Dedication

To Edward T. LaRoe III.

Deceased

Here’s to the first of many, Ted!

Acknowledgments

Efforts such as Gap Analysis belong to no one person. They derive their strength from the interactions of motivated, energetic and innovative individuals, pushing forward the frontier of science even when those interactions become tense and troubled. In Utah, I have been fortunate to share the frustrations, anger and joy of numerous dedicated individuals and organizations who have explicitly and implicitly supported the effort.

I begin by extending my thanks to the numerous technicians, Rick Baker, Nathan Bentley, Marye Jane Crandall, Greg Crosby, David Early, Kent Hirschi, Paul Meyers, Matt McCune, Dan Morgan, Lisa Morris, Lorraine Munguia, Bill Ostrand, Aaron Price, Kevin Sherman, Janene Shupe, Manjula Vangipuram, and Robert Washington-Allen, who ably assisted in the synthesis of the Gap Analysis information. Many of the tasks you performed were simple, repetitive and, to be honest, quite boring. You nonetheless cheerfully completed them all, presenting me with quality information within the impossible time lines I demanded. Every one of you has the right to be proud of your contribution to this effort, and I thank you for your help.

As a process, Gap Analysis relies heavily on collaboration with Federal, State and non-government agencies. I have been fortunate to receive help and expert advice from a variety of sources. From the Utah Division of Wildlife Resources, Dan Foster, Wes Johnson and Catherine Quinn all provided guidance in the development of the wildlife-habitat relations models that figure so prominently in Utah Gap Analysis. I further appreciate the patience, which I sorely tested, they demonstrated while waiting for the completion of our efforts. Julie Romney of the USDI Bureau of Land Management, Utah State Office, helped us obtain information and advice from BLM contacts throughout Utah. John Hutchinson and Tom Loveland of the USGS Eros Data Center, and Jack Whitman of the USGS National Mapping Division, all contributed to our effort. In particular, the maps that John and Jack helped develop, and which are found in this report, reflect highly on the USGS and demonstrate how sister federal agencies can interact positively with one another.

Staff from the USDA Forest Service Region 4 have supported this effort from the beginning, providing much appreciated advice regarding plant ecology in the Intermountain West. Principal among these is Doug Meyers, who helped coordinate advice from we obtained from the many plant ecologists in the Forest Service. I also thank Doug for his efforts in obtaining funding for our accuracy assessment of the cover-map, which greatly enhanced the scientific defensibility of our product. Additional funding for the accuracy assessment came from Henry Lachowski, USDA Forest Service Geometronics Lab. Larry Deblander and William Dunning of the Forest Service deserve special mention for their dedicated efforts in aerial interpretation. The training points they obtained via photo interpretation were critical to our vegetation modelling process. Theresa Swietech, a USDA Forest Service Cooperative

Education student, was instrumental in helping to develop an approach for modelling riparian areas in the state. Last, I owe a great deal to of appreciation to Dave Winn, much more than I can express here. His critical questioning of our modelling processes, and his gentle reminders that our product needed to have applicability to the management world or it would not be used, greatly improved our efforts. In particular, he stimulated much discussion on methods to transfer our information to field biologists in a manner that it would be used, a critical aspect many of us in research unfortunately forget. Thanks, Dave.

The USDA Forest Service Intermountain Research Station assisted us in the assessment of the uncertainty of our information. Dave Born, working in conjunction with Doug Myers, provided valuable information on plant ecology in his quirky way. Dave was a tireless supporter of Gap Analysis and played a lead role in designing and implementing protocol by which USDA Forest Service and BLM field crews provided Utah Gap Analysis with ground training information used in mapping cover-types. His dry sense of humor throughout this entire process helped us through some tense situations. I am grateful to Duane Van Hoser and Renee O'Brien of the Research Station for allowing Gretchen Moisen release from her duties to work with me on statistical methods for assessing the uncertainty of our information. Gretchen developed a statistically sound but logistically simple approach to assessing uncertainty of a map containing over 21 million sample units, in the process publishing several excellent papers and forcing me to reject my long-held hypothesis that most statisticians have little grasp of a world outside their arcane mathematical formulae. It is a shame she prefers tequila to scotch!

Many colleagues at the College of Natural Resources (CNR), Utah State University (USU), supported our effort over the past several years, from the level of Joe Chapman, Dean CNR, to Ray Dueser, Head, Fisheries and Wildlife. Doug Ramsey, Geography and Earth Resources, aided in the image processing used to develop the cover-map and was always available for technical discussions. Doug Wight invested a tremendous amount of his personal energy into the CD-ROM format, our principal means of transferring Gap Analysis information to the user community. Others in the CNR Remote Sensing/Geographic Information Systems Lab, including Nate Bentley, Brian Biggs, and Andy Rakowski, all helped provide the collegial atmosphere so important to the success of major research efforts like Gap Analysis. To Allan Falconer, Head, Geography and Earth Resources, I, and the Gap Analysis effort in general, owe a great deal of gratitude. More than anyone else, he stimulated thinking on how best to convert the necessarily complex Gap Analysis information to user-friendly formats. He brought to Utah Gap Analysis his vision of translating our scientific information into a structure that was accessible and interpretable by the variety of constituents with whom we interact. His actions epitomize the terms colleague and collaborator.

Numerous individuals in the National Biological Service contributed to this project. Connie Walker, Division of Cooperative Research, deserves special thanks for maintaining her sense of humor in the face of money-hungry Principal Investigators like myself. She protected us from unnecessary paperwork and was always available to ensure my accounting was correct. John Bissonette, Unit Leader, provided an atmosphere in the Unit supportive of my research. He allowed me the flexibility to pursue my ideas without stifling oversight, but was always available for consultation when needed. Ted LaRoe, since deceased, was Gap Analysis' most ardent supporter and fought most of the battles for us in Washington, D.C. His vision of Gap Analysis' potential for use in resource management decisions is the basis for our success. As for Mike Scott, I am not sure where I can begin or what to say. Credit for these ideas goes to you, Mike, and I am proud to be one of the first to deliver a completed Gap Analysis product. P.S. I am finally finished, Mike, so you can stop worrying!

Staff at the Environmental Systems Research Institute (ESRI) were instrumental in preparing our final product. They helped review the interactive models used in the CD-ROMs contained in this package, assisted in the design and printing of our artwork and report, and provided critical review of our AMLs, thereby ensuring our CDs were compatible with the many different computer platforms used by the clientele of Gap Analysis.

Scott Bassett and Collin Homer, my two principal Research Associates at USU, were my support and rightly deserve most of the credit for Utah Gap Analysis. Scott cheerfully accepted every programming challenge I presented, delivering results in time frames that I still find astonishing. No challenge seemed too large for him. Collin is responsible for the cover-map so central to Utah Gap Analysis. He sifted through an amazing amount of material, synthesizing a cover-map for which he and the Gap Analysis program can be proud. In addition, he undertook the oversight of our many technicians, training and mentoring them while ensuring they completed their work in timely fashion.

More than any single individual, I owe a profound debt of gratitude to Collin. His steadfastness, sense of humor, and pragmatism moderated with a healthy dose of skepticism kept me honest even when it seemed "pragmatic" to cut corners. Thank you, my friend.

Thomas C. Edwards, Jr.
17 February 1995

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Chapter 1

Introduction

> *I dreamt of being a geographer but*
> *found the subject too complex.*
> *So I switched to physics.*
>
> *A. Einstein*

Background

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 near 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, failure to develop and implement recovery plans in a timely fashion, and 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 towards "charismatic megafauna" having broad public appeal (Pitelka 1981, Scott et al. 1987, Noss 1991). Last ditch efforts also contribute to economic conflict because they fail to provide a reasonable planning framework for economic interests. While necessary, these efforts need to be complemented with more proactive methods that attempt to maintain species and ecosystems while they are still common (Scott et al. 1987*a*, Scott et al. 1993).

Maintenance of biodiversity is the concept around which new concerns about biological conservation are centered. Calls for the maintenance of biodiversity are an explicit recognition that biological loss occurs at all levels of biological diversity and that efforts to maintain this diversity must be applied to all levels, not just endangered species (Noss 1991, Scott et al. 1991). One approach for assessing the current status of biodiversity at all levels, not just endangered species, is called Gap Analysis. As an evaluation process, it provides a systematic approach for determining the protection afforded biological diversity 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, Edwards et al. 1993, Edwards and Scott 1994).

Gap Analysis includes four primary GIS layers: (1) the distribution of actual vegetation cover types delineated from satellite imagery and ancillary data; (2) land ownership; (3) land management status; and (4) distributions of terrestrial vertebrates as predicted from the distribution of vegetation and known observations. Within the GIS, overlays of animal distribution and land ownership can be used to estimate the relative extent of protection afforded cover-types and vertebrate animals. Gap Analysis also functions as a first pass approach for organizing biological information. Depending on the nature of the issue, the Gap Analysis information can be used as a basis for other, more detailed studies. It is meant to be used as a proactive rather than reactive management tool.

The Gap Analysis Concept

Gap Analysis provides an overview of the distribution and conservation status of several components of biodiversity. It uses the distribution of actual vegetation types (hereafter cover-types) and terrestrial vertebrate and, when available, invertebrate taxa as indicators of, or surrogates for, biodiversity. Digital map overlays in a GIS are used to identify individual species, species-rich areas, and cover-types that are unrepresented or under-represented in existing management areas. It functions as a preliminary step to the more detailed studies needed to establish actual boundaries for potential biodiversity management areas. Gap Analysis, by focusing on higher levels of biological organization, is likely to be both cheaper and more likely to succeed than conservation programs focused on single species or populations (Scott et al. 1993).

Biodiversity inventories can be visualized as "filters" designed to capture elements of biodiversity at various levels of organization. The filter concept has been applied by The Nature Conservancy, which has established Natural Heritage Programs in all 50 states, most of which are now operated by state government agencies. The Nature Conservancy employs a fine filter of rare species inventory and protection and a coarse filter of community inventory and protection (Jenkins 1985, Noss 1987). It is postulated that 85-90% of species can be protected by the coarse filter, without having to inventory or plan reserves for those species individually. A fine filter is then applied to the remaining 15-10% of species to ensure their protection.

The intuitively appealing idea of conserving most biodiversity by maintaining examples of all natural community types has never been applied, although there exist numerous approaches to the spatial identification of biodiversity (Bolton and Specht 1983, Kirkpatrick 1983, Margules and Nicholls 1988, Pressey and Nicholls 1991, Nicholls and Margules 1993). Furthermore, the spatial scale at which organisms use the environment differs tremendously among species and depends on body size, food habits, mobility, and other factors. Hence, no coarse filter will be a complete assessment of biodiversity protection status and needs. However, species that fall through the pores of the coarse filter, such as narrow endemics and wide-ranging mammals, can be captured by the safety net of the fine filter. Community-level (coarse filter) protection is a complement to, not a substitute for, protection of individual rare species.

Gap Analysis is essentially an expanded coarse-filter approach (Noss 1987) to biodiversity protection. The cover-types mapped in Gap Analysis serve directly as a coarse filter, the goal being to assure adequate representation of all types in biodiversity management areas. Landscapes with great vegetation diversity often are those with high edaphic variety or topographic relief. When elevational diversity is very great, a nearly complete spectrum of vegetation types known from a biological region may occur within a relatively small area. Such areas provide habitat for many species, including those that depend on multiple habitat types to meet live history needs (Diamond 1986, Noss 1987). By using landscape-sized samples (Forman and Godron 1986) as an expanded coarse filter, Gap Analysis searches for and identifies biological regions where unprotected or under-represented cover-types and vertebrate species occur.

A second filter is based on identifying areas of high species richness (i.e., areas of maximum overlap in the ranges of mapped species) and centers of endemism. Although most species will be represented in a set of areas of high species richness, some otherwise widely distributed species, such as large carnivores, may require individual attention. Species with very local or restricted distributions may not occur in areas of high species richness and also may require individual protection. Additional data layers can be used for a more holistic conservation evaluation. These include indicators of stress or risk (e.g., human population growth, road density, rate of habitat fragmentation, distribution of pollutants) and the locations of habitat corridors between wildlands that allow for natural movements of wide-ranging animals and migration of species in response to climate change.

The indicator concept assumes that the attributes being measured, in this case, cover-types, vertebrate, and invertebrate distributions, correspond to a broader "endpoint" of overall biodiversity (Noss 1990). Vegetation is one of the most widely used indirect indicators of the distribution of terrestrial plant and animal species (Austin 1991). Although a number of microhabitat features and other abiotic and biotic factors determine the ultimate suitability of a site for a species, the composition and structure of the dominant vegetation is an important and easily described measure of habitat, especially for animals. A problem with using vegetation as a coarse filter in long range planning, however, is that plant communities break up and assemble in new combinations as species respond individually to climate change (Hunter et al. 1988, Hunter 1991), and that vegetation is usually defined by the distribution of dominant species, most of which are habitat generalists. Use of broadly defined cover-types to identify important sites of biodiversity can lead to the inadvertent exclusion of other components plant diversity (Pressey and Bedward 1991) and should be recognized in any biodiversity analysis.

Crumpacker et al. (1988) conducted a Gap Analysis of Potential Natural Vegetation (PNV) (Kuchler 1964) in the conterminous United States. They assumed that Federal ownership equaled land protection, an assumption that Scott et al. (1993) believe must be qualified. However, even with this optimistic assumption, they found that one fourth of the PNV types in the United States were inadequately represented on Federal or Indian lands. To the extent that PNV types reflect the current vegetation in an area, they are valuable indicators of biodiversity. However, many areas have been more or less permanently converted to human uses (i.e., urban and agricultural areas) or subjected to management practices that have altered plant community structure and composition (i.e., forests and range lands). In such areas, animals respond to actual vegetation, not PNV.

Prior to Gap Analysis there was no broad-scale assessment of the protection given actual vegetation types or areas of high species richness in the United States or, more specifically, Utah. A Gap Analysis conducted by Scott et al. (1987*b*) in Hawaii focused on distributions of endangered forest birds. When compared with a map of the existing reserves, <10% of the ranges of endangered forest birds were protected. Several of the areas of high endangered bird species richness have since been protected by The Nature Conservancy and State and Federal agencies (Scott et al. 1987*b*).

Gap Analysis products include maps and tables summarizing the predicted distribution and conservation status of vegetation types and terrestrial vertebrate species. They also include a conservation evaluation identifying cover-types and animal species unrepresented or under-represented in biodiversity management areas. Representation of threatened, endangered, and other species of concern in biodiversity management areas also is evaluated. These products can be used to develop an integrated biodiversity conservation strategy (Scott et al. 1991). Assuming that it is in society's best interest to maintain biodiversity and avoid endangering ever more species, Gap Analysis products can be used to predict the contribution of new biodiversity management areas, or to identify existing areas where management practices can be changed, to the goal of maintaining biodiversity.

Objectives

Here we describe the approach used to perform Gap Analysis in Utah. We outline the processes used to model, map and test the accuracy of our mapped cover-types, land ownership, and the wildlife-habitat relations data used to model distributions of terrestrial vertebrates. Sequentially, our process flows through the development and assessment of our cover map (Chapter 2); the creation of the biodiversity management area and land ownership maps (Chapter 3); synthesis of the wildlife-habitat relations data for the terrestrial vertebrates, and their subsequent linkage to the cover-map, and an assessment of our models (Chapter 4); and a simple analysis of the protection of biodiversity in Utah (Chapter 5). Literature cited is found in Chapter 6. Each chapter is supported by relevant data dictionaries and appendices. Last, we close with a short description of methods by which the Utah Gap Analysis information may be obtained via electronic media (Chapter 7).

Chapter 2

Vegetation Classification and Mapping

The symbol is NOT the thing symbolized;
the word is NOT the thing;
the map is NOT the territory it stands for.

S. I. Hayakawa

Background

Numerous vegetation classification systems exist and are used in the United States (e.g., Driscoll et al. 1984, Brown et al. 1980, Kuchler 1964). These schemes represent attempts to group vegetation into classes based on factors such as structure, taxonomy or evolutionary history. Implicit in the classification of vegetation is the assumption that vegetation acts as an indicator of most of the physical and biological attributes of an area, and that it can be used as a surrogate for ecosystems in conservation evaluations (see Specht 1975, Austin 1991).

Methods of mapping vegetation vary (see Kuchler and Zonneveld 1988), and selection of a specific mapping method is largely goal-specific. Within Gap Analysis, vegetation acts principally as the surrogate for predicting distributions of terrestrial vertebrates through linkage with wildlife-habitat relation (WHR) models (see Chapter 4). Mapping of vegetation also provides a baseline for conservation efforts directed towards plant communities. Although several different vegetation mapping methods have been applied to Gap Analysis thus far (Ramsey et al. 1992, Kautz et al. 1993, Davis 1994), all methods share the following properties: (1) vegetation types must be discriminated from satellite imagery and/or aerial photographs; (2) mapped types must be linked with existing wildlife-habitat relation data bases; (3) types must encompass seral as well as climax vegetation; and (4) types developed in one state must be complimentary with neighboring states (Scott et al. 1993).

Large study areas requiring the spatial resolution of Landsat TM data, such as states or ecoregions like the Great Basin, invariably require multiple scenes. Classification and analysis of multiple TM scenes can be carried out individually or as multi-scene mosaics. Individual, or single scene classification potentially offers more accuracy for mapping vegetation cover-types because of reduced pixel sample size and variability (Homer et al. 1993). However, single scene independent classification within a multi-scene region can require a greater investment in time and money. More ground training sites are often required for cover-type associations because scene boundaries are arbitrary from an ecological perspective. Further, this method potentially requires extensive post-classification edge matching to other independently classified scenes. Conversely, multi-scene mosaic classification can minimize post-classification edge matching and maximize use of ground training sites for ecologically similar areas located in different images. One possible disadvantage to a mosaic is the increased variability of multi-scene spectral data and potentially higher confusion between spectrally similar cover-types. Regardless, a multi-scene classification strategy offered the best solution to our mapping objectives, allowing for maintenance of relatively fine spatial and vegetation description levels for Utah, an area 212,181 km^2 in size.

Here we present an overview of the methodologies used to develop a multi-scene cover-type/landuse map (hereafter cover-map) for the state of Utah. Criteria important to the development of a cover-map for conservation planning in Utah included the need for: 1) a non-scalar map usable from the minimum data resolution (30 m pixel) and up; 2) the preservation of a complete lineage for each pixel from raw data to finished classification, offering future advantages in updating, consistency and repeatability; 3) the creation of a stand-alone digital classification not requiring extensive input from existing vegetation maps; 4) a relatively short completion time frame of 2-3 years; 5) the optimization of limited resources for training site collection and; 6) seamless results that minimized post-classification edge-matching. We describe our approach in creating a multi-scene mosaic, and how we classified and modelled cover-types for the state of Utah. Included is an assessment of the accuracy of our modelling effort. We close with a discussion of the strengths and weaknesses of a multi-scene approach to mapping cover-types at ecoregion scales.

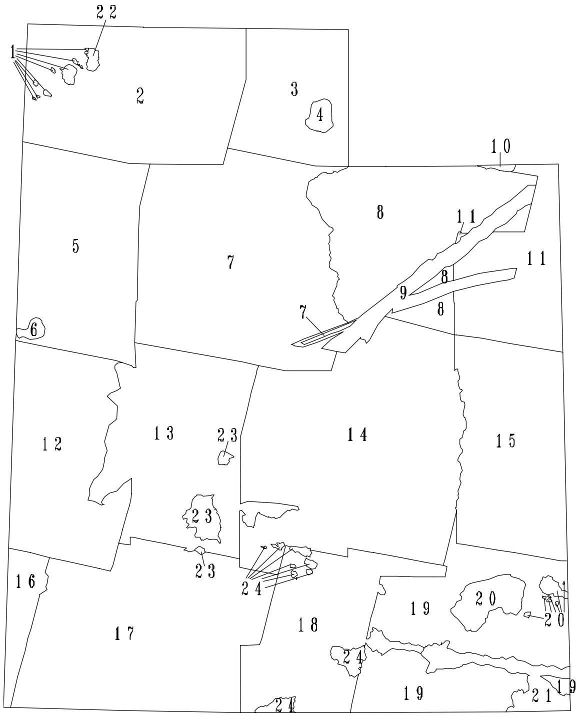
Methods

TM Mosaic.--Utah is covered by 14 TM images. Twenty-four images were required to provide a complete, cloud free mosaic, including 14 primary base scenes and 10 secondary cloud patch scenes (Figure 2.1). The primary base scenes were selected relative to temporal distribution, cloudiness, and availability. When possible we used temporally close images collected during the growing season to reduce spectral signature variability resulting from seasonal and yearly differences in plant phenology and biomass production. Concessions were made between temporal adjacency and cloud restrictions. All base imagery were collected between June and August of 1988 and 1989. However, the additional 10 scenes used for cloud patching varied in dates from 1985 to 1993, but were all still in the summer growing season.

All base images were geographically registered using 1:24,000 USGS quadrangles or orthophotoquads. Approximately 50 control points were selected as uniformly as possible across each image. A bilinear interpolation algorithm was used to resample the images with a root mean square (RMS) error of 1 pixel (30 m). Additional cloud patch images were rectified using image to image rectification. A two step approach of atmospheric standardization and histogram adjustment was used to mosaic the imagery. One image representing the variety of environments in Utah was selected to serve as a "master" image.

This image was adjusted for atmospheric haze by plotting each of the reflective spectral bands against the middle infrared band 7 (2.08 - 2.35 m) as described by Jensen (1986).

Figure 2.1. Path/Row and date of Landsat TM scenes used to develop the Utah TM mosaic.



Major Scenes			Cloud Patches		
Index	Path/Row	Date	Index	Path/Row	Date
2	39/31	29Jul88	1	40/31	07Jul89
3	38/31	22Jul88	4	38/31	01Jul86
5	39/32	29Jul88	6	39/32	05Jul85
7	38/32	23Aug88	9	37/32	27Jun85
8	37/32	18Jul89	10	36/32	27Jun84
11	39/33	22Jun88	20	36/34	25Jun89
12	39/33	11Jun88	21	36/34	-[1]
13	38/33	22Jul88	22	39/31	27Jul93
14	37/33	02Jul89	23	38/33	20Jul93
15	36/33	17Jun89	24	37/34	22Jun91
16	39/34	14Aug88			
17	38/34	04Jun88			
18	37/34	24Jun89			
19	36/34	22Jun88			

[1] Date unknown.

Path 37, row 33, referred to as the Manti image, was chosen as the master image because of its central location in the state (allowing maximum overlay with adjacent scenes), and because it covered a significant range of the ecological conditions likely to be encountered in the state (Table 2.1). Images adjacent to the master image were referred to as "slave" images. The area of overlap between master and slave was compared band-by-band and the average difference calculated for each band. These differences were used as bias values to radiometrically adjust the slave to the master (Table 2.2). Once a slave image was radiometrically matched to the master, it became a master for its’ adjacent scenes. Bias values for the Manti image are a result of a normal atmospheric adjustment as described by Jensen (1986). Bias values for the remaining 13 images are a result of the difference between the overlap of slave and master images.

As images were biased to match adjacent images, they were mosaicked to assess residual differences. An average residual difference of no more than 2 brightness values served as a standard for radiometrically edge-matching imagery. An average spatial error between images of 1 pixel served as a standard for geographic accuracy. An example of the mosaic using bands 7, 4 and 2 is presented in Figure 2.2.

Color plate unavailable in B/W postscript format.

Figure 2.2. Landsat TM mosaic of Utah using bands 7, 4, and 2.

Table 2.1. List of primary master and slave images in the Utah mosaic. This details which scenes were used in which priority for histogram adjustment. Secondary cloud patch scenes were matched to the adjacent scene in which they are contained.

Master Image Path-Row	Slave Image Path-Row	Common Name
37/33	37/32	Duchesne
	36/33	Moab
	37/34	Escalante
	36/34	Monticello
37/34	38/34	Dixie
38/34	39/34	St. George
	38/33	Richfield
38/33	39/33	Wah Wah
	38/32	Provo
38/32	38/31	Logan
	39/32	West Desert
38/31	39/31	Grouse Creek
37/32	36/32	Vernal

Table 2.2. Bias values applied to each image as a result of comparison between slave and master images.

Path/Row	1	2	3	4	5	7
37/33[1]	-53	-19	-16	-9	0	0
37/32	-50	-17	-8	-5	+13	+9
36/32	-69	-24	-19	-15	0	+3
36/33	-57	-29	-20	-18	-6	-7
36/34	-71	-24	-20	-10	+2	+3
37/34	-61	-28	-12	-10	+7	+2
38/34	-51	-25	-7	0	+19	+12
39/34	-31	-6	+4	+15	+36	+21
39/33	-44	-12	-2	+5	+26	+15
38/33	-53	-16	-11	+2	+20	+13
38/32	-14	-11	-4	+12	+32	+21
39/32	-29	-3	+24	-2	+34	-10
39/31	-39	-9	+1	+11	+37	+27
38/31	-54	-16	-9	+2	+24	+18

[1] Master image

Digital Classification.--A possible disadvantage of classifying mosaicked images is an increase in spectral variability and the potential to increase misclassification rates of spectrally similar but ecologically different cover types. To reduce variation and improve classification results, the Utah mosaic was segmented into ecologically homogeneous regions, the Wasatch-Uinta, Colorado Plateau, and the Northern Great Basin (after Omernik 1987) (Figure 2.3).

The Wasatch-Uinta ecoregion is characterized by high mountains and plateaus containing typical rocky mountain flora such as evergreen and deciduous forest, shrubland, and alpine meadows. The Colorado Plateau is characterized by lower elevation canyonlands, plateaus, and buttes supporting arid and semi-arid shrub, grass, and woodlands. The Northern Great Basin ecoregion is typified by mountain ranges and broad valleys trending north to south. Vegetation within the Northern Great Basin includes semi-arid shrubs and grasses with montane vegetation occurring at higher elevations. Each ecoregion was subset from the state mosaic image and processed using the ERDAS$^{(tm)}$ Isodata algorithm to generate unsupervised spectral clusters. Before clustering, agricultural and urban areas were masked from the image to further reduce spectral variability. An iterative process was used to identify the optimum number of spectral clusters needed to characterize land-cover variation in each ecoregion. Each iteration was evaluated by examining average per band signature standard deviations. A maximum allowable SD threshold was determined for each ecoregion by increasing the total number of spectral clusters generated by Isodata for each iteration. At each Isodata run, the number of final clusters were increased by 25. Average SD for all clusters was compared to the total number of clusters for each iteration, and the point of diminishing returns (i.e., the decrease in standard deviation vs increase in number of clusters) was chosen as the maximum allowable average standard deviation.

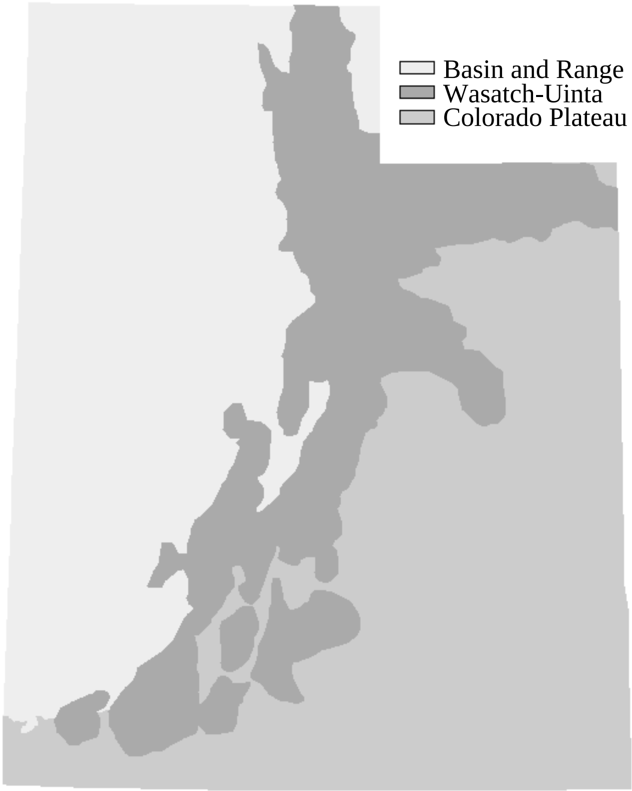


Figure 2.2. Ecoregions used in modelling cover-types in Utah (after Omernik 1987).

For the Wasatch-Uinta ecoregion an average per spectral band standard deviation of 3 was chosen as the maximum. For the Colorado Plateau and Northern Great Basin an average per spectral band standard deviation of 4 was chosen. Standard deviations below this point required a significant increase in the number of spectral clusters. In the Wasatch-Uinta, a total of 125 unsupervised spectral clusters were generated from TM bands 2-5 and 7 (Green, Red, NIR, MIR,). For the two remaining ecoregions a total of 150 spectral clusters each were generated from 5 TM bands. A minimum distance to the means classification algorithm, using the generated spectral clusters, was used in each ecoregion to assign individual pixels to a spectral class.

Training Data.--Data recorded at each training site included UTM coordinate from a global positioning system (GPS) receiver, vegetation composition and percent cover, soil type, topography, and a qualitative site physical and location description to assist in the location of each site on TM imagery. Heads-up screen digitizing on radiometrically enhanced TM data using GPS-collected UTM coordinates and site description data was used to create each site training polygon. Site characteristics, such as adjacency to a road or other features visible on the TM data, served as a secondary check for correct placement of the training site boundary.

To increase the number of training sites, low-level true color aerial photographs in stereo pairs (1:12,000) were interpreted by USDA Forest Service Region 4 photo interpreters (Larry Deblander and William Dunning, USDA Forest Service Region 4, 324 25th Street, Ogden, UT 84401-2301). These photos were located in primarily high elevation forest sites which were difficult to access. Vegetation cover-types were identified on the photograph by photo interpreters and the corresponding site found on the imagery. Heads-up digitizing was used to identify the training polygon.

Another source of training data was provided by federal agency resource managers during the course of their normal field activity. In a program designed by the Intermountain Forest and Range Experiment Station, Forest Inventory and Analysis group (Ramsey et al. 1992), standardized field forms were mailed to district offices of the U.S. Forest Service and Bureau of Land Management. Field personnel were instructed to identify areas of homogeneous vegetation cover, and collect vegetation, topographic and physical characteristics for each site. Because GPS units were not available to all field crews, each site was located on an aerial photograph and a 1:24,000 scale quadrangle. On receipt of the field data, photos, and maps, we photointerpreted sites onto TM imagery to determine data location quality. If a strong correlation existed between all location data sources, the field information would be accepted as a training site.

Programmatically, Gap Analysis has adopted the UNESCO hierarchical classification system (Driscoll et al. 1984) to classify vegetation. Hence field data on species composition, height, and canopy closure were used to classify the training plot to the appropriate UNESCO series level, although in some cases a cover-type had to be stepped back to the UNESCO formation level because of our inability to discriminate to the series level.

A total of 667 field training sites were used to correlate spectral classes with vegetation cover-types in the Wasatch-Uinta ecoregion. Three hundred-fifty six (53%) were collected using a GPS in the field, 221 (35%) were collected using aerial photographs and 80 (12%) collected using ground/photo interpreted sites. For the Colorado Plateau ecoregion, the primary data set was composed of 518 points. Four hundred twenty-two (81%) were GPS located, 59 (12%) were photo interpreted, and 37 (8%) were ground/photo interpreted. A secondary data set based on the BLM soil-vegetation inventory method (SVIM) were collected in the Henry Mountain Resource Area located in Southeastern Utah. These data were linked to 1780 polygons and overlaid onto spectral classes for association. The Northern Basin and Range consisted of 573 training sites. Four hundred ninety (86%) were GPS based, 57 (10%) were ground/photo based and 26 (4%) were photo interpreted.

Modelling.--Each ecoregion was independently classified, modeled and subsequently edgematched into a state-wide coverage (Wasatch-Uinta, Appendix A1; Colorado Plateau, Appendix A2; Basin and Range, Appendix A3). Cover-type modelling consisted of two phases: (1) correlation of cover-type associations with spectral values; and (2) ecological modelling based on ancillary information. Spectral modelling was based on statistical relationships between field data and spectral information. Because field data were collected independent of image classification, training polygons often included more than one unsupervised spectral class. These polygons, which frequently differed in area, were standardized by deriving weighting values based on polygon area. The weight of a spectral class within a training polygon was determined by dividing the number of pixels of that class by the total number in the training polygon (i.e., one pixel from a 10 pixel training polygon would carry the same weight as 10 pixels from a 100 pixel training polygon). Standardization of training polygons was required to eliminate spectral class association bias based on training polygon area.

Two sets of summary statistics were generated from the weighted values. One summed the weighting value of each cover-type by spectral class. For example, 73% of Basin and Range spectral class 99 was salt desert scrub, 23% greasewood and 2% desert grassland (Appendix A3). These summary statistics were used to determine the principal cover-type associated with each spectral class. The second set of statistics ranked each cover-type by spectral class (e.g., pinyon-juniper comprised 72% of class 6, 64% of class 5, 32% of class 13, 5% of class 8, etc.). Both sets were required to balance overall and per class ancillary modeling.

The second phase of modelling incorporated ancillary data to clarify cover-type associations by spectral class. Ancillary data focused on topographic and regional patterns of vegetation. Ancillary data used to support modelling included 3 arc-second resolution digital elevation data, slope, aspect, region specific vegetation cover-type polygons, and sub-ecoregion polygons. Region specific (sub-ecoregion) vegetation cover-type polygons were developed from existing literature and maps and used to limit the geographic extent of some cover-types. Information from field data, literature, localized maps, and personal communications provided the input for specific ancillary modelling parameters (Appendix A4). Environmental parameters collected from field training sites were summarized to enhance and verify published vegetation parameters. An intensive effort was made to ensure as much objectivity as possible in generating spectral class/ancillary data models. Ancillary data modelling was extensive for some spectral classes.

The summary statistics provided the basis for determining the extent ancillary data modelling was required for a specific spectral class. For example, the weighted pixel analysis of Colorado Plateau class 22 showed a 70% relationship with juniper, 19% with pinyon-juniper, and 6% with pinyon (Appendix A2). The remaining 5% was related with a variety of cover types and considered insignificant. Because separate cover types had the same spectral association, ancillary data were used to separate individual pixels of class 22 into the appropriate cover type. Model adequacy was determined by qualitatively comparing the output ground cover data layer to aerial photography. Deviations between photographs and model results caused a re-evaluation of the GIS model.

Thirty-one of the 36 cover-types generated were modelled using this two-phased procedure. The remaining five cover-types were land-use categories which required alternative ancillary modelling methods. Two of the five land use classes, agriculture and urban, were mostly derived from land-use polygons provided by the Utah Department of Natural Resources, and Utah's Automated Geographic Reference Center (AGRC) (AGRC, 4130 State Office Building, Salt Lake City, UT 84114). Areas of the state not available in this data set were modelled into agriculture and urban classes using localized image classification and road network information. Lowland riparian and mountain riparian cover-types were derived by buffering a perennial and intermittent stream network coverage for Utah and overlaying onto the unsupervised classification. Spectral clusters representing areas of actively growing vegetation falling within the buffer area were classified as mountain or lowland riparian depending on elevation. Wetlands were mapped using on-screen digitizing of enhanced TM imagery.

Conversion of Pixel-based Data to Gap Analysis-specified Minimum Mapping Units.-- National standards for Gap Analysis require the individual pixel data be converted to polygons having a minimum mapping unit (MMU) of 100 ha. Riparian and wetlands, considered sensitive cover-types, have Gap-specified MMUs of 40 ha. Because of a tendency for the commercially available software to create random polygons during aggregation from single pixel to larger MMUs, we developed our own algorithm for aggregation to larger MMUs (Bassett et al., unpublished manuscript). This algorithm dissolves smaller polygons into larger polygons following an ecologically-based decision set rather than being based on the length of shared border between adjacent polygons (ARC/INFO Eliminate). It further has the ability to protect user-specified classes, such as sensitive wetlands or riparian zones, from aggregation into larger cover-types, thereby preserving ecologically important cover-types.

This "smart" eliminate program is an ecological-based algorithm that increases the minimum grain of a thematic map. Polygons smaller than the user-specified grain size for retention (targets) are identified for elimination and subsequently subsumed into adjacent polygons through a series of linked programs written in ARC/INFO Macro Language and C. Our mapped cover-types served as the ecological basis for the elimination process. Target polygons were re-coded from smallest to largest in area by consulting a matrix of weighting values for all possible combinations of adjacent cover classes (Table 2.3). The larger the weighting value of an adjacent cover class the more likely the target polygon will be subsumed into that cover class. A weighting value of -1 was assigned to wetlands, wet meadow, and mountain and lowland riparian cover-types. This weighting maintained these cover-types at a 40 ha grain size, and eliminated all other polygons with an area <40 ha size and with cover-type weighting values greater than -1. Frequently, the highest relative weighting value was the same for more than one adjacent polygon. In these cases the target polygon was subsumed into the adjacent polygon having the longest shared boundary. Once a target polygon was assigned an adjacent polygon’s cover class that adjacent polygon could not be targeted for elimination. This insured that adjacent polygons smaller than the specified grain size were not incorrectly assigned a new cover class.

Smart eliminate is an interative process. We first applied a 3X3 smoothing routine to the pixel-based cover-map to make the map more tractable for aggregation by eliminating most single pixel heterogeneity. This left a .8 ha or greater base map that served as a starting basis for aggregation. Beginning with a 1-ha grain size, we re-coded all polygons <1 ha in size. After all target polygons were re-coded, the boundaries between like cover classes were removed and the target polygons subsumed into their neighbors of the same cover-type. Test comparisons by Basset et al. (unpublished manuscript) suggested that aggregation by small steps preserved boundary integrity better than large incremental steps. Consequently, we stepped up the pixel level data in 1-ha increments from 1 to 5 ha, then 5-ha increments up to the Gap-specified 100 ha MMU.

Results

A total of 425 spectral clusters were generated and modelled into 31 cover-types and 5 land-use classes across the three ecoregions in Utah (Table 2.4). Cloud and lava, although modelled, were subsequently ignored, with lava being subsumed into the Barren cover-type. Cover-type categories are listed by *principal* species, which define the cover-type (Appendix A5). Because Gap Analysis focuses on landscape scale cover-type mapping, each cover-type includes many *primary associate* tree or shrub species which occur as substantial parts of a cover-type in localized areas. These are necessarily subsumed into the broader categories

Table 2.3. Representation of the "smart" elimination matrix used for Utahs 38 vegetation cover-types. An id and the vegetation cover-type are given on the x-axis and correspond to the ids given on the y-axis. The x-axis represents the polygon that is targeted for elimination and the y-axis illustrates the possible adjacent polygons. The values located in the matrix are weighting values for polygon elimination. If a target polygon vegetation cover-type is Water and the only two adjacent polygon cover types are Spruce-fir, weighting value of 6, and Ponderosa Pine, weighting value of 3, the target polygon will be subsumed into the Spruce-fir polygon because of the larger weighting value. Values of -1 are given to target polygons which are not to be eliminated into that adjacent cover-type ls even if they do not meet the minimum area requirement.

ID-Cover Type	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
01-Water	38	6	3	5	4	1	2	1	1	1	1	1	1	1	1	1	1	1	9	1	1	1	1	1	1	8	7	1	1	1	1	1	1	1	1	1	1	37
02-Spruce-Fir	1	38	16	21	19	1	7	2	1	1	1	1	1	1	1	1	4	1	1	1	6	3	37	5	9	0	0	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1
03-Ponderosa Pine	1	16	38	20	21	9	11	10	8	1	1	1	1	1	1	1	1	1	1	1	1	37	2	3	6	0	0	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1
04-Lodgepole Pine	1	16	12	38	11	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1	37	1	4	7	6	0	0	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1
05-Mtn. Fir	1	18	19	17	38	7	9	8	6	1	1	1	1	1	1	1	1	1	1	1	13	15	14	37	16	0	0	-1	1	-1	-1	-1	-1	-1	-1	-1	1	1
06-Juniper	1	4	9	5	8	38	36	37	35	1	7	6	1	21	16	11	1	1	1	1	1	1	1	1	1	0	0	-1	1	1	1	1	1	3	1	1	1	1
07-Pinyon	1	10	16	11	13	36	38	37	20	1	5	1	2	21	22	1	1	1	1	1	1	7	8	9	1	0	0	-1	1	1	1	1	1	1	1	1	1	1
08-Pinyon-Juniper	1	12	15	13	14	37	36	38	19	1	11	10	1	21	16	2	1	1	1	1	3	6	4	5	1	0	0	-1	1	1	1	1	1	1	1	1	1	1
09-Mtn. Mahogany	1	11	12	1	1	16	13	15	38	1	1	1	7	6	5	1	1	1	1	1	1	1	1	1	1	0	0	-1	1	1	1	1	1	1	1	1	1	1
10-Aspen	1	1	1	1	1	1	1	1	1	38	31	33	21	1	1	1	3	10	11	1	36	1	1	1	35	0	0	-1	1	4	1	1	1	1	1	1	1	1
11-Oak	1	1	1	1	1	6	8	7	5	31	38	31	26	1	1	1	1	4	1	1	1	11	1	9	10	0	0	-1	1	1	1	1	1	1	1	1	1	1
12-Maple	1	1	1	1	1	7	1	9	7	31	29	38	21	1	5	1	1	6	1	1	1	4	1	14	13	0	0	-1	1	1	1	1	1	1	1	1	1	1
13-Mtn. Shrub	1	1	1	1	1	4	5	6	7	21	31	26	38	1	20	3	15	14	13	1	2	19	17	18	16	0	0	-1	1	2	1	1	1	1	1	1	1	1
14-Sagebrush	1	1	1	21	1	35	33	34	32	1	1	1	1	38	37	31	1	23	1	1	1	1	1	1	1	0	0	-1	1	1	1	29	28	30	1	27	1	1
15-Sagebrush/Perennial Grass	1	1	1	9	1	16	15	17	3	1	11	1	12	37	38	19	10	21	1	1	1	2	1	1	1	0	0	-1	1	1	1	7	14	8	1	5	1	1
16-Grassland	1	1	1	1	1	1	1	1	1	1	1	1	1	6	26	38	8	36	1	1	1	1	1	1	1	0	0	-1	1	1	1	19	37	18	17	4	1	1
17-Alpine	1	1	1	1	1	1	1	1	1	1	1	1	6	1	1	4	38	16	11	2	1	1	3	1	1	0	0	-1	1	1	1	1	1	1	1	1	1	1
18-Dry Meadow	1	1	1	1	1	1	1	1	1	11	13	14	15	9	21	16	26	38	31	1	1	1	1	1	1	0	0	-1	1	1	1	1	1	1	1	1	1	1
19-Wet Meadow	2	1	1	1	1	1	1	1	1	16	11	30	9	1	1	1	26	31	38	1	6	3	8	5	7	24	22	-1	1	4	1	1	1	1	1	1	1	1
20-Barren	1	1	1	1	1	13	1	1	11	1	1	1	1	1	1	16	21	1	1	38	1	1	1	1	1	0	0	36	30	1	1	4	2	3	5	6	1	1
21-Lodgepole/Aspen	1	11	2	37	5	1	1	1	1	31	1	1	17	1	1	1	3	13	14	1	38	7	18	6	36	0	0	-1	1	1	1	1	1	1	1	1	1	1
22-Ponderosa Pine/Mtn. Shrub	1	1	36	5	9	1	7	1	1	1	29	27	31	1	2	1	1	1	1	1	1	38	11	21	20	0	0	-1	1	1	1	1	1	1	1	1	1	1
23-Spruce-Fir/Mtn. Shrub	1	36	1	6	5	1	1	1	1	3	1	1	31	1	1	1	27	28	2	1	33	1	38	32	29	0	0	-1	1	1	1	1	1	1	1	1	1	1
24-Mtn. Fir/Mtn. Shrub	1	4	5	3	36	1	1	1	1	1	23	21	31	1	1	1	1	1	1	1	2	29	27	38	25	0	0	-1	1	1	1	1	1	1	1	1	1	1
25-Aspen/Confier	1	11	10	8	9	1	1	1	1	36	4	5	6	1	1	1	1	3	2	1	31	21	20	19	38	0	0	-1	1	1	1	1	1	1	1	1	1	1
26-Mtn. Riparian	2	1	1	1	1	1	1	1	1	16	10	9	18	1	1	1	34	13	36	1	6	1	1	1	1	38	37	-1	1	1	1	1	1	1	1	1	1	34

ID-Cover Type	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
27-Lowland Riparian	2	1	1	1	1	1	1	1	1	11	12	16	15	1	1	1	1	10	35	1	1	1	1	1	1	37	38	-1	1	34	33	1	1	1	1	1	1	36
28-Cloud	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	37	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
29-Lava	2	5	3	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	30	1	1	1	1	1	0	0	0	38	1	1	1	1	1	1	1	1	-1
30-Agriculture	1	1	1	1	1	1	1	1	1	11	5	4	15	1	1	1	1	1	3	1	1	1	1	1	1	1	1	-1	0	38	37	1	1	1	1	1	1	1
31-Urban	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	-1	0	37	38	1	1	1	1	1	1	1
32-Salt Desert Scrub	1	1	1	1	1	1	1	1	1	1	1	1	1	7	5	6	1	1	1	1	1	1	1	1	1	0	0	-1	0	1	1	38	12	11	10	13	1	1
33-Desert Grassland	1	1	1	1	1	1	1	1	1	1	1	1	1	4	5	31	1	1	1	1	1	1	1	1	1	0	0	-1	0	1	1	21	38	16	6	11	1	1
34-Blackbrush	1	1	1	1	1	1	1	1	1	1	1	1	1	9	1	10	1	1	1	1	1	1	1	1	1	0	0	-1	0	1	1	18	11	38	31	1	1	1
35-Creosote-Bursage	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6	1	1	1	1	1	1	1	1	1	0	0	-1	0	1	1	11	3	16	38	1	1	1
36-Greasewood	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	3	1	1	1	1	1	1	1	1	1	0	0	-1	0	1	1	21	4	5	6	38	11	1
37-Pickleweed Barrens	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25	1	1	1	1	1	0	0	-1	1	1	1	21	1	1	1	31	38	1
38-Wetland	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	1	1	1	1	1	1	5	31	-1	1	16	1	1	1	1	1	1	1	38

we mapped. Additional specifics of the Utah vegetation modelling process are outlined in Homer et al. (unpublished manuscript).

Table 2.4. Utah cover-types by area, based on the 100 ha. MMU polygon classification. The 100 mmu cover-type file was clipped at the state boundary with a 1:100,000 border file verses the single pixel level clipped with a 1:500,000 scale border file which results in slightly different cover-type totals

Cover-Type	km^2	Cover-Type	km^2
Agriculture	9,353	Mountain Mahogany	3
Alpine	809	Mountain Riparian	387
Aspen	7,350	Mountain Shrub	2,067
Aspen/Conifer	136	Oak	7,934
Barren	5,755	Pickleweed Barrens	4,316
Blackbrush	9,544	Pinyon	6,490
Creosote-Bursage	473	Pinyon-Juniper	20,145
Desert Grassland	8,978	Ponderosa Pine	475
Dry Meadow	2,167	Ponderosa Pine/Mountain Shrub	2,280
Grassland	8,581	Sagebrush	21,485
Greasewood	981	Sagebrush/Perennial Grass	16,953
Juniper	15,789	Salt Desert Scrub	45,395
Lodgepole	2,293	Spruce-Fir	4,971
Lodgepole/Aspen	59	Spruce-Fir/Mountain Shrub	42
Lowland Riparian	511	Urban	1,447
Maple	752	Water	8,550
Mountain Fir	2,611	Wetland	538
Mountain Fir/Mountain Shrub	93	Wet Meadow	58
		TOTAL	219,771

Ancillary data modelling was required in 400 of the 425 spectral classes (94%). Of the remaining 400 spectral classes, 356 (89%) required two or more model statements and 49 of 400 (12%) required 10 or more model statements. The resulting classification (Figure 2.4) was smoothed using a 3x3 cell majority filter to remove the majority of single pixel classes. However, to maintain data lineage, the original classification prior to smoothing was not eliminated. Therefore, a direct geographic lineage from the georeferenced, pre-mosaic Landsat TM imagery to the final classification was maintained.

Accuracy Assessment

Assessing uncertainty of cover-type maps covering thousands of km^2 is problematic. The sheer size of areas modelled in Gap Analysis, such as the Great Basin, pose immense logistical difficulties that complicate any sample design for accuracy assessment. Nonetheless, estimates of the classification accuracy of Gap Analysis coverages are needed to assist land mangers confronted with conflicting demands from user groups and to provide a defensible basis for use of the coverages in conservation decisions (Karieva 1994).

Color plate unavailable in B/W postscript format.

Figure 2.4. Utah cover-map.

Problems of assessment relating to Gap Analysis cover maps include access to sample points, the high cost of movement between sample sites, and those associated with combining data of a diverse nature collected at different scales and at various levels of error and uncertainty (Chrisman 1989, Goodchild 1989, Openshaw 1989). Numerous studies have addressed the problem of choosing appropriate sample sizes and designs to assess classification accuracy (Berry and Baker 1968, Hord and Brooner 1976, Ginevan 1979, Hay 1979, Rosenfeld 1982, Congalton 1991). Congalton (1988a, b) also discussed simple random, systematic and cluster sampling and the effect of spatial autocorrelation (i.e., dependency between neighboring "pixels", or units) on the efficiency of sample designs used in classification assessment. Yet, questions remain about the choice of appropriate design, even for estimating something as simple as the percent missclassified pixels in landscape.

A major constraint for assessing uncertainty of the Utah Gap Analysis cover-map was the cost of movement between sample sites. Although tempting to apply a simple random design for selection of sample units, the cost of collecting information at locations randomly distributed across the entire state is substantially higher than collecting information at clustered locations. Further, software constraints in GIS packages preclude the building of a single coverage for the state, a neceassry precursor for any stratified approach based on cover-type polygons. Moisen et al. (1994) evaluated the relationship between spatial autocorrelation and a simple cost function on the relative efficiency of simple random, systematic and cluster sampling designs, demonstrating that cluster sampling for areas difficult to reach returned greater information per unit sampling cost. These results were used to develop methodology for assessing accuracy of the Utah Gap Analysis cover-map.

Methods.--Because we modelled cover-types by three ecoregions, we first stratified the state into three areas for assessment. A total of 100 7.5-min quadrangles, distributed proportionally among the three ecoregions, were randomly selected (Figure 2.5). We further divided each quadrangle into road, defined as the corridor 500 m wide on each side of the road, and off-road strata. A total of 20 1-ha sample points were then evaluated on each quadrangle, 10 randomly selected within 500 m of the road and one randomly selected starting point for a linear cluster of 10 off-road sample units (Figure 2.6).

The mix of an off-road linear cluster and randomly selected points within a road corridor served two purposes. First, sample units next to roads are easy to access, can be rapidly assessed, and are cheap to collect, thereby boosting sample size. Unfortunately, there exists the real possibility that samples next to roads are biased significantly altered or impacted by man and do not represent the true landscape. Collection from off-road linear clusters allowed for comparison between the two strata to determine if differences do exist. Second, use of a linear cluster for off-road points reduced sampling effort and reduced the per sample unit cost (see Moisen et al. 1994). Field personnel needed only to find a single starting sample unit and walk a 1 km transect.

All random points were generated in the lab prior to personnel going to the field. Selection of sample was accomplished by creating a numbered 500 m grid and overlaying it on top of orthophoto quadrangles. Using a random number table, field sample points were selected, digitized into coverages, and noted on the orthophoto quadrangles. The orthophoto quadrangles were carried into the field during data collection for aid in field orientating.

Sample points were located with the aid of GPS units. Information collected at each sample point included: (1) class type; (2) a subjective measure of the adequacy of fit using definitions developed by Gopal and Woodcock (1994); (3) primary and secondary cover-types within 100 m of the sample point; and (4) primary and secondary vegetation cover-types within 200 m of the sample point. Both primary and secondary vegetation cover-types needed to be at least 1 ha in size or connected to a vegetation block at least 1 ha in size to be consistent with the 1-ha base model of the Utah cover-map.

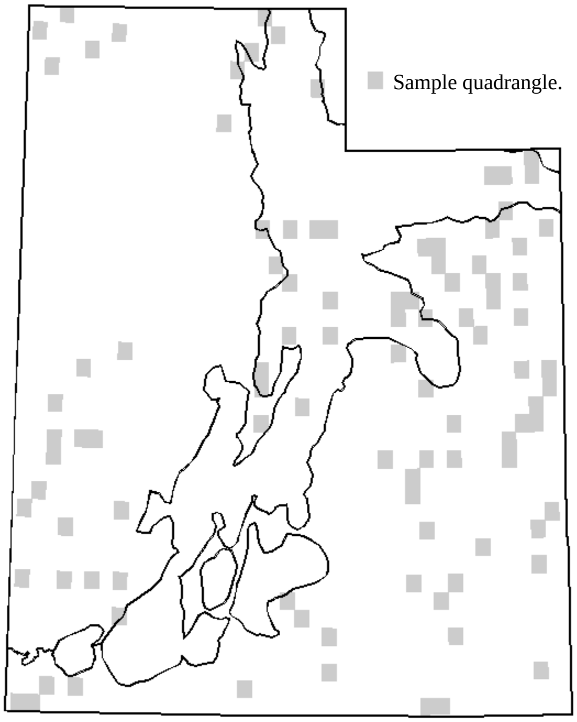


Figure 2.3. Location of sample quadrangles.

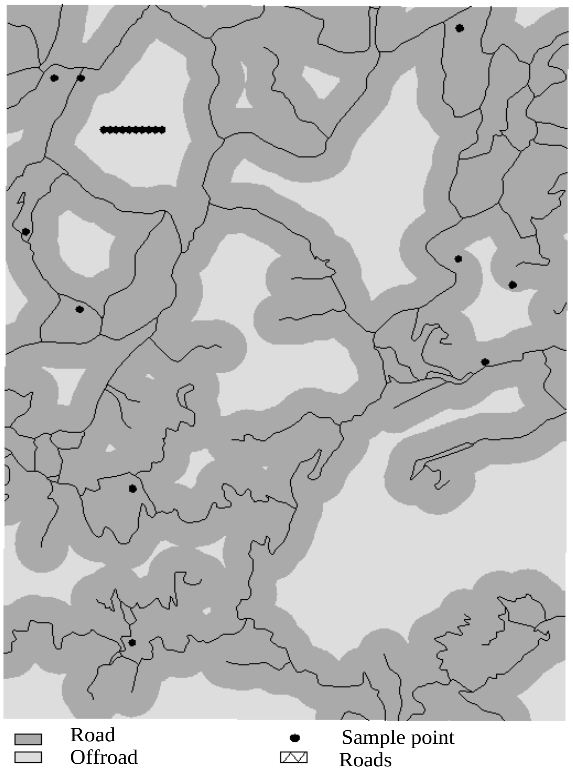


Figure 2.4. Illustration of sampling strategy used to assess accuarcy of the Utah cover-map. See text for explanation.

Results.--Six of the initial 100 quadrangles were eliminated because of problems with access (i.e., private lands, DOD lands) and were replaced with other randomly selected quadrangles. Although every effort was made to ensure that the full 20 sample points (10 road, 10 off-road) were evaluated in every quadrangle, logistical constraints occasionally precluded field personnel from visiting every point. Problems encountered were principally access, either an impassable road or uncertainties regarding ownership and our desire to avoid trespass on private lands without permission. An additional 4 quadrangles were eliminated because of inaccessibility, leaving a total of 96 quadrangles containing 960 road and 960 off-road points in 96 clusters (n=1920).

Overall map accuracy was 75.3% (σ^2=0.0003). Accuracy by ecoregion ranged from 72.8% to 76.3% (Table 2.6). Percent correct classification was similar for both road and off-road strata in the Basin and Range and Wasatch-Uinta ecoregions. Differences were substantially higher between road and off-road strata in the Colorado Plateau ecoregion.

Table 2.6. Percent accuracy, variance and sample size by ecoregion.

	Basin and Range	Wasatch-Uinta	Colorado Plateau
% correct	76.3	72.8	76.1
Variance	0.0012	0.0009	0.0004
n	360	540	1020

Percent correct classification by cover-type exhibited considerable variability (Table 2.7). Only 11 of 38 classes had sample size of $n \geq 30$, making evaluation of all mapped cover-types difficult. For cover-types with $n \geq 30$, percent accuracy ranged from a low of 50.6% for Sagebrush/Perennial Grass to a high of 88.0% for Oak.

Table 2.7. Percent correct classification, variance and sample size by cover-type.

Cover-type	%	var	*n*	Cover-type	%	var	*n*
Agriculture	79.9	0.023	29	Mountain Mahogany	--[1]	--[1]	0
Alpine	--[1]	--[1]	0	Mountain Riparian	0	0	9
Aspen	67.1	0.009	56	Mountain Shrub	58.6	0.022	20
Aspen/Conifer	--[1]	--[1]	0	Oak	88.0	0.009	56
Barren	61.9	0.038	14	Pickleweed Barrens	--[1]	--[1]	0
Blackbrush	71.7	0.005	96	Pinyon	46.6	0.030	27
Creosote-Bursage	73.5	0.026	33	Pinyon-Juniper	83.8	0.004	150
Desert Grassland	76.8	0.003	170	Ponderosa Pine	50.0	0.002	4
Dry Meadow	90.8	0.002	18	Ponderosa Pine/Mountain Shrub	75.6	0.001	27
Grassland	79.5	0.002	103	Sagebrush	60.1	0.003	230
Greasewood	64.1	0.063	11	Sagebrush/Perennial Grass	50.6	0.003	150
Juniper	71.2	0.005	94	Salt Desert Scrub	82.3	0.002	384
Lodgepole	87.0	0.001	24	Spruce-Fir	84.4	0.009	11
Lodgepole/Aspen	--[1]	--[1]	0	Spruce-Fir/Mountain Shrub	41.7	0.009	6
Lowland Riparian	80.4	0.016	19	Urban	94.4	0.003	17
Maple	55.0	0.019	25	Water	74.1	0.025	29
Mountain Fir	68.2	0.026	15	Wetland	90.0	0.001	12
Mountain Fir/Mountain Shrub	50.0	0.002	2	Wet Meadow	0	0	2

[1] No samples for this cover-type.

Discussion

Use of unsupervised classification for cover-type mapping typically requires post classification comparison of spectral classes to field data for land-cover training. A serious disadvantage to this approach when mapping large, remote landscapes is gaining access to field sites identified from an unsupervised classification. This can be expensive, time consuming and result in limited sample size. An alternative method was to collect field training sites independently of the unsupervised classification, based on merits of access, vegetative composition, and location. This approach optimizes time in the field, and can result in a much larger sample of training data. However, some post-classification field work may still be required where plot data is inadequate for training some spectral clusters.

Classification of large-area mosaics does require significant post-classification ancillary modelling. This ancillary modelling of post-classified pixels at complex landscape levels can cause localized homogenization of cover-types because model parameters are focused on optimum landscape results, not local results. Reduction of post-classification modelling could be achieved in two ways. One is by finer landscape regionalization of the mosaic. However, increased regionalization creates the need for additional training sites, processing time and edge-matching. Second is to "cluster bust" spectral classes which represent many cover-types by masking the specific class in the raw data and reclustering into two or more clusters. This provides a way to target specific classes which are spectrally similar without increasing the total initial number of classes.

Based on our results, multi-scene digital classification holds promise as a viable landscape level mapping methodology, especially in diverse biogeographical areas. For most of the wildland vegetation mapping, digital classification of TM data and post-classification ancillary data models in a GIS provided effective results for cover-types. Ecoregion-based classification provided a reasonable framework to work with when creating such a spatially large data set. Further, it tends to optimize ground training site extrapolation, and ancillary model application. Edge-matching between ecoregions proved minimal, especially since ecoregion boundaries were placed in spectrally homogeneous areas.

The effect of the mosaicking process on image classification accuracy at ecoregional scales is difficult to assess. Obviously, spectral clustering is influenced by among scene variability rather than ground based variability at some level. This could significantly influence the accuracy of the classification. Our experience with clustering at the ecoregion level, however, provided little evidence of significant problems in among scene clustering influence. Nonetheless, finer spectral partitioning of the image might cause more within scene confusion in cover-type correlations. It is possible the more bands used in developing spectral clusters, the less potential of among scene clustering influence because of multi-band stabilizing potential.

Multi-scene mosaics can also be created using the histogram matching approach, which manipulates the distribution of brightness values in the slave image (the histogram) to match the master scene. One possible negative consequence of histogram matching is modification of within slave scene radiometric variability, resulting in greater loss of radiometric accuracy for classification. The alternate histogram adjustment method we employed functions just as an atmospheric correction, allowing for histogram modification but maintaining unique radiometric characteristics of the slave scenes. In multi-date imagery mosaics this possibly allows for increased recognition of localized phenomenon in digital classification and less homogenization of the mosaic.

Our chief objective was to generate a cover-map that met the needs of the NBS Gap Analysis, an effort focused on ecoregion scales. However, by maintaining data lineage from final product to the georeferenced, un-mosaicked imagery, there is the ability to "step-down" the classification from the 36 relatively broad categories presented here to finer categories based on enhanced, local-area modelling. In this sense, our cover-map acts as an additional ancillary data layer to reduce spectral variability and allow land managers to focus on narrow reflectance parameters to dissect broad categories to more specific cover-types. This ability is further enhance by using a hierarchical classification strategy such as the UNESCO system.

Chapter 3

Land Ownership

We are the children of our landscape;
it dictates behavior and even thought
in the measure to which we are responsive to it.

Lawrence George Durrell

Background

Land ownership constitutes one of the three central layers of Gap Analysis (Scott et al. 1993). Differences in ownership provide some indication of the kinds of activities that can occur on a given piece of land, and hence provide an indication of the potential impact on the land's biological diversity. For example, Federal mandates preclude the permanent conversion of natural habitat types to anthropogenic habitats on most Federal lands. In contrast, most private landowners are free to modify their land to suit their individual goals, subject only to local zoning constraints. Once land ownership is mapped, it provides a measure of the relative protection afforded plant communities and their associated terrestrial vertebrates, thereby providing descriptive information on "gaps" in the protective network. Here, we describe the method used to map land ownership for Utah, including information on source information and coding protocols, and follow with descriptive statistics of land ownership for Utah.

Methods

Utah land ownership information was digitized from 46 BLM 1:100,000-scale Surface Management Status maps (Appendix B1). Each 1:100,000 quadrangle was digitized with a maximum root mean square error tolerance of <.005 digitizing inches (13 m). Given the ready accessibility of the BLM 1:100,000 scale maps, we found it convenient to partition the state ownership into 1:100,000 tiles for digitizing. Once each tile was completed, it was transformed into the appropriate UTM zone coordinates (Zone 11 or 12). Transformed coverages were then appended to each other and edge matched. Discrepancies in polygons between map edges (usually caused by differences in map dates) were simply closed off. Imbedded, missing or extra polygons were searched for and corrections made when necessary. Labels were generated for each polygon and attributed for categories of land ownership. All coverages were stored in double precision format. Once the state-wide coverage was completed, it was transformed to Lambert Conformal Conic projection for archiving. Ownership coding is presented in Appendix B2.

One problem in delineating land ownership was the frequency of land exchanges. While small-area (<160 acres) transfers between private owners are of little concern to the ecoregion emphasis of Gap Analysis, exchanges among Federal agencies frequently involve significant areal extent and change in administrative control (e.g., delineation of a new Wilderness area on lands under control by the FS or BLM). Although every effort was made to obtain an update of major land exchanges (Appendix B1), it is likely that some exchanges were overlooked. Under no circumstance should the land ownership map developed here be considered a legal document.

To assess protection, each ownership was assigned one of four management status codes (Table 3.1). Because management practices may differ considerably among areas having the same ownership, care was taken to ensure that coding was properly applied. For example, all parks in Utah are controlled by the Department of Natural Resources (DNR). Some Utah parks, such as those associated with aquatic recreational opportunities (e.g., Willlard Bay), are managed principally for human use while others, such as Wild Horse Butte, have benefit to biological diversity because of limited human impact. Because both areas are controlled by the same agency, care was taken to research the specific management plans associated with each area prior to assigning a management status code. One additional source of confusion was coding of large water bodies. Most large, interior natural water bodies are owned by states and could conceivably be coded as state-owned. However, for Gap Analysis water and land need to be differentiated. Thus we decided to code water as a distinct category

Table 3.1. Management status codes applied to Utah land ownership (after Scott et al. 1993).

Code	Description
1	An area having an active management plan in operation to maintain a natural state and within which natural disturbance events are allowed to proceed without interference or are mimicked through management.
2	An area generally managed for natural values, but which may receive use that degrades the quality of existing natural communities.
3	Most nondesignated public lands. Legal mandates prevent the permanent conversion of natural habitat types to anthropogenic habitat types and confer protection to Federally listed endangered and threatened species.
4	Private or public lands without an existing easement or irrevocable management agreement to maintain native species and natural communities and which is managed for intensive human use.

Results

State and Federal public lands comprise roughly 81% of the 21,979,000 ha of Utah (Table 3.2). These lands are distributed in a patchwork of Federal, State and private ownership (Figure 3.1). The Bureau of Land Management, controlling over 92,000 km^2 (41.8%) of Utah land, is the single largest administrator of lands in Utah. Less than 2% of Utah lands are designated as Wilderness. Analysis of ownership by management status codes is presented in Chapter 5.

Table 3.2. Utah land ownership and administration (km^2) by major category.

Ownership	Area (km^2)	%
Bureau of Land Management	92,029	41.85
Wilderness Area	113	0.05
Department of Defense	7,348	3.34
U.S. Forest Service	29,518	13.42
National Recreation Area	313	0.14
Wilderness Area	2,993	1.36
National Park Service	3,520	1.60
National Recreation Area	4,080	1.86
U.S. Fish and Wildlife Service	252	0.11
Bureau of Indian Affairs	9,425	4.29
Utah State Lands	14,758	6.71
State Parks	295	0.13
State Wildlife Area	1,610	0.73
Private Lands	46,991	21.37
Perennial Water Bodies	6,094	2.77
Intermittent Water Bodies	544	0.25

Discussion

Like most western states, Utah contains a large amount of land managed by the Federal government. These lands have historically provided resources to surrounding communities, principally through grazing, logging and mining interests. Current national, regional and local social changes, however, have resulted in conflict over the future uses of these lands.

An important issue surrounding public lands in Utah is the status of State-owned school and institutional trust lands embedded in this matrix of Federal public land (Figure 3.1). State trust lands in Utah are managed as School Trust lands, with their sole objective being to provide a monetary return to the State treasury for education. Specific objectives of the school and institutional trust lands are to (1) maximize commercial gain for the long-term

Color plate unavailable in B/W postscript format.

Figure 3.1. Utah land ownership and administration.

support of beneficiaries (i.e., citizens of Utah); (2) manage the lands for their highest and best trust land use; (3) obtain fair-market value for use, sale or exchange; (4) reduce risk of loss; (5) upgrade land assets where prudent by exchange; and (6) permit uses of land that do not constitute a loss of trust assets (UT Division of State Lands and Forestry, 355 W. North Temple, 3 Triad Center, Suite 400, Salt Lake City, UT 84180-1204). These objectives frequently collide with those of the surrounding Federal lands, particularly as it relates to the construction of roads to access the lands. Current case law (State of Utah v. Andrus, 486 F. Supp. 995, 10th Cir. 1979) is somewhat ambiguous, suggesting that while the State can access the lands to realize their economic potential, Federal land management agencies can regulate the method and route of access so as not to impair the wilderness character. It is easy to envision future situations where Federal and State mandates will again clash, particularly given the systematic placement of state trust lands throughout the matrix of Federal lands. We hope that the biological information contained in Gap Analysis might provide some direction on how to simultaneously achieve both Federal and State objectives while minimizing impact on biodiversity.

Chapter 4

Wildlife-Habitat Relations Modelling

> *The Dodo never had a chance.*
> *He seems to have been invented for the sole purpose of becoming extinct,*
> *and that was all he was good for.*
>
> *Will Cuppy*

Background

Biologists have long used knowledge of animal life history attributes to model animal ecology. A common approach is to model animal habitat by linking known habitat use patterns with maps of existing vegetation, thereby identifying the spatial extent of important habitat features for use in conservation and management (see Verner et al. 1986). These kinds of models transcend a variety of different scales and purposes, ranging from species-specific Habitat Suitability Index models (Schamberger et al. 1982) to multiple-species wildlife-habitat matrices (e.g., Verner and Boss 1980) to spatially explicit descriptions of animal distributions for conservation planning (Scott et al. 1987*a*). Kinds and uses of different modelling approaches are outlined in texts by Verner et al. (1986) and Morrison et al. (1992), and should be consulted for additional background.

As conservation efforts begin placing greater emphasis on landscape scales, there is need to make better use of site- and species-specific habitat relation models in predicting broad-scale spatial distributions of animal species. Historically, approaches to mapping species distributions included (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 of specimens, and typically include no information on the ecological conditions, such as vegetation, that favor presence of the species. Using vegetation as a surrogate to model presence of animals has limitations (see Verner et al. 1986:Part III, VanHorne and Wiens 1991, Morrison et al. 1992:chapt. 6), but does provide enhancement over the traditional approaches to mapping described above. Because the process does not rely only on known locality records, unsampled areas can be included in predictive models. Coupling known locations with those predicted from vegetation can lead to exceedingly refined maps of species distribution which can then be used for bioregional conservation planning. Given sufficient samples, the distributions can be mapped as a series of probability or density isoclines (e.g., kriging, see Kemp et al. 1989, Schotzko and O'Keefe 1989).

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 floristic composition (Miller 1951, Cody 1985). Because Gap Analysis vegetation mapping relies principally on floristic composition rather than structure, bird distribution maps may contain error. Gap Analysis assumes that within floristically defined vegetation classes the structural characteristics necessary to the bird occur. Similarly, many species, such as bats, are associated with point-specific habitat attributes such as caves. Such associations are difficult to map within the context of Gap Analysis.

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.

Associated with habitat breadth is a distinction between static and dynamic models. By using species presence/absence and WHR models, Gap Analysis-predicted ranges are static representations of the dynamic processes whose result is a species distribution. Maps could be erroneous due to spatial error such as incorrect mapping of cover-types, or reasons such as range expansion or contraction, or some combination of the two. Gap Analysis models do not include provisions at this time for the modelling of community- and population-level processes. Consequently, Gap-based spatial depictions of species ranges contain some level of uncertainty.

A third problem is the level of refinement, or scale, of information available for many species. Although the number of plant communities in a geographic area can be high, natural history data linking animals to these specific communities is sparse for most species. This requires that mapped habitats be grouped into categories that correspond to the known information about a species--a scaling up or down issue wherein information collected at one scale is used at a different scale. For example, the best information on a bird species may be that it is associated with coniferous forests. Given that at least 7 mapped classes in Utah contain conifers (Chapter 2), the potential distribution for that species is exceedingly general. Conflict can arise when general habitat information for one species is coupled with more fine-scale habitat information for another species and used for a multi-species evaluation. Imprecise multi-species models may occur under this circumstance.

Last, we assume a measure of perfect knowledge. Our linkage of WHR models to the spatially explicit cover map implicitly assumes the cover map is 100% accurate. This is clearly false (see Chapter 2). Unfortunately, the combined effect of spatial error in the vegetation map and error in the WHR models is unknown. How error propagates when dealing with numerous information layers in a GIS remains a fruitful area of research for which little is known (see Verregin 1989; Goodchild and Gopal 1989), and for which no clear guidelines currently exist.

Here we describe the process by which we developed models for predicting the spatial extent of terrestrial vertebrates in Utah. We begin by outlining the process by which life history information was synthesized for terrestrial vertebrates in Utah, including a discussion of the data structure we developed and used. We next explain the process by which we linked the species-specific WHR models to our cover map of Utah, and how the information is stored for access and analysis. WHR information and the supporting references for each terrestrial vertebrate species in Utah are contained in eight associated appendices. We close with an assessment of the accuracy of our WHR models and a discussion of the Utah Gap Analysis WHR models.

Methods

Data Collection.--Data on life history attributes and distributional information for every terrestrial vertebrate in Utah were obtained from a variety of sources, including published and unpublished literature, museum and Federal and State agency records on distributions, and from individuals having expert knowledge on a particular species (Foster 1988, Foster and Shrupp 1991; Table 4.1). Information was collected on a total of 524 species. Not surprisingly, the exact number of species by taxonomic group varied among different agencies having management responsibilities in Utah. Given that Gap Analysis is a state-based information system, we selected the species list accepted by the State of Utah Division of Wildlife Resources (UT DWR, 1596 W. North Temple, Salt Lake City, UT 84116-3154). This does not imply that life history and distributional information was not collected on species not included in the UT DWR list. To the contrary, information was collected on all species, including non-breeding migrant birds, unverified or occasional species, and those few species extirpated from Utah but still found in the Intermountain West (e.g., gray wolf *Canis lupus*). However, for purposes of Gap Analysis, and the analyses presented here, only that list recognized by the UT DWR was used.

Modelling Habitat Relations.--To the extent possible, information on species-specific habitat associations was collected at as fine a scale as possible. Given uncertainties about the number and types of habitat classes to be derived from the vegetation mapping, we elected to associate species with recognized cover types during data base creation. These included types recognized by the American Society of Foresters (SAF) (Eyre 1980), potential natural vegetation (Kuchler 1964), and a land use class defined by the Multi-State Fish and Wildlife data group (Mason et al. 1979, Cushwa et al. 1980, see Foster 1988 for listing of all cover-types used). Additional data collected included species gross distribution by latitude-longitude block (birds, Walters 1983; amphibians and reptiles, Schwin and Minden 1979) or county (mammals, Durrant 1952), an ecoregion designation (after Bailey 1979), information on slope and elevation, National Wetlands Inventory class (Cowardin et al. 1979) where appropriate, a structural stage for each cover-type used by the species, and season of use.

Species associations were noted for all habitat types, even if the type was clearly outside of Utah and the surrounding Intermountain West. Once the vegetation map was completed, animal associations were cross-walked into the mapped cover types. As the animal-habitat associations were cross-walked into the cover map, each cover-type to which an animal was assigned was given one of four designations: (1) Critical Habitat, defined as sensitive areas that, because of limited abundance and/or unique qualities, constitute irreplaceable, critical requirements for wildlife, excluding Federally listed threatened and endangered species; (2) High Priority Habitat, intensive use areas that, due to relatively wide distribution do not constitute critical values but which are highly important to wildlife, excluding Federally listed threatened and endangered species; (3) Substantial Value Habitat, existence areas used regularly by wildlife, excluding Federally listed threatened and endangered species, but at moderate levels with little or no concentrated use; and (4) Limited Value Habitat, occasional use areas that either are sparsely populated or that show sporadic or unpredictable use by wildlife, excluding Federally listed threatened and endangered species (Dalton et al. 1990, Nelson et al. date unknown, Wilson and Grandison date unknown, Howe personal communication). Descriptions of animal-habitat associations, and supporting references for each animal species, are found in Appendices C1-C8.

Table 4.1. Data fields used for synthesizing life history attributes and distribution information on terrestrial vertebrates in Utah. Detailed descriptions for each data field can be obtained from the Division of Wildlife Resources, Salt Lake City, Utah. See Foster (1988) and Foster and Shrupp (1991) for additional details.

- Taxonomy
    - Group
    - Common name(s)
    - Scientific nomenclature
    - Authority
- County Level Distribution
    - Historical
    - Resident
    - Non-resident
    - Seasonal
    - Distribution (%)
    - Abundance
    - Population
    - Harvest
- Administrative Units
    - USFWS-refuges
    - NPS-units
    - BLM-units
    - USFS-units
    - State-WMAs
    - Latilong data
- Status
    - Legal
    - Biological
    - Economical
    - Ecological
- Site-specific data
    - Latitude-longitude
    - USGS quadrangle
    - Township/range/section
    - River reach
    - River mile
    - Other (eg. UTM)
- National Map standards
    - OWDC hydrologic units
    - USFS ecoregions
    - Potential natural vegetation
    - Land use/land cover
    - National wetland inventory
- References
    - Literature base
    - Species expert-credit
- Life History Information
    - Nesting/denning/spawning
    - Gestation/incubation
    - Clutch/litter
    - Territoriality/dispersion
    - Mortality/turnover rate
    - Limiting factors
- 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
- Management Practices
    - Adverse management practices
    - Beneficial management practices
    - Existing management practices

Customized C programs were used to link species-specific habitat information obtained from the UT DWR database to the cover map. Every cover-type polygon was attributed with a unique identification number so that species distribution could be predicted based on characteristics contained in that polygon. These characteristics were derived from the 36 mapped cover-types, 24 150-m elevation zones and 524 existing species ranges. A total of 311,779 polygons were linked on a species-by-species basis to predict species distributions. Frequently, a cover-type to which a species was associated extended beyond the known distribution (e.g, a cover-type polygon was bisected by two separate latitude-longitude blocks, but the species was only known to occur in one of the blocks). Under these circumstances the predicted range was extended into the adjoining block, but was limited to the extent of contiguous cover-type polygons extending into the adjoining block. Species distributions were stored in 1:100,000 USGS quadrangles because of software limitations and ease of use.

Five major water bodies were evaluated to determine whether they could be potential habitat for various species. The five major water bodies were Great Salt Lake, West Desert pumping area, Utah Lake, Sevier Lake and Bear Lake. If these water bodies were potential habitat for a specific species they were included in the predicted distribution for that species; otherwise, they were excluded. A problem in modelling suitability of water bodies for wildlife is the distinction between shallow and deep water. For example, some shorebirds (Charadriiformes) use shallow water (e.g., American avocet *Recurvirostra americana*) while others are use deeper water (e.g., Wilson's phalarope *Phalaropus tricolor*). Distinguishing between the two classes, particularly as it relates to the mapping of wetlands, is crucial to the accurate depiction of the spatial extent of species associated with water. Because spectral reflectance decreases as water depth increases, we were able to model a shallow water polygon that extended to approximately 1.5 m depth. By this process shallow water could be modelled and incorporated into the species distribution algorithms.

The last component added to the species distribution models was a distance-to-water buffer. Digital Line Graph coverages were obtained from the USGS and intermittent streams, perennial streams and water bodies were selected out of these coverages and placed in a separate coverage. This coverage was then buffered by 100 m to create a distance-to-water buffer. The buffer was added to the predicted species distribution models to correct distributions of species closely linked to water (e.g., muskrat *Ondontra zibethica* can be found in a lodgepole pine, but only close to water, therefore the water buffer zone must be applied to the muskrat's predicted distribution model).

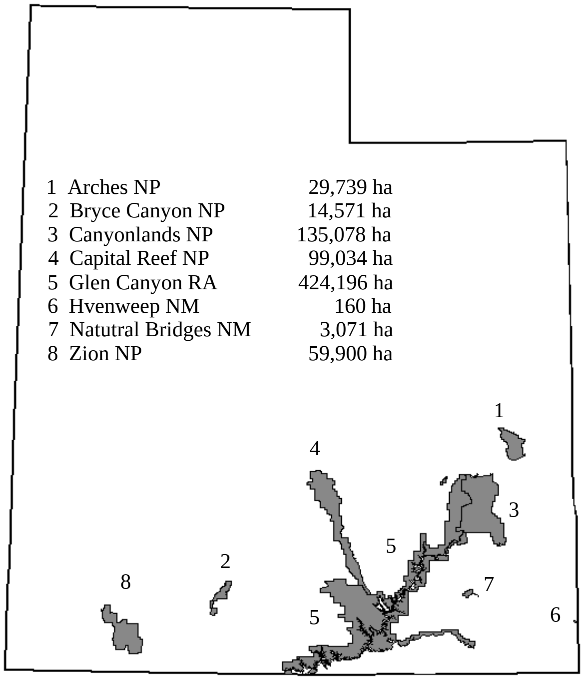
Results

Models were built for a total of 525 terrestrial vertebrates in Utah, including 315 birds, 129 mammals, 67 reptiles, and 14 amphibians. Information on an additional 58 accidental or unverified birds and one extirpated mammal (gray wolf *Canis lupus*) was also collected. Models for some individual species and groups of species were modified to more accurately reflect habitat use patterns, especially those associated with point-oriented features beyond our mapping capability (e.g., caves, talus slopes) (see Appendices C1, C3, C5, C7). In these cases, general habitat surrounding the attribute was modelled but the model was modified to note that the species selects a specific attribute contained in that cover-type, not the cover-type itself. All information is currently stored in Advanced Revelation software and maintained by the UT DWR (UT DWR, 1596 W. North Temple, Salt Lake City, UT 84116-3154).

Accuracy Assessment: Wildlife Habitat Relations

To assess the uncertainty in using vegetation as a surrogate for animal distributions, data from eight National Parks in Utah not included in the development of the WHR models were used to assess the adequacy of the WHR models in predicting presence of species (Figure 4.1). A list of Gap-predicted species for each park was created by intersecting cover-type polygons and animal species distributions based on the WHR models within each park boundary. This list was compared to a park-generated matrix of species observed in each park. Park data were compiled from sources such as wildlife observation cards and faunal collections, if present. We included park-specific unpublished reports and checklists and some published documents (e.g., Rado 1975, Atwood et. al. 1980). The park species lists were reviewed by researchers who were familiar with the fauna in each of the national parks prior to use in our analysis.

Figure 4.1 Location of park study areas and size (ha).



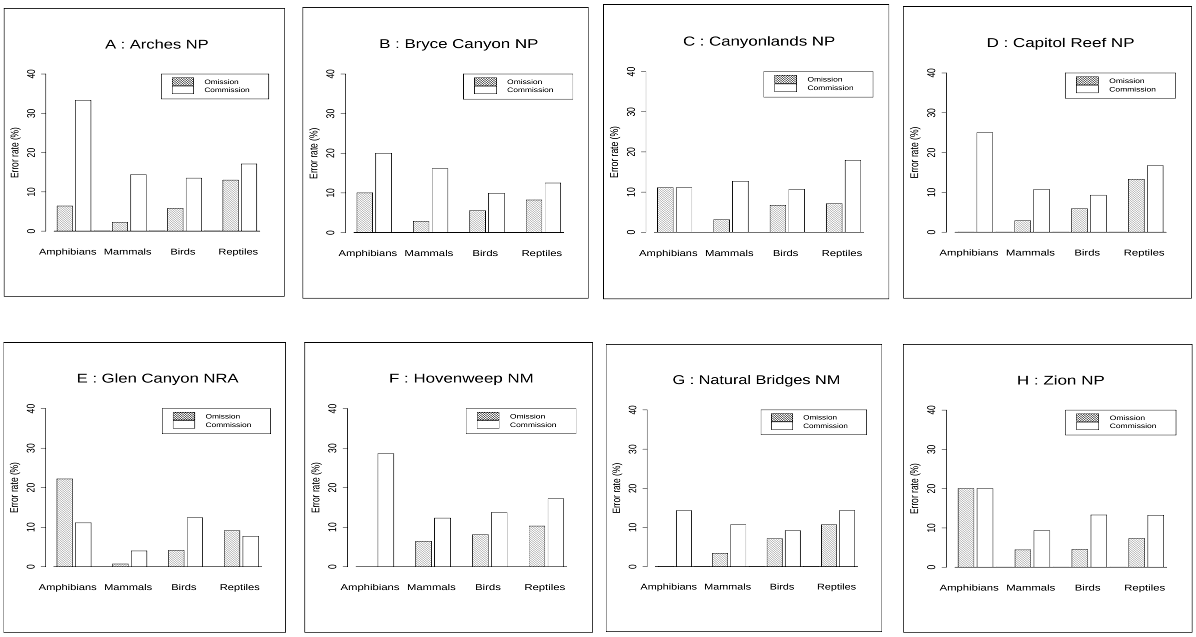
Omission and commission error rates were used as indicators of the strength of the Utah Gap Analysis WHR models. Errors of omission were defined as the percent of species not included on the Gap-predicted list, but present on the corresponding park-generated list. Conversely, an error of commission measured the percent of species incorrectly included on the Gap-predicted list. Accuracy was defined as the percent of species appearing on both the Gap-predicted and corresponding park-generated list. Omission and commission error rates were further plotted against park size to determine if error varied as a function of park size. Because information on use of each cover-type by each animal species was limited, we were unable to evaluate specific cover-type use by species. Instead, only the geographic presence of species was assessed.

Results.--A total of 481 of the 566 (84.9%) state-recognized species were predicted to occur in the eight national parks, representing 15 of 15 amphibians (100%), 315 of 353 birds (89.2%), 110 of 131 mammals (83.9%) and 41 of 67 reptiles (61.2%) in the state. Numbers of species found in the eight parks were 10 amphibians (66.7% of the state list), 282 birds (60.0%), 98 mammals (74.8%), and 46 reptiles (68.6%).

Commission and omission error for four major taxonomic groups (amphibians, birds, mammals, reptiles) in eight national parks in Utah are shown in Table 4.2. Within parks, omission error ranged from 0% to 25% for amphibians, 0.7% to 6.4% for birds, 4.1% to 7.8% for mammals, and 7.2% to 18.8% for reptiles. Omission was lowest for birds and greatest for reptiles. Commission was similarly lowest in birds, but was greatest in amphibians rather than reptiles (Table 4.2). Accuracy ranged from a high of 90.6% for birds to a low of 69.4% for amphibians.

Omission and commission error varied considerably among parks and by taxonomic group (Figures 4.2.A-H). Overall, commission was greater across all parks and taxonomic groups, with the exception of amphibians and reptiles in Glen Canyon National Park (Figure 4.1.E).

Figures 4.2.A-H. Omission and commission error by national park and taxonomic group.



A : Arches NP

B : Bryce Canyon NP

C : Canyonlands NP

D : Capitol Reef NP

E : Glen Canyon NRA

F : Hovenweep NM

G : Natural Bridges NM

H : Zion NP

Within taxonomic group, error rates tended to decrease from amphibians to reptiles to mammals to birds. Overall accuracy by taxonomic group ranged from 60.0% to 85.7% for amphibians, 81.1% to 95.3% for birds, 78.2% to 84.8% for mammals, and 69.9% to 83.2% for reptiles (Table 4.3).

Table 4.2. Number of commission errors (N_c), omission errors (No), matches (Na), and accuracy (%) for four taxonomic groups in eight national parks in Utah. Results are based a comparison of Gap Analysis-predicted and park-observed species lists.

	Amphibians				Birds				Mammals				Reptiles			
Park	N_c	N_o	N_a	% accuracy[a]	N_c	N_o	N_a	% accuracy[a]	N_c	N_o	N_a	% accuracy[a]	N_c	N_o	N_a	% accuracy[a]
Arches	2	0	4	66.7	25	4	145	83.3	7	3	42	80.8	4	3	16	69.6
Bryce Canyon	1	1	6	75.0	36	6	181	81.3	9	5	77	84.6	3	2	19	79.2
Canyonlands	1	1	7	77.8	28	7	185	84.1	7	5	63	84.0	5	2	21	75.0
Capitol Reef	2	0	6	75.0	25	7	202	86.3	8	5	73	84.9	5	4	21	70.0
Glen Canyon	1	2	6	66.7	11	2	259	95.3	12	4	81	83.5	3	4	32	82.1
Hovenweep	2	0	5	71.4	19	10	126	81.4	7	4	40	78.5	5	3	21	72.5
Natural Bridge	1	0	6	85.7	19	6	152	85.8	6	5	54	83.1	4	3	21	75.0
Zion	2	2	6	60.0	27	13	249	86.2	12	4	74	82.3	5	3	30	78.9

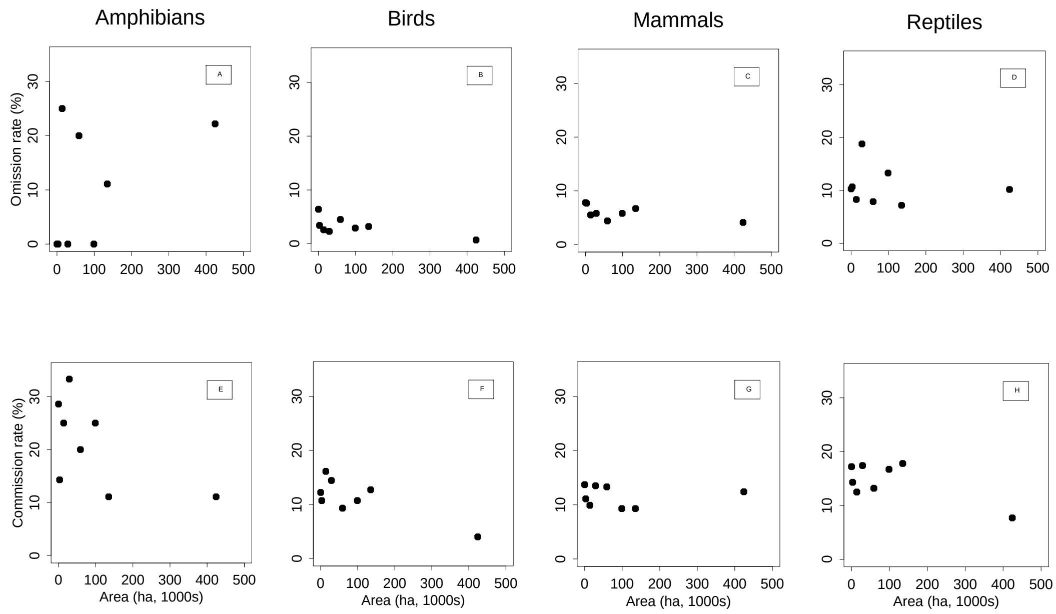
[a] Accuracy = $N_a/(N_c+N_o+N_a)$.

Table 4.3. Mean (SD) omission and commission error, and accuracy of Gap Analysis-predicted WHR models by taxonimic group for eight national parks in Utah.

	Omission (%)		Commission (%)		Accuracy (%)	
Taxonomic group	Mean	(SD)	Mean	(SD)	Mean	(SD)
Amphibians	16.07	(8.45)	14.51	(6.23)	69.42	(5.41)
Birds	1.86	(1.33)	7.51	(4.04)	90.63	(5.18)
Mammals	4.92	(1.04)	11.50	(1.51)	83.58	(1.07)
Reptiles	9.99	(1.94)	11.57	(4.50)	78.44	(4.59)

In general, omission and commission error decreased as park area increased (Figures 4.3.A-H). Amphibian error was highest; however, much of this scatter can be attributed to few amphibians per park (maximum of 11) and the resulting influence of single observations on the error rates. Park by park examination of error revealed no pattern based on guilds or other life history attributes.

Figure 4.3A-H. Omission and commission error by taxonomic group as a function of park size.



Discussion

The Gap Analysis process relies on WHR models to link animals to mapped vegetation, and then to use vegetation as a surrogate for predicting potential spatial distributions of terrestrial vertebrates (Scott et al. 1993). Once distributions are mapped, the information can be used as a course filter for siting of reserves or for other management purposes. Accordingly, an estimate of the uncertainty associated with use of WHR models is critical to use of Gap Analysis information in reserve siting or other management issues (Kareiva 1993).

Our analyses indicate that linkage of WHR models to mapped cover-types and the subsequent prediction of vertebrate spatial distributions is fairly reliable in eight national parks in Utah. Accuracy ranged from a high of 91% for birds to a low of 69% for amphibians. Error rates for amphibians and reptiles were greater than birds and mammals, not an unexpected result given the difficulties associated with observing the former two taxonomic groups relative to the latter two groups (see Heyer et al. 1994). Further, data from the parks, while carefully screened by park biologists, was not specifically collected to answer the questions we posed. The lack of design directly linked to our question undoubtedly resulted in undersampling for some rare and localized species, thereby contributing to our overall error rate.

In general, commission error was greater than omission error. This indicates that our models tend to over-predict rather than under-predict the presence of animal species. Given that Gap Analysis is a tool for predicting geographic distributions of terrestrial vertebrates for use in conservation planning, we argue that commission is preferred over omission. As a measure of uncertainty, commission could arise from many factors, including difficulties in detection among species (e.g., Mayfield 1981), bias associated with observers and sampling technique (e.g., Bart and Schoultz 1984) and problems with rare species. Although many of these problems can be overcome by establishment of rigorous inventory designs, it is virtually impossible to retroactively apply a rigorous analysis to data collected from numerous sources over extensive time periods. From the perspective of conservation planning, commission error can be considered risk-aversive. It is better to over-predict rather than under-predict. Omission, in contrast, represents species whose WHR models are inadequate in their predictive ability, and high omission leads to the potential exclusion of species from conservation plans.

Although our analyses indicate that the WHR models were sufficient for predicting species presence in eight national parks in Utah, several problems still exist in evaluating the strength of Utah Gap Analysis WHR models. First, no data exist to statistically evaluate specific habitat associations for individual animal species. Our results are restricted to presence or absence within geographic regions only and draw no conclusions about habitat use. Second, our data sets were restricted to the Colorado Plateau region of Utah. No systematically collected and reviewed data exist to test predicted animal distributions in the Wasatch-Uinta or Basin and Range ecoregions. Thus, the predicted distributions of species not found in the other two ecoregions were not evaluated. Last, as mentioned earlier, the combined effect of spatial error in the vegetation map and error in the WHR models is unknown. How error propagates when dealing with numerous information layers in a GIS remains a fruitful area of research for which little is known (see Verregin 1989, Goodchild and Gopal 1989).

A statistically reliable evaluation of specific habitat associations is currently beyond the scope of Utah Gap Analysis, and would require a long-term commitment of resources applied to numerous, randomly selected areas in the state. Nonetheless, use of vegetation as a surrogate for modelling animal species distributions remains a powerful tool for the conservation and management of biological diversity. The Utah WHR models performed well when used to predict presence or absence of terrestrial vertebrates in eight national parks in Utah and should provide valuable information for making conservation decisions in Utah.

Chapter 5

Analysis

> *There are three kinds of lies:*
> *lies, damned lies, and statistics.*
>
> *Benjamin Disraeli*

Background

A major function of Gap Analysis is to present statistics evaluating the current level of protection afforded mapped cover-types and terrestrial vertebrates. This information serves as the precursor to additional analyses designed to identify areas of high biodiversity. In other words, the identification of possible locations for the siting of additional reserves (see Bolton and Specht 1983, Kirkpatrick 1983, Margules and Nicholls 1988, Pressey and Nicholls 1991, Nicholls and Margules 1993) or areas where changes in land management practices could be considered. These kinds of analyses are beyond the scope of this report and will be presented elsewhere. Instead, we present simple descriptive statistics designed to identify those cover-types and animals receiving little current protection in Utah.

Land Ownership and Management Status

State and Federal public lands comprise roughly 81% of the 21,979,000 ha of Utah. Land protection status likewise reflects this preeminence of public control over lands (Table 5.1). Only 1,554 ha (<0.1%) of the state's land are considered Status 1 lands. These lands are owned exclusively by The Nature Conservancy. Area in Status codes 2 and 3 is 874,739 ha (3.98%) and 15,464,474 ha (70.36%), respectively. The remaining 5,638,235 ha (25.65%) are Status 4 lands. By far, most lands in Utah are nondesignated public lands subject to multiple use guidelines (i.e., Status 3) (Figure 5.1).

One potential problem with Gap Analysis management status codes is their relative "coarseness". Clearly, an administrative unit may have land that can be classified using all 4 codes. For example, Forest Plans on National Forests typically have areas placed under different management regimes, with some lands not logged and reserved for watershed or wildlife protection. Unlike a wilderness area, which has legislative basis, placement of lands under an active forest plan represents administrative control of local forests. As such, they are subject to change as forest plans evolve. Because these plans are dynamic, they do not represent protected areas as defined by Gap Analysis. Lands of this kind were considered multiple use lands and assigned management status 2. Although there

Color plate unavailable in B/W postscript format.

Figure 5.1. Depiction of the spatial distribution of Status 1, 2, 3 and 4 lands in Utah.

clearly exist some exceptions to the status rules, the status codes employed by Gap Analysis provide a meaningful context for examining biodiversity protection at ecoregion scales.

Table 5.1. Land ownership and protection status by major administrative category.

Management Status	Federal		Bureau of Indian Affairs		Private		State		Water	
	ha	%	ha	%	ha	%	ha	%	ha	%
Status 1	0	0	0	0	1,554	<0.1	0	0	0	0
Status 2	699,692	5.0	0	0	1,935	<0.1	173,109	10.4	0	0
Status 3	13,307,095	95.0	0	0	0	0	1,493,591	89.6	663,792	100
Status 4	210	<0.1	942,363	100	4,695,656	99.9	0	0	0	0
Total	14,006,997	63.7	942,363	4.3	4,699,145	21.4	1,666,700	7.6	663,792	3.0

Cover-types and Management Status

How much land is required to be protected is problematic and subject to considerable debate. Of the 36 cover-types mapped, only 6 (16.7%) have >10% of their area in Status 1 or 2 (Appendix D1). Four of these six cover types are timber or other high elevation cover types. The remaining two cover types are wetlands and barrens. Five (13.9%) cover-types have 6-10% of their area in Status 1 or 2, while the remaining 25 (69.4%) cover-types have <5% in Status 1 or 2 (Appendix D1).

A common perception is that there currently exists sufficient protected lands that preserve and maintain biological diversity. Our analyses indicate that while some cover-types are protected, the majority of mapped cover-types in Utah have less than 10% of their area in protected status. Our analysis also indicates that any protection afforded Utah lands is more a product of random sampling than a systematic approach to the protection to the diversity of vegetation cover-types found in Utah. It may be, however, that a more reasoned approach to the management of lands for conservation of biological resources should include a systematic evaluation of the geographic distribution of these resources.

Species Distributions and Management Status

Levels of protection afforded terrestrial vertebrates varies by taxonomic group (Table 5.2), with mammals as a group having the greatest number of species with >10% of their habitat contained in Status 1 and 2 lands. Birds and reptiles had the least number of species with >10% habitat in Status 1 or 2, and amphibians somewhere intermediate. By far, the vast majority of Utah terrestrial vertebrates have <5% of their habitat in Status 1 or 2 lands. Most habitat occupied is Status 3, reflecting in part the large amount of public lands subject to multiple use guidelines (Appendix D2).

Table 5.2. Number (%) of species by taxonomic group and amount of Status 1 and 2 habitat in 0-5%, 6-10% and >10% increments.

	0-5%		6-10%		>10%	
Taxonomic Group	No.	(%)	No.	(%)	No.	(%)
Amphibians	11	(78.6)	2	(14.3)	1	(7.1)
Birds	206	(65.4)	100	(31.8)	9	(2.8)
Mammals	71	(55.0)	41	(31.8)	17	(13.2)
Reptiles	53	(79.1)	13	(19.4)	1	(1.5)

No real patterns were apparent when examining those species with >10% of their habitat(s) in Status 1 or 2. Only one species each of reptiles and amphibians had >10% of their habitat in Status 1 or 2. The 9 birds having >10% of their habitat in Status 1 or 2 were all associated with wetland, a cover-type well represented in the Status 2 category (18.5%). In contrast to the low Status 1 or 2 percentage of other taxonomic groups, 13% (17 of 129) of the mammals had >10% of their lands in Status 1 or 2. Species meeting this criterion are typically found at higher elevations (e.g., mountain goat *Oreamnos americanus*, pine marten *Martes americana*) and occupy habitat found almost exclusively in current Wilderness Areas in Utah. Whether the areal extent of these lands is sufficient to maintain viable populations is questionable and requires additional research. Of the 13 Wilderness Areas in Utah, only 5 are even large enough to encompass the estimated home range of the largest mammal whose distribution overlaps the wilderness area (A. Hoss, unpublished data); clearly their value as a reservoir for maintenance of viable populations of the state's largest mammals is questionable. How these lands might interact with surrounding Status 3 lands, however, deserves further consideration before any definitive statements regarding their value for maintaining viable populations can be made.

Chapter 6

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Chapter 7

Gap Analysis Encyclopedia

Gap Analysis is a proactive approach to protecting biodiversity. It seeks to identify gaps in the biological reserve network that may be filled through the establishment of new reserves or changes in land management practices. This will ensure that a complete sample of taxa will be guarded from future disturbance. In the past, areas have been set aside often without regard to their biodiversity content. As a result, many managed areas have little significance in terms of biodiversity, and many areas that are highly significant lack management. Gap Analysis works by overlaying maps of land cover and species occurrence onto maps of managed areas, using Geographic Information System (GIS) technology. The resulting maps show the relationship between areas of biological significance and the level of management afforded these areas.

The Encyclopedia is an effort to bring together all aspects of Gap Analysis into one complete package accessible through the INTERNET. It is available via the World Wide Web using a hypermedia viewer such as NCSA Mosaic. It's Universal Resource Locator (URL) is:

http://www.nr.usu.edu/gap/gaphome.htm

The goal of the Encyclopedia is to facilitate communication and the dissemination of Gap Analysis information to the user community. The Encyclopedia provides you with information through links to the following sections:

1. OVERVIEW

   Here are three introductions to Gap Analysis including the unabridged Wildlife Monographs pamphlet. There is also a section the United Nations and biodiversity, and even an on-line slide show.

2. HOW-TO MANUAL

   Click here to find out all of the technical aspects of GAP. The links tell how each stage of the process is completed including national standards and metadata standards.

3. ON-LINE DATA AVAILABLE

   Within this link you will find a map of the United States, and you can click on individual states or ecoregions to download GAP data.

4. BULLETIN BOARD

   This link puts you in touch with the people behind the scenes. Post a bulletin or read what others have to say. You can even have bulletins e-mailed directly to you.

5. INVESTIGATORS AND COLLABORATORS

   This is a complete list of GAP contacts listed by state.

6. REFERENCES

   References contains articles written about Gap Analysis or biodiversity.

We are committed to improving access to and the quality of our information and welcome all comments and suggestions. For more information contact:

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