

A Landscape Approach for Detecting and Evaluating Change in a Semi-arid Environment; San Pedro Watershed (U.S./Mexico)

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ENVIRONMENTAL ISSUE

Land managers in the Southwest have traditionally been interested in status and trends in environmental conditions. The principal degradation processes that have occurred throughout the western arid and semi-arid watersheds involve 1) changes of vegetative cover, i.e. decrease in above ground biomass and compositional diversity, which result in the introduction of exotic annual species or woody xerophytic shrubs and trees, and 2) acceleration of water and wind erosion processes which result in soil loss and decrease water infiltration and storage potential. Historically, these have been linked to both human-induced and natural stressors, i.e. livestock grazing and short-term drought. However, within the last 25 years, rapid urbanization in the arid and semi-arid Southwest has become an important anthropogenic factor in altering land cover composition and pattern.

The U.S. Environmental Protection Agency (EPA) and the Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora (IMADES) have initiated a regional approach to assess ecological risk relative to exposure to environmental stressors under the Interagency Semi-Arid Land Surface-Atmosphere (SALSA) program. SALSA is a collaborative research effort composed of international scientists committed to the study of land degradation processes in semi-arid areas using advanced space-based technologies. The project area is the Upper San Pedro River basin, an international watershed, which is part of the Lower Colorado River system. A key component of the SALSA framework entitles landscape ecology as a theoretical basis from which to assess cumulative exposure to stress at multiple spatial and temporal scales. This project has focused its research in developing a system of landscape composition and pattern indicators that can be used to estimate current status, trends, and changes in ecological and hydrological condition.

RESEARCH GOALS

ESD Landscape Science is focused on the interaction between landscape patterns and ecological processes, especially as they affect the natural flows of water, energy, nutrients, and biota in the environment. The goal is to improve decision-making relative to natural and human resource management through the development of landscape metrics and models.

The goal of this project was to determine ecosystem vulnerability in a Southwestern semi-arid watershed (described below) relative to large-scale natural or human-induced disturbances using a system of landscape pattern metrics derived from remote sensing, spatial statistics, and geographic information systems technology. The project uses the database from the North American Landscape Characterization (NALC) project, which incorporates triplicate Landsat Multi-Spectral Scanner (MSS) imagery from the early 1970s, mid-1980s, and early 1990s, which have been reprojected to UTM coordinates with 60-m pixels. It also utilizes 1997 Landsat Thematic Mapper (TM) imagery which has been re-sampled and mapped at 60-m resolution for comparison.

Site Description

The Upper San Pedro Watershed represents a transition area between the Sonoran and Chihuahuan Deserts and is internationally renowned for its biodiversity. It supports the second highest land mammal diversity in the world and provides habitat for almost 300 bird species. The riparian zone has been acquired by the U.S. Department of the Interior and has been assigned special land status as a National Conservation Area. Topography, climate, and vegetation vary across the watershed. Elevation ranges from 900 to 2,900 m and annual rainfall ranges from 300 to 750 mm. Biome types include desertscrub, grasslands, oak woodland-savannah, mesquite woodland, riparian forest, coniferous forest, and agriculture. The upper watershed encompasses an area of approximately 7,600 km² (5,800 km² in Arizona and 1,800 km² in Sonora, Mexico).



Upper San Pedro Watershed (U.S./Mexico)

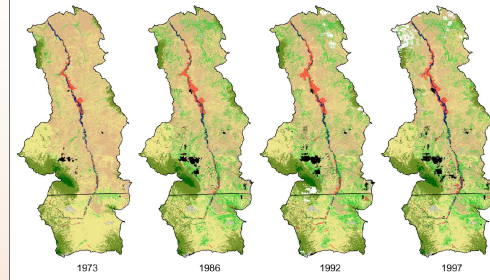
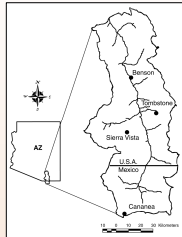
Collaborators:

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METHODS/RESULTS

Source Data

For this project, remote imagery was derived from Multi-spectral Scanner (MSS) and Thematic Mapper (TM) sensors via Landsat earth observing satellites (path/row 35/38 and 35/39). Landsat-MSS satellite scenes were selected from the North American Landscape Characterization (NALC) project. The scenes available in the NALC database (1973-92) and Landsat TM (1997) are from four pre-meridian dates for a period of approximately 25 years (i.e. 5 June 1973, 10 June 1985, 2 June 1992, 8 June 1997). All imagery in the database is re-registered and georeferenced to a 60 x 60 meter Universal Transverse Mercator (UTM) ground coordinate grid with a nominal geometric precision of 1-1.5 pixels (60-90 m). Digital land cover maps were developed separately for each year using 10 classes: Forest, Oak Woodland, Mesquite Woodland, Grassland, Desertscrub, Riparian, Agriculture, Urban, Water, and Barren.



Change Detection/Statistics

The first step in the image classification was using ERDAS IMAGINE 8.3 software procedure (ISODATA) to perform an unsupervised classification using bands 1 (green), 2 (red) and 4 (near infrared) to produce a map with 40 spectrally distinct classes. The choice of 60 classes was based on previous experience with NALC data and usually gave satisfactory trade-off between the total number of classes and the number of mixed classes. In this context, it proved helpful to define a larger set of 21 intermediate classes, which were easier to relate to the spectral information. For example, the Barren class contains bare rock, chalk deposits, mine tailings etc., which have very different spectral signatures. Each class was then displayed over the false-color image and classes were assigned into one of the 21 land cover categories or as mixed. The software allows the interactive manipulation of the signatures for each class which allowed many of the mixed classes to be resolved. The remaining mixed classes were separated into different categories using a variety of ancillary information sources, such as the topographic maps (scale 1:50,000) produced by INEGI, the Mexican National Institute of Statistics, Geography and Information, and by the U.S. Geological Survey (scale 1:24,000). The land use information varied depending on the image being analyzed. Thus the classification of the 1997 image relied heavily on field visits to establish ground control. Five 3-day site visits were carried out from September 1997 to June 1998 to collect specific land cover data with the aid of Global Positioning System equipment, and these data were incorporated into successive iterations of the classification process.

Change was analyzed using landscape statistical software to produce landscape statistics, including total extent, image enhancement in ARC/INFO allows mathematical treatment of the composite images and to display change, either as gain, loss, or no change. Landsat-MSS 1973 was used for the baseline condition. Change between time intervals, i.e., 1973, 1986, 1992, and 1997 was measured and the discrete landscape metrics were described. Landscape statistics that describe shape and size were used to assess dominance, fragmentation, and rates of conversion in an effort to determine sensitive measures for resistance to change (i.e., landscape resilience). Sample size was 2,100,407 pixels (60 m resolution) per digital image map.

Results indicate that extensive grassland and desertscrub areas with high connectivity are the most vulnerable biome type to encroachment of woody shrubs (mesquite). During the period of study, grasslands and desertscrub decreased by approximately 16% and 22%, respectively, on a relative basis. Xerophytic cover types, i.e. mesquite woodland, increased in overall extent by 38%, in 1997, grasslands remained the most extensive land cover type within the study area; however, human-dominated activity has resulted in major increases in anthropogenic cover during the last 25 years.

Mesquite woodland has experienced the most rapid increase in extent during the study period. More than 80,000 ha of mesquite were gained since the 1973 baseline, and it has undergone expansion by aggregation to form clusters which later coalesced into large woodland patches. The number of mesquite polygons (patches) and average patch size have increased steadily throughout the study area. Mesquite patches have increased up to 5.71 ha in size and increasingly become more connected resulting in large stands with closed canopies. Urban cover has also increased during the study period. Similar to mesquite, urban cover has increased in the number of patches and size from 418 and 982 ha to 3,010 and 4,938 ha, respectively. However, average urban patch size and connectivity have actually decreased, likely due to urbanization of the outlying suburban areas. The majority of mesquite and urban gain during the 25-year study period were predominantly derived from desertscrub and grassland cover classes. Subsequently, desertscrub and grassland show a general trend in fragmentation and actual loss. Total extent for these two cover classes decreases through time and the number of patches increases. Additionally, the average patch size for desertscrub and grassland decreases from 11.3 to 5.76 ha and 6.18 to 4.54 ha, respectively and connectivity decreases from the 1973 baseline.

	GRASSLAND			DESERTSCRUB		
	1973	1997	% Rel. Change	1973	1997	% Rel. Change
AREA (ha)	312,850	263,432	-15.8	296,330	229,953	-22.4
% COVER	41.4	34.8	-15.8	39.2	30.4	-22.4
# OF PATCHES	50,715	58,142	+14.6	26,260	39,991	+52.3
LARGEST PATCH (ha)	126,258	53,173	-57.9	201,165	37,361	-81.4
AVERAGE PATCH SIZE (ha)	6.18	4.54	-26.5	11.3	5.76	-49.0
CONNECTIVITY	0.62	0.56	-9.7	0.66	0.55	-16.7

	MESQUITE WOODLAND			URBAN		
	1973	1997	% Rel. Change	1973	1997	% Rel. Change
AREA (ha)	20,821	101,602	+388.0	3,205	16,494	+414.6
% COVER	2.8	13.4	+388.0	0.4	2.2	+414.6
# OF PATCHES	15,558	53,310	+242.7	418	3,010	+620.1
LARGEST PATCH (ha)	462	3,574	+674.3	982	4,938	+402.8
AVERAGE PATCH SIZE (ha)	1.34	1.91	+42.5	7.86	5.55	-29.4
CONNECTIVITY	0.31	0.37	+19.4	0.74	0.69	-6.8

CONCLUSIONS

The methods developed as an outcome of this study have been employed for their capability to assess the spatial and temporal changes in land use and land cover at a landscape scale and to subsequently determine an effective means to measure landscape stability over large assessment areas such as watersheds. The ability to interpret condition and change over large areas has only become feasible with the availability of remotely sensed data such as Landsat. The advantages of this new approach make it possible to 1) observe large geographic areas and multi-jurisdictions in their entirety, 2) quantify landscape pattern and the areal extent of resources, 3) observe changes and trend in large-scale patterns through time, and to 4) assess cumulative sources of environmental perturbation.

Specifically, remote sensing integrated into a GIS environment provides an ability to characterize large assessment areas and establish reference condition. The use of landscape metrics based on land cover generated from remote sensors provides a unique opportunity to assess areas of large regional scale. In terms of the alternative landscape analysis it fulfills the need to describe the landscape in terms of content, boundaries, space, and time and thus provides the representative model for the initial step of scenario analysis.

Moreover, the results of this research will benefit decision-makers and natural resource managers who are principally interested in evaluating present and past cumulative impacts to a watershed or formulating alternative management strategies to sustain environmental health and economical viability into the future. The pattern measurements from this research provide predictive inference (a change model) for measuring and evaluating change in the San Pedro watershed. Thus it serves to answer questions related to how might the landscape be changed by current projected trends.

