Transnational Gap Analysis of the Rio Bravo/Rio Grande Region

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Abstract

Gap analysis is a GIS *approach to biodiversity currently employed throughout the continental United States to determine how well native biodiversity is represented in the network of conservation lands. Here, we describe an effort to apply gap analysis to the Rio Bravo/Lower Rio Grande region of Mexico and the United States. Implementation of the study was preceded by establishment of an agreement between the Mexican National Commission for the Knowledge and Use of Biodiversity (*CONABIO*) and the U.S. Geological Survey. The study will generate land-cover habitat and vertebrate distribution maps for an area that straddles the Rio Bravo/Lower Rio Grande basin extending from Ciudad Juarez, Chihuahua/El Paso, Texas to the Gulf of Mexico. Vertebrate modeling, based on habitat associations, will identify habitats potentially important to vertebrate life cycles and areas of high biodiversity. A map of land management practices relevant to biodiversity conservation will precede a "gap analysis," which will identify potential areas for the region's reserve network. We also describe the project's use of a novel software program (Spectrum) to analyze Landsat Thematic Mapper imagery. Conducting the gap analysis in Mexico and relating it to the gap analysis for Texas will reveal how well biodiversity of the Rio Grande Border region is actually protected by the current reserve network.*

Introduction

The lower reach of the Rio Grande (known in Mexico as the Rio Bravo) forms 2,000 km of the international border between Mexico and the United States from Ciudad Juarez, Chihuahua/El Paso, Texas to the Gulf of Mexico. This natural border has been a focus of increasing interest among a wide variety of state and federal agencies in both countries primarily because of a recent economic agreement (North American Free Trade Agreement, NAFTA). NAFTA has the potential to promote additional commerce and population growth along the Lower Rio Grande. However, additional human activity in the Lower Rio Grande region has important ecological consequences because the Lower Rio Grande Valley contains high biodiversity within a variety of ecosystems (Inglis, 1961; Diamond *et al.*, 1992). Given current projections of economic growth, the viability of many species and natural communities in the Lower Rio Grande region may well depend on cooperative planning efforts between the United States and Mexico.

In the United States, efforts to define a conservation strategy have led to development of three approaches: (1) addressing acute problems (e.g., Endangered Species Act; Gordon *et al.*, 1997), (2) focusing on integrated management of existing reserves and adjacent lands (e.g., ecosystem management; Grumbine, 1994), and (3) identifying sites for new reserve establishment (Scott *et al.*, 1987; Scott *et al.*, 1993). The latter approach has been primarily implemented through "gap analysis," a GIS approach to determining "gaps" in the current reserve network. In the U.S., gap analysis is being conducted in all of the continental states under the coordination of the U.S. Geological Survey's National Gap Analysis Program (USGS-GAP, http://www.gap.uidaho.edu/gap/). Over the past several years, USGS-GAP has developed a four-stage method of identifying conservation gaps. The first step is to map land-cover types primarily through interpretation of Landsat Thematic Mapper (TM) imagery, aerial videography, field reconnaissance, and other ancillary information. Second, models of vertebrate distributions are produced based on geographic location data and habitat association models. The third step is the delineation of land-management categories relevant to biodiversity. Land management categories range from 1 to 4, with one indicating a protected reserve where natural processes occur and four indicating land management that does not consider impacts on biodiversity. The final step is the actual gap analysis, in which models are run to determine which species and which habitat types are not adequately represented in the existing reserve network.

Although practicalities limited the first decade or so of USGS-GAP efforts to establishing the program at a state-by-state level and linking those states together, it is obvious that effective conservation of biodiversity must overcome limitations imposed by political boundaries at the national level. The gap analysis effort in Texas (http://www.tcru.ttu.edu/txgap/home/index.html) is now in the process of mapping vegetation alliances and vertebrate species distributions in that state. The value of that effort to the many parties interested in conservation issues related to the biodiversity of the Lower Rio Grande is diminished due to the truncation of the analysis at the international border.

In response to criticisms related to the inadequacy of gap analysis for concerns related to the Lower Rio Grande Basin, the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO)(http://www.conabio.gob.mx/) and the U.S. Geological Survey (USGS)(http://www.usgs.gov/) es-

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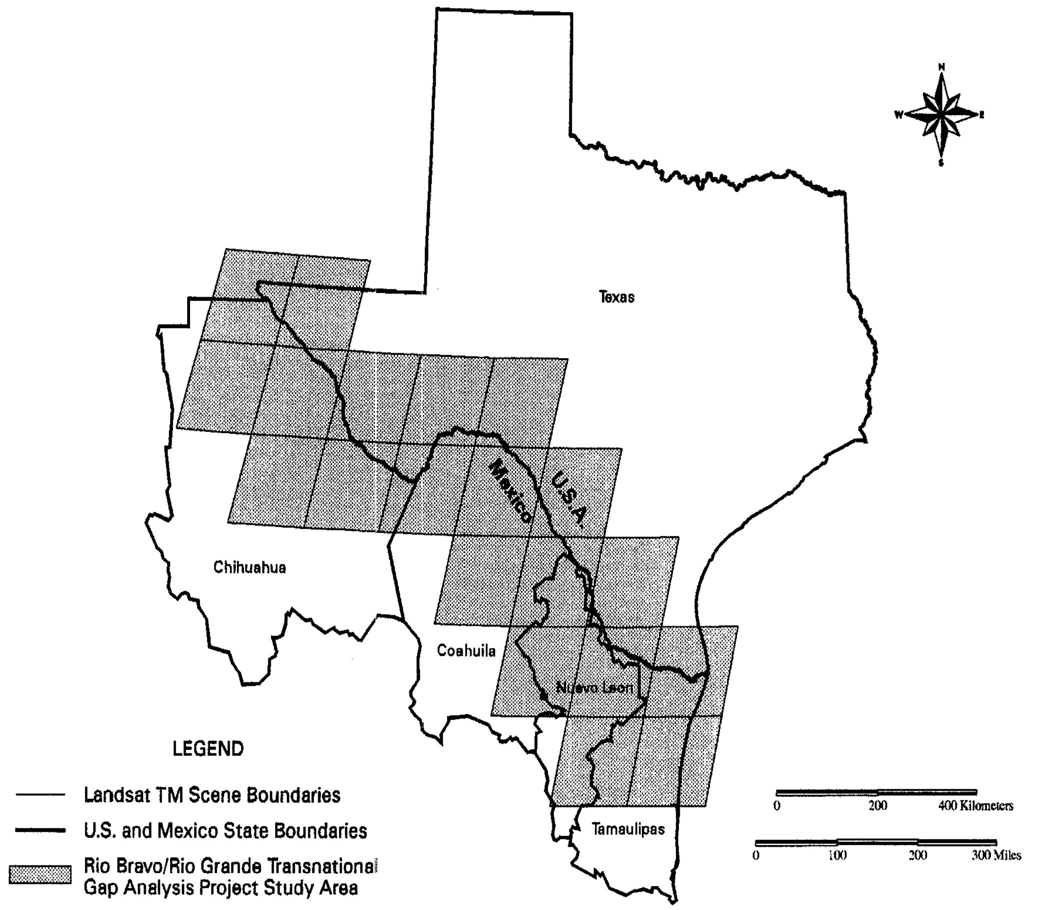

Figure 1. Rio Bravo/Rio Grande Gap Analysis Project study area (delimited by satellite scenes).

tablished a partnership to conduct a gap analysis of the region. These efforts represent the first international gap analysis project (Gonzalez-Rebeles *et al.*, 1997a).

The total area proposed for the Mexico-U.S. gap analysis effort includes a region covered by 20 Landsat TM scenes (corresponding to northeastern Chihuahua and the northern portions of Coahuila, Nuevo Leon, and Tamaulipas in Mexico and to southern Texas in the U.S.). Fourteen of the scene areas straddle the border, and the portions of these scene areas in Texas are being mapped as part of the Texas Gap Analysis Project (Texas GAP). The remainder of these scene areas and a set of six adjacent scene areas entirely contained in Mexico will be mapped to form the 150-km wide coverage for the Rio Grande border region (Figure 1). The project is planned to be completed by the end of 1999.

Project Description

Although the Lower Rio Grande gap analysis will adhere to standards set by National GAP (Scott *et al.*, 1993; Gap Analysis Program, 1997), some new analysis techniques will also be employed during the study. Standard techniques used for the project include land cover, which will be mapped through digital classification of satellite imagery supported by field surveys and ancillary information. Accuracy assessment will involve a statistical comparison of subset samples from the classified scene to ground observations. Vertebrate distribution predictions will be modeled from known location data based on recent museum and other records and the species-habitat associations described earlier. These distribution estimates will be verified through expert review and comparison of the estimates for specific areas where detailed inventories exist. Mexico has established a strong centralized database of vertebrate specimen records housed at CONABIO's headquarters in Mexico City. This database will substantially improve vertebrate distribution modeling for the study area.

Although land-management classification will follow the National GAP methodological approach, land management in Mexico differs considerably from the system in the United States. Ultimately, however, the specific system of Mexican land tenure (e.g., "ejidos," communal, public, and private land) will be categorized into the four levels of management oriented to biodiversity conservation that were described earlier. Vegetation, species, and land stewardship maps from both Mexico and Texas must be combined (edge-matched) before analysis. The gap analysis will involve combining all data (integrated as different thematic coverages) into a geographic information system (GIS) to evaluate how vegetation communities, sites with maximum number of species overlap, and, where appropriate, single species distributions are represented in existing managed areas. Once the final gap analysis has been completed, the variety of agencies and groups interested in biodiversity conservation can begin a knowledge-based dialogue about the adequacy or inadequacy of the region's current reserve system.

Application of Spectrum Software to Gap Analysis

Land cover is both the initial and perhaps most critical thematic layer in gap analysis. It represents the spatial distribution of current vegetation in the study area, it is an indicator of habitat type, and it is a primary parameter in models of

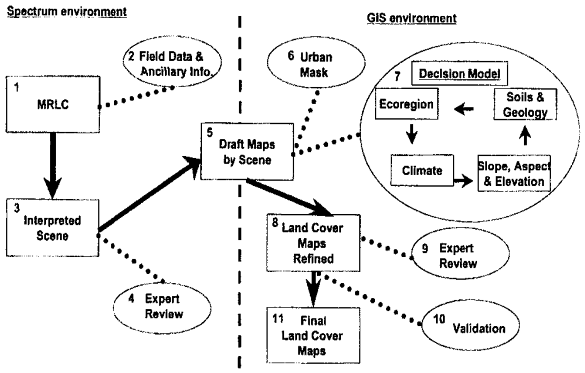

Figure 2. Land-cover analysis process followed by Texas and the Rio Bravo/Rio Grande Gap Analysis Projects.

(1) MRLC hyperclustered TM scene (240 classes of clusters/scene).

(2) Location (UTM coordinates) and description of the vegetation observed in the field together with ancillary information (vegetation maps, literature, and expert consultation) are used to ground-truth the MRLC scene.

(3) Spectral patterning on the scene labeled with the different types of vegetation present in the area.

(4) Preliminary map by scene in raster format (printed or digital copy is submitted for expert review).

(5) Preliminary labeled scene exported from Spectrum and saved as a binary file for further spatial analysis and editing (GIS processing).

(6) USGS digital line graphs are used to create a mask of urban and other cultural features and facilitate the refinement (edition) of vegetation.

(7) Interpreted (labeled) scenes are run through a model that adds and eliminates classes from clusters. This model is developed from logical arguments based upon a class being present or eliminated from combinations of habitat characteristics. This step, checks the interpretation process in Step 2.

(8) An edited map with land cover refined by scene is produced (vegetation descriptions from the field are aggregated to the level of land-cover classes defined by the classification scheme selected).

(9) Another round of expert reviews of the models and refined products.

(10) The accuracy in predicting vegetation types is assessed in the field based on a random sample of points.

(11) A final land-cover layer is produced in the GIS (raster or vector format) and is ready to be edge-matched and processed according to the standards required by the National Gap Analysis Program.

Additional Notes:
- Squares represent products (images, thematic coverages, or maps).
- Ovals represent processes performed to products.

wildlife species distribution (Scott *et al.*, 1993; Stoms, 1996). For Texas GAP, a methodological approach was adopted for producing an analysis of land cover in a relatively short time frame (Gonzalez-Rebeles *et al.*, 1997b). This same approach will be followed for the Lower Rio Grande gap analysis. Here, we provide a brief description of the methodology for interpreting preprocessed Landsat TM scenes (Benjamin *et al.*, 1996; Campbell, 1996; Loveland and Shaw, 1996) using the Spectrum software package (Khoral Research, Inc., Albuquerque, New Mexico; http://www.Khoral.com). Spectrum was specifically designed for the analysis of preprocessed satellite images such as those used by GAP (i.e., Multi-Resolution Land Characterization (MRLC) Consortium TM imagery; Benjamin *et al.* (1996); see also the MRLC web-page: http://www.epa.gov). Texas GAP has been one of the pioneers to apply these new tools and has worked together with Spectrum software developers to test and enhance the program for gap analysis applications (Gonzalez-Rebeles *et al.*, 1997b).

The MRLC scenes are radiometrically and geometrically corrected and preliminarily classified following a special unsupervised classification approach termed "hyperclustering" (Kelly and White, 1993; Benjamin *et al.*, 1996). The hyperclustering algorithm identifies 240 clusters of spectral data, grouping sets of individual pixels having similar spectral characteristics in six of the seven spectral bands recorded by the satellite. In the resulting scene, individual pixel values represent the mean values of the clusters produced across the six bands. These clusters are linked to a statistical codebook that permits calculations to explore spectral properties of the hyperclustered scene. The format of the consequent dataset provides a minimum ground mapping unit of 30-m pixels which is then available for use in a common computer display environment for further image analysis and manipulation. Spectrum is a special image visualization and analysis program developed specifically for the categorization of these hyperclustered scenes. Its design and analysis capabilities provide a means for the direct interpretation of the spectral pattern observed in the scene as supported by ancillary information or ground-truthing (Benjamin *et al.*, 1996; and Myers *et al.* 1995).

In general terms, land-cover analysis is based on a computer-assisted image interpretation approach (Figure 2). Through visual examination of the MRLC hyperclustered scenes in the Spectrum environment, the analyst identifies and delineates different geographic areas based on their combined spectral and spatial characteristics (e.g., reflectance values, color, texture, associations or context, and location). Ancillary information (e.g., vegetation and topographic maps) together with ground-truthing (field surveys, air photos, and airborne videography) can then be used to classify and label the geographic areas selected according to the landscape features they represent (i.e., land-cover types). The process involves the selection and labeling of those pixel clusters that form the area of interest. The Spectrum program will select and automatically label into the same class all other pixel clusters of the hyperclustered scene with the same spectral values as the ones selected. The process is continued iteratively until all pixel clusters (individually and by groups) potentially representing different landscape features are classified according to predetermined categories. An interpreted image, with all pixel clusters labeled for the land-cover classes of interest, is produced and saved as a binary file. At this point, the file can be transferred to a GIS program (e.g., ARC/INFO, ESRI, Inc., Redlands, California) for iterative refinement and editing.

Finally, the map vegetation polygons are labeled according to The Nature Conservancy (TNC) classification scheme (Weakley *et al.*, 1996). This is a hierarchical system based on both vegetation physiognomy and floristics and follows the standards established by National GAP (Jennings, 1993; Jennings, 1996). For labeling purposes, we extracted all the vegetation types (i.e., Alliance level) described for Texas by the TNC. Based on our fieldwork data and expert review, we plan to also include additional vegetation communities present in Texas and adjacent regions of Mexico (i.e., some not listed by the TNC). Although no formal accuracy assessments have been developed at this time, the iterative process of going to the field and returning to the laboratory for the digital classification process permits progressive verification of the developing classified maps. Preliminary observations have shown a high correlation of the maps under preparation and the vegetation types observed in the field. Overall, Spectrum has proved to be a quick and effective tool for mapping land cover, and has freed resources formerly applied to image analysis techniques, allowing greater attention to biology, systematics, and groundtruthing.

Conclusions

The Rio Bravo/Rio Grande International Gap Analysis project will generate valuable geographic and biological data sets to support conservation and land-use planning; provide opportunities for cooperative, binational data sharing; and develop the potential standardization of procedures applicable in this region with common ecological characteristics. General objectives proposed for the project are (1) to conduct a regional gap analysis of the Rio Bravo/Rio Grande region and produce maps of land cover, terrestrial vertebrates distributions, and land management; and (2) to combine the biological and geographic databases produced to propose a strategy for the integrated conservation and land-use planning of this Mexico-U.S. border region. It is expected that the experiences and results obtained from this study will help CONABIO evaluate the feasibility of applying gap analysis techniques to other regions of Mexico. Indeed, recent discussions between USGS representatives and CONABIO have focused on development of a Mexican gap analysis program at the national level to complement present conservation planning activities in Mexico.

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References

Benjamin, S., J. M. White, D. Argiro, and K. Lowell, 1996. Land cover mapping with Spectrum, *Gap Analysis: A Landscape Approach to Biodiversity Planning* (J.M. Scott, T.H. Tear, and F.W. Davis, editors), Amer. Soc. for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp. 279–288.

Campbell, P., 1996. MRLC update and new data rules for TM access: The Landsat program management agreement, *GAP Analysis Bulletin*, 5:11–12.

Diamond, D.D., L.A. Linman, J.M. Poole, P. Mehlhop, and M. Trevino, 1992. Rare species and communities in the Texas-Mexico borderlands, *Proceedings of the Fifth U.S.-Mexico Border States Conference on Recreation, Parks, and Wildlife*, 24 p.

Gap Analysis Program, 1997. *A Handbook for Gap Analysis*, USGS Gap Analysis Program, Moscow, Idaho (http://www.gap.uidaho.edu/gap/handbook).

Gonzalez-Rebeles, C., N. Parker, V. Burke, M. Jennings, and G. Ceballos, 1997a. First International Gap Analysis Project, *GAP Analysis Bulletin*, 6:33–34.

Gonzalez-Rebeles, C, N.C. Parker, R.W. Sims, Y. Lan, and M. Cano, 1997b. Spectrum software for Texas Gap Analysis, *GAP Analysis Bulletin*, 6:24–27.

Gordon, R.E., Jr., J.K. Lacy, and J.R. Streeter, 1997. Conservation under the Endangered Species Act, *Environment International*, 23(3): 359–419.

Grumbine, R.E., 1994. What is ecosystem management? *Conservation Biology*, 8(1):27–38.

Inglis, J.M., 1961. *History of Vegetation on the Rio Grande Plain*, Texas Parks and Wildlife Department, Publication No. 45, 122 p.

Jennings, M.D., 1993. Natural terrestrial cover classification: Assumptions and Definitions, *Gap Analysis Technical Bulletin 2*, U.S. Fish and Wildlife Service, Moscow, Idaho, 17 p.

———, 1996. Mapping units: Their classification and nomenclature for Gap Analysis land cover data, *Gap Analysis: A Landscape Approach to Biodiversity Planning* (J.M. Scott, T.H. Tear, and F.W. Davis, editors), Amer. Soc. for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp. 71–78.

Kelly, P.M., and J.M. White, 1993. Preprocessing remotely sensed data for efficient analysis and classification, *SPIE Proceedings: Applications of Artificial Intelligence 1993: Knowledge-Based Systems in Aero-Space and Industry*, pp. 24–30.

Loveland, T.R., and D.M. Shaw, 1996. Multi-resolution land characterization: Building collaborative partnerships, *Gap Analysis: A Landscape Approach to Biodiversity Planning* (J.M. Scott, T.H. Tear, and F.W. Davis, editors), Amer. Soc. for Photogrammetry and Remote Sensing, Bethesda, Maryland, pp. 79–85.

Myers, W., G. Thelin, A. Rasberry, S. Benjamin, J. Hood, P. Etzler, J. Majure, J. Brakebill, P. Green, and J. Findley, 1995. SPECTRUM – Satellite image interpretation with automated delineation: A workshop-based assessment of SPECTRUM software, *GAP Analysis Bulletin*, 4:10–13.

Scott, J.M., B. Csuti, J.D. Jacobi, and J.E. Estes, 1987. Species richness – A geographic approach to protecting future biological diversity, *BioScience*, 37:782–788.

Scott, J.M., F. Davis, B. Csuti, R. Noss, B. Butterfield, S. Caicco, C. Groves, T.C. Edwards, Jr., J. Ulliman, H. Anderson, F. D'Erchia, and R.G. Wright, 1993. Gap Analysis: A geographic approach to protection of biological diversity, *Wildlife Monographs*, 123:1–41.

Stoms, D.M., 1996. Actual vegetation layer, *A Handbook for Gap Analysis*, USGS Gap Analysis Program, Moscow, Idaho (http://www.gap.uidaho.edu/gap/handbook).

Weakley, A.S., K.D. Patterson, S. Landaal, M. Gallyoun, and others (compilers), 1996. *International Classification of Ecological Communities: Terrestrial Vegetation of the Southeastern United States*, Working Draft of April 1996, The Nature Conservancy, Southeast Regional Office, Southern Conservation Science Dept., Community Ecology Group, Chapel Hill, North Carolina, 374 p.