and spatial change in the extent and distribution of vegetation types. When coupled with information on other "stressors" such as air pollution or urban development (Noss 1990), Gap Analysis data layers can provide a stable planning and forecasting environment for assessing impacts of man-induced change.

The magnitude of the databases generated for Gap Analysis also underscores the need for greater cooperation among different management agencies. The databases are large, require trained personnel to manage, and no single agency or group can continue to update the information in the databases without cooperation from others. Moreover, given the cost of developing the database (approximately $300,000 per state), it would be a waste of limited conservation dollars to duplicate the database in all agencies. Ideally, agencies with different mandates would springboard from the base Gap Analysis data layers and refine the data to meet their specific needs.

Gap Analysis originated from the idea that a species-by-species approach to the loss of biodiversity is neither effective nor efficient. It ignores the principal reason for the loss of biodiversity, i.e., the continual loss and fragmentation of natural landscapes. Ideally, Gap Analysis data could provide a framework in which sound conservation planning could be developed and implemented. This planning will require, at an early stage, consideration of a nationwide network of core biodiversity management areas (Noss 1987). Sustainable human uses would occur in other wildlands that serve to buffer and link core biodiversity areas (Scott et al. 1990). The accelerating loss of biodiversity places great premium on approaches like Gap Analysis. These approaches provide a logical basis for evaluating and, ultimately, protecting national biological diversity.

Table 2. Data fields for the Utah Wildlife Information Network. Detailed descriptions for each data field can be obtained from the Division of Wildlife Resources, Salt Lake City, Utah.

- Taxonomy
  - Group
  - Common name(s)
  - Scientific nomenclature
  - Authority
- County Level Distribution
  - Historical
  - Resident
  - Nonresident
  - Seasonal
  - Distribution (%)
  - Abundance
  - Population
  - Harvest
- Administrative Units
  - USFWS-refuges
  - NPS-units
  - BLM-units
  - USFS-units
  - State-WMAs
  - Latilong data
- Ecological Baseline
  - Habitat associations
  - Forest associations
  - Animal/plant associations
  - Environmental requirements
  - Habitat suitability information
  - Guilding information
- Food Habits
  - Trophic information
  - General food habits
  - Important food habits
  - Information by life stage
- Status
  - Legal
  - Biological
  - Economical
  - Ecological
- Site-specific Data
  - Latitude-longitude
  - USGS quadrangle
  - Township/range/section
  - River reach
  - River mile
  - Other (e.g., UTM)
- National Map Standards
  - OWDC hydrologic units
  - USFS ecoregions
  - Potential natural vegetation
  - Land use/land cover
  - National wetland inventory
- Life History Information
  - Nesting/denning/spawning
  - Gestation/incubation
  - Clutch/litter
  - Territoriality/dispersion
  - Mortality/turnover rate
  - Limiting factors
- Management Practices
  - Adverse management practices
  - Beneficial management practices
  - Existing management practices
- References
  - Literature base
  - Species expert-credit

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