Mapping Land Cover and Animal Species Distributions for Conservation Planning: An Overview of the Southwest Regional Gap Analysis Program in Arizona

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Abstract. The Southwest Regional Gap Analysis Program will build upon previous gap analysis programs conducted in Arizona, Colorado, Nevada, New Mexico, and Utah to provide products that are consistent among areas of this large geographic region. The program will develop new land cover, vertebrate species distributions, and land stewardship data layers using a cooperative approach and similar methods across the five states. The three data layers will be seamless across the five state region, and detailed in resolution and content. The data layers will be used in a gap analysis to evaluate the conservation status of natural habitats and vertebrate species within and among all five states, and point out biotic elements needing further protection or management attention. The program will also provide region-wide digital map and database products that allow land managers, planners, scientists, and policy makers to make better informed land use decisions.

Key words: gap analysis, biodiversity, Southwest, Arizona, remote sensing, vegetation, land cover, wildlife habitat relationship models, GIS.

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BACKGROUND

Loss of biological diversity is a serious ecological problem, with a major cause being human action in the form of altering land use (Freedman 1989). Human-caused changes have accelerated extinction (Wilcove et al. 1998), which threatens biodiversity. With foresight, people can minimize further biodiversity loss due to human activity. One important tool is biodiversity gap analysis, which has been developed by geographers and biologists to map distributions of vertebrate species and vegetation communities and identify gaps in their protection (McKendry and Machlis 1991, Scott et al. 1993). This coarse filter approach can be used for conservation planning at the ecosystem level (Noss 1987).

Kepler and Scott (1985) found a gap in endangered Hawaiian honeycreeper protection on the island of Hawaii. They modeled the distribution of three honeycreeper species and compared maps of their distributions to determine areas of honeycreeper richness. Maps of existing nature reserves were then compared with the honeycreeper richness map to determine if reserves coincided with species-rich areas. As a result of their findings, the Hakalau Forest National Wildlife Refuge was established in one of the areas of highest honeycreeper richness, addressing the gap in protection revealed by their analysis (Scott et al. 1993). This study became the founding research for the National Gap Analysis Program.

The National Gap Analysis Program (GAP), initially housed within the U.S. Fish and Wildlife Service and now managed by the U.S. Geological Survey, has guided the subsequent development and application of biodiversity gap analysis throughout the nation and internationally. The Gap Analysis Program maps distributions of land cover (vegetation communities) and vertebrate species. These maps are overlaid in a geographic information system with maps of land stewardship (showing levels of biodiversity management) to identify biotic elements at potential risk of endangerment because of "gaps" in conservation management. A gap in conservation management is identified where a biotic element (vegetation community or animal species) is not present, or only occurs marginally in areas protected and managed primarily for biodiversity. One of the major goals of GAP is to provide consistent, periodic, regional assessments of the gaps in conservation management; in other words, to determine the conservation status of native vertebrate species and natural land cover types, and facilitate the application of this information to land acquisition, protection, and other management activities.

In this paper, we describe the second generation gap analysis in the Southwest, which builds upon the successes and shortcomings of previous work on gap analysis in the region. This effort, the Southwest Regional Gap Analysis Program (SW ReGAP), is being conducted as a multi-state effort between Arizona, Colorado, Nevada, New Mexico, and Utah. This five state region covers almost 140 million hectares with 21% of that, or almost 30 million hectares, within the state of Arizona. The project is developing the operational model for the next phase of biodiversity gap analysis projects in the west (Prior-Magee, SW ReGAP Coordinator, pers. comm.). In addition to much-improved resolution and accuracy of map products, important refinements within the regional effort are consistent land cover classification throughout the area, and seamless coverage of maps across political and agency management boundaries.

First Generation GAP – The State Model

Gap analysis has traditionally been conducted on a state-by-state basis, with first generation biodiversity GAP completed in 10 states. In the Southwest, first generation gap analysis programs were initiated in the early 1990s. A complete gap analysis and accompanying map products were published in Utah (Edwards et al. 1995) and New Mexico (Thompson et al. 1996). Partial map products were produced in Arizona (USGS WERC 2001) and Nevada. Colorado is currently finishing the first generation GAP products for their state (Schrupp et al. 2000).

The first generation Arizona project began in 1991. This effort, initially directed by Lee Graham of University of Arizona, Tucson, produced land cover, vertebrate distribution, and land stewardship maps in 1994. The USGS Sonoran Desert Field Station in Tucson, revised the initial Graham maps and plans on completing analysis for this first generation project. When published, their report will represent the first-ever detailed maps on a state-wide level of biotic elements and their conservation status.

State boundaries rarely coincide with ecological units. The island ecosystem of Hawaii was convenient for mapping and conducting gap analysis because of the island's boundaries. However, a continental ecosystem such as the Colorado Plateau has fuzzy boundaries and may span several states, making mapping and conducting a gap analysis more difficult on a state-by-state basis. Gap analyses confined to a state's boundary tend to give incomplete or biased results when taken in the context of an extensive ecosystem. For example, a species may be rare in a state only because it is at the edge of its range. To recommend protection for this species in one state, when it is common in adjacent states, is not accounting for the regional nature of the distribution. For this reason, strategies to manage for the long-term maintenance of biodiversity are better focused on the characteristic biota of larger regions (Noss 1983).

Individual state GAP maps have proven difficult to merge into regional representations. State data layers typically have different classification systems, such that similar vegetation types are given different names in each state. This necessitates a cumbersome process to merge the types among the different classifications, followed by a cross-walk to the least detailed classification.

In addition to classification problems, another edge-matching issue arises when the resolution of the data layer differs between states. The use of different primary data sources and methods to derive polygons can create maps that have different spatial properties across state lines. An ecoregional land cover map was created for the Mojave Desert using portions of the first generation Arizona, California, Nevada, and Utah GAP maps. The resulting ecoregional land cover map shows striking differences in map unit delineation across state lines (Fig. 1). The map unit inconsistencies could be due to source imagery resolution differing between the states because the Arizona, Nevada, and Utah projects used Thematic Mapper imagery with 30 meter pixel resolution, while the California project used Multispectral Scanner imag-

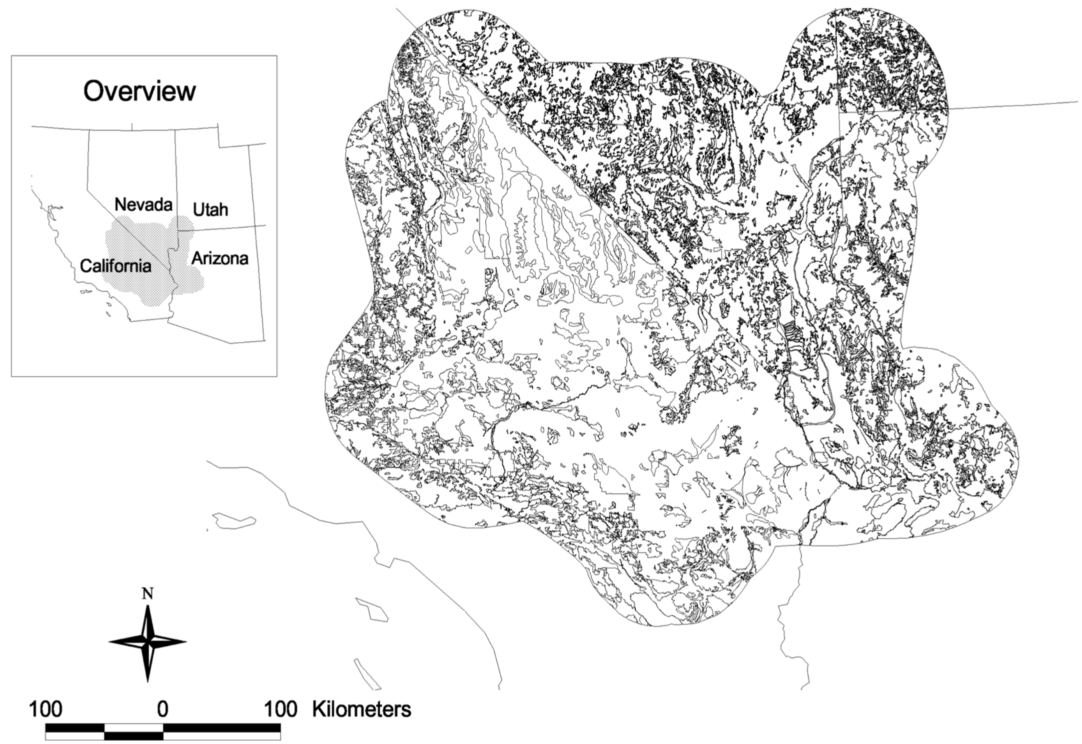

Figure 1. Mojave Desert Ecoregion Project land cover map (MDEP 1998) showing map unit inconsistencies across state boundaries.

ery with 80 meter pixel resolution. The different resolutions of the base imagery layer and available technology produced land cover maps with different resolutions (100 ha in California vs. 40 ha in Arizona).

Differences in spatial properties of land cover map units can introduce error in predictions of vertebrate species distributions, where distributions are modeled using the land cover map. Uneven map units can result in errors of omission or commission in predicted species' occurrence.

Another motivation for second generation GAP studies is that gap analysis was designed to be repeated at approximately 10-year intervals, in order to provide periodic reassessment of the distribution of biota and their conservation management. Changes in distribution of land cover and vertebrate species may occur due to naturally occurring disturbances (e.g., fire or flood), direct human disturbance (e.g., land clearing), or from the indirect effects of human activities (e.g., global warming).

This second generation gap analysis in the Southwest will provide an updated view of current conditions, and is specifically designed to utilize a regional model. This will correct some of the problems that arose from the state model, such as the poor match across state boundaries of vegetation classification, map unit spatial discontinuity, and lack of a regional gap analysis.

Second Generation GAP – The Regional Model

The Southwest Regional Gap Analysis Program is multi-year, and will create land cover, vertebrate species distributions, and land stewardship data layers. This effort will conduct a gap analysis conservation assessment for each state and for the entire five-state region. Some remote sensing and animal modeling activities will be conducted by regional teams for the benefit of all participating states. State projects will collect distribution data, create models and map labels for their state, and coordinate with regional teams. A regional project coordinator will facilitate activities among regional teams, state projects, and federal agency offices.

The project in Arizona will produce data layers that support a well-documented gap analysis conservation assessment throughout the state. These data and analyses will be readily available to land and resource managers, whether private, tribal, state, or federal. The project in Arizona is being coordinated by the USGS Forest and Rangeland Ecosystem Science Center, Colorado Plateau Field Station, in Flagstaff.

While Arizona, Colorado, Nevada, New Mexico, and Utah have previously conducted a gap analysis, vast improvements in technology and cooperative efforts will make this project more fruitful than first generation projects. The project will address the inconsistencies of methodology, information, classification, resolution, and expertise to produce seamless data layers across state boundaries for the Southwest.

METHODS

Mapping Land Cover

A consistent approach to mapping land cover is essential for success of a regional gap analysis. A seamless land cover map for the region will contribute to vertebrate species distributions and gap analyses that encourage an ecoregional approach to land management.

National Vegetation Classification

In previous GAP projects, each state had its own accepted standard of vegetation classification, which often did not correspond with neighboring states. The regional project will use a standardized classification system, the National Vegetation Classification (NVC; Grossman et al. 1998), to ensure classification consistency across the region and to retain an acceptable level of detail. In 1997, the Federal Geographic Data Committee recommended the that NVC become the standard for all federally funded vegetation mapping projects (FGDC 1997). Since that time, National GAP has sponsored the development of vegetation type (alliance) descriptions so as to provide a consistent, repeatable classification system across state and administrative boundaries.

The NVC is regarded as a major step toward enhancing our ability to understand, protect, and manage the natural resources of the United States. It provides a hierarchical framework for describing vegetation, and a convention for identifying and naming additional vegetation types. The first five levels of the hierarchy are based on physiognomic characteristics of the vegetation, and the last two levels are floristic (Table 1). A set of 105 preliminary alliance descriptions have been developed for Arizona, but it is expected that the project will expand and further identify and define alliances for Arizona. As an example, 15 preliminary alliances have been de-

Table 1. Hierarchy of the National Vegetation Classification.

Level	Primary Basis for Classification	Example
Class	Growth form and structure of vegetation	Woodland
Subclass	Growth form characteristics, e.g., leaf phenology	Evergreen woodland
Group	Leaf types, corresponding to climate	Temperate or subpolar needle-leaved evergreen woodland
Subgroup	Relative human impact (Natural/semi-natural, or cultural)	Natural/semi-natural
Formation	Additional physiognomic and environmental factors, including hydrology	Rounded-crowned temperate or subpolar needle-leaved evergreen woodland
Alliance	Dominant/diagnostic species of uppermost or dominant stratum	*Pinus ponderosa* woodland alliance
Association	Additional dominant/diagnostic species from any strata	*Pinus ponderosa/ Quercus gambelii* woodland

scribed for the relatively small region of Sunset Crater National Monument and environs (7,600 ha) in northern Arizona (Table 2).

The target of SW ReGAP is to map land cover to the alliance level, at 5-hectare spatial resolution. This is a fine resolution and level of floristic detail that has not yet been accomplished in a land cover mapping project of this size. Where distinction between alliances is not possible, due to the ecological complexity or difficulty in remotely sensing or modeling the vegetation type, groups of alliances, known as ecological complexes or compositional groups, may be used for map labels. The Association of Biodiversity Information, responsible for creation and maintenance of the NVC for the United States, will coordinate application of the NVC across the five states to promote the consistent development and application of map labels.

Table 2. Preliminary NVC alliances for Sunset Crater National Monument and environs, Arizona (Thomas et al. in prep).

Class	Alliance
Forest	*Pinus edulis* Forest Alliance
Forest	*Pseudotsuga menziesii* Forest Alliance
Woodland	*Pinus edulis* - (*Juniperus* spp.) Woodland Alliance
Woodland	*Pinus flexilis* Woodland Alliance
Woodland	*Pinus ponderosa* Woodland Alliance
Woodland	*Populus tremuloides* Woodland Alliance
Shrubland	*Ericameria nauseosa* Shrubland Alliance
Herbaceous	*Andropogon hallii* Herbaceous Alliance
Herbaceous	*Bouteloua gracilis* Herbaceous Alliance
Herbaceous	*Muhlenbergia montana* Herbaceous Alliance
Herbaceous	*Pascopyrum smithii* Herbaceous Alliance
Herbaceous	*Pinus ponderosa* Wooded Herbaceous Alliance
Sparse	*Eriogonum corymbosum* Sparsely Vegetated Alliance
Sparse	*Fallugia paradoxa* Sparsely Vegetated Alliance
Sparse	Lava Bed Sparsely Vegetated Alliance

Processing of Satellite Imagery

Most GAP projects used Landsat Thematic Mapper satellite as the base imagery layer. Also, previous GAP projects have used only one date of imagery per scene to keep costs low. However, this limited the ability to distinguish between land cover types, resulting in more generalized land cover classes. Methods for delineating land cover classes from satellite imagery have included photo interpretive techniques, supervised and unsupervised clustering, and modeling using ancillary data sets (Eve and Merchant 1998). However, the application of various techniques inconsistently across the landscape has produced different map unit boundaries, and caused edge-matching problems across state boundaries.

This project will use three dates of imagery in 1999, 2000, or 2001 from the latest earth-observing satellite, Landsat 7 Enhanced Thematic Mapper Plus. This imagery will be preprocessed (i.e., georectified and cleaned) and clustered by a regional remote sensing team. Preliminary cover types, using plot data supplied by each state and previous land cover maps, will then be assigned to the cluster map. Preliminary clusters will be given NVC vegetation type labels at the state level. The project in Arizona will use predictive modeling with ancillary data sources (e.g., elevation, slope aspect, precipitation, and soils) and focused field verification (i.e., labeling of individual polygons) for final cluster map labeling. The regional remote sensing team will then create a single land cover data layer for the entire Southwest region from individual state data layers.

Mapping Zones

Previous projects have mapped land cover on a satellite scene-by-scene basis (Eve and Merchant 1998). These scenes may contain a wide variety of ecological conditions and can cause confusion in delineating land cover types, leading to a land cover map that does not provide detailed floristic information. In this project, we will use vegetation-based mapping zones to maximize information extraction by separating imagery into more homogeneous areas prior to classification (Fig. 2). This will allow our classification to focus on a smaller set of land cover types, which will reduce variation and improve classification results (Homer et al. 1997). Our proposed mapping zones have been delineated primarily based on elevation, latitude, and longitude, which are important factors in the regional zonation of vegetation throughout the Southwest.

Each of the five states will be responsible for mapping zones that fall completely or partially within that state. Where a zone overlaps state boundaries, one state will take primary responsibility for mapping that zone, with the other state(s) providing logistical support and information. Each state project will collect existing and new field data for mapping zones, model specific vegetation/environmental parameters, work with the regional remote sensing team in developing cluster images, and provide final labeling of the land cover types in their assigned mapping zones.

The Arizona project has primary responsibility for classifying 11 of 73 regional mapping zones, an area of about 26 million hectares (19% of the region), and will contribute to land cover mapping in five shared zones. For each shared mapping zone, Arizona will coordinate with the adjoining state project(s) to map the overlapping areas. When land management crosses state and mapping zone boundaries, such as the Navajo Nation in the Four-Corners area, one state project will take the lead to coordinate with involved land manager.

The ecological labeling rules for vegetation types will be consistent within mapping zones. However, they may vary across mapping zones because of real differences in cover type distribution characteristics. For example, the elevation range of the "Pinyon Woodland Alliance" (Reid et al. 1999) will be higher in the Hualapai mapping zone in Arizona than in a mapping zone in Utah due to latitudinal changes. Farther north, the pinyon cover type occurs at lower elevations. We are ensuring consistency in applying map labels through periodic meetings with the state projects,

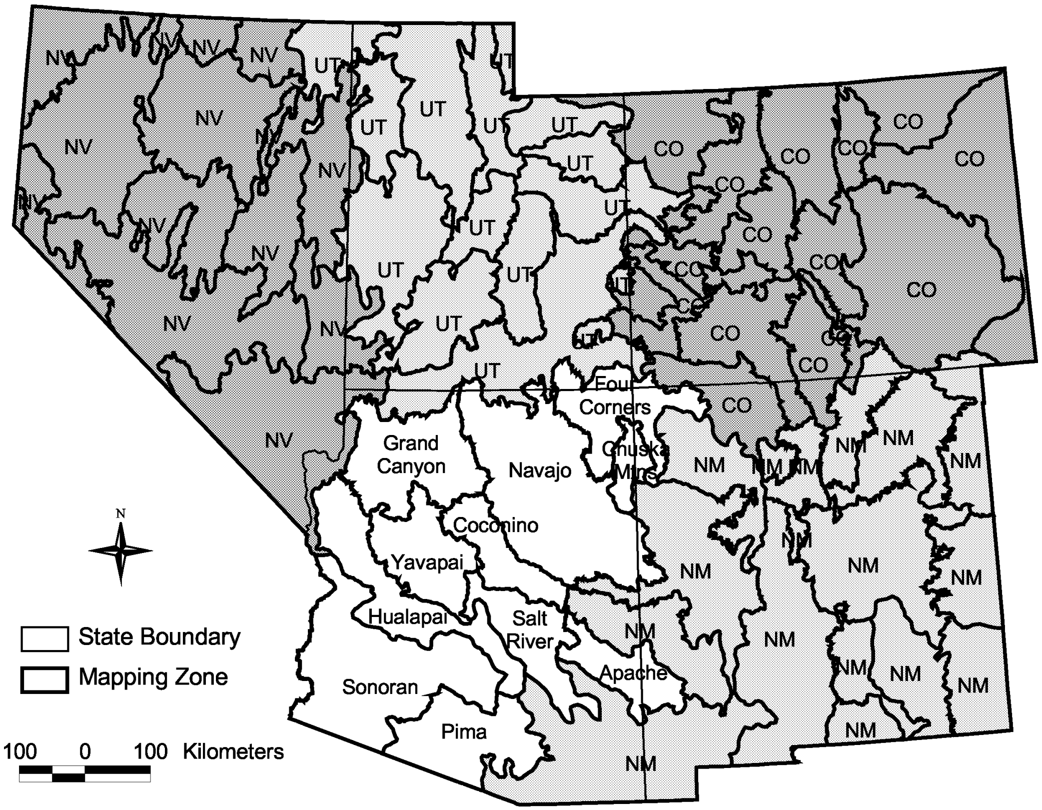

Figure 2. Mapping zones for SW ReGAP. Zones are labeled with a descriptive name in Arizona. Elsewhere, they are labeled with the state responsible for mapping the zone.

and by overview of map label application by the Association of Biodiversity Information and regional remote sensing team.

Vertebrate Species Distribution Maps

The regional project will model predicted distributions of each vertebrate taxon that resides, breeds, or uses habitat in the five-state Southwest region for a substantial part of its life history, including winter range and important migration stopovers. In addition to native species, the project will model subspecies of particular interest and widespread non-native species. There are approximately 960 vertebrate taxa within the region, and the Arizona project will model the distribution of approximately 570 taxa. A regional animal modeling team will be responsible for resolving differences in models of taxa that cross state boundaries.

Previous GAP projects developed vertebrate distribution models based on literature sources (USGS GAP 2000). Similarly, our project will construct wildlife habitat relationship models (WHRMs) from the best available literature on the distribution and habitat associations for each species, maintaining consistency with the traditional GAP approach to vertebrate distribution modeling. In addition, our project will use field information in a data-driven approach of distribution modeling for select groups of taxa. This process will be used for passerine birds and possibly other groups, depending on the availability of sufficient field inventory data. Primary data sources for birds will be breeding bird survey data (Sauer et al. 1999) and breeding bird atlas data currently being gathered for the state of Arizona (McCarthey et al. 1995). This data-driven approach will use correlation of georeferenced taxa location data (e.g., from census plots) with maps of habitat features (e.g., elevation and land cover type) to extract the WHRM.

The WHRMs will be applied to maps of habitat features to produce distribution maps indicating known, probable, and possible presence of each vertebrate taxon within its geographic range. Models produced from the data-driven approach will be compared with the traditional GAP approach to evaluate and then resolve any apparent differences.

Land Stewardship Map

Land ownership often does not cross state boundaries. However, in certain cases, such as tribal and federal lands, land ownership does cross state boundaries and will be mapped as such. In addition, the five states will cooperate to apply a consistent definition of land stewardship across the region.

Land stewardship of public and private land has traditionally been categorized by a four-level rating (Table 3). For the Arizona project, the first generation GAP land stewardship map will be used as a starting point; however, changes in land ownership and management are expected, and the land stewardship data layer will require an extensive update. Digital parcel boundaries will be obtained from each county within Arizona in order to refine the stewardship map resolution. Each tract will be attributed for land ownership, managing institution, and management status. A

Table 3. Biodiversity management status categories used in the land stewardship map (USGS 2000).

Status	Description
1	An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management
2	An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance
3	An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area
4	There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout

substantial effort will be made to identify and contact all known conservation land owners and/or managers holding tracts at least as large as the minimum resolution size (16 ha) in order to verify stewardship status of that land tract.

State and Regional Gap Analyses

The conservation gap analysis consists of intersecting land cover and vertebrate distribution maps with the stewardship map, and calculating the amount of each vegetation type and vertebrate species distribution in each land stewardship category. This analysis will identify important gaps that have potential for mitigation by land stewards (USGS 2000). The analysis will consist of two steps: individual state analyses and a regional analysis. This will allow land stewards to better assess their role and responsibility for biota occurring on their lands, and in the greater context of the Southwest.

ANTICIPATED RESULTS

The Southwest Regional Gap Analysis Program will provide detailed, spatially explicit information on the distribution and management status of each mapped vertebrate species and vegetation community within the greater Southwest region.

Map products and conservation analysis results will be released in the beginning of 2005 (Table 4). Preliminary products are expected to be available in 2004 for examination and comment.

Table 4. Products from Southwest Regional Gap Analysis Program in Arizona.

Product	Format	Outlet
Land Cover Map	ArcGIS layer	CD and website
Terrestrial Vertebrate Species Distribution Maps	ArcGIS layers	CD and website
Land Stewardship Map	ArcGIS layer	CD and website
Wildlife Habitat Relationship Models	Microsoft Access database and metadata	CD and website
Final Report for Arizona	Report	Technical Report
Final Report for the Southwest Region	Report	Technical Report

Important advances with this regional project for the Southwest include much finer resolution (5 ha) land cover mapping, use of a consistent vegetation classification system (NVC) at a fine level of detail, and coordinated mapping to eliminate edge-matching problems across state boundaries. Vertebrate distribution models will be developed based on comprehensive syntheses of information on habitat and distribution, and recent inventory data. Development of vertebrate distribution models will make specific use of detailed accuracy assessment of earlier GAP distribution models.

With the regional information base resulting from this project, decisions about human activities that affect biodiversity can be made with specific reference to scientific data on distribution of biota over entire landscapes and ecoregions. The application of a regional model will allow data users interested in locally-occurring plant communities or vertebrate species to evaluate species status in the context of a watershed, ecoregion, national range, or ultimately continental and global range (Crist and Jennings 1997). Cooperative planning among neighboring land managers (e.g., Bureau of Land Management, National Park Service, U.S. Forest Service, state lands, and private land owners) will benefit from the consistency afforded by the regional land cover and vertebrate distribution maps. In this way, products of this project will provide an important tool for management and conservation planning in the varied ecosystems of the Southwest.

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