A Landscape Approach to Monitoring and Assessing Environmental Condition in the Upper San Pedro River Basin

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1. ABSTRACT

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 enlists 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 into developing a system of landscape composition and pattern indicators that can be used to estimate current status, trend, and changes in ecological and hydrological condition. Specifically, it is designed to determine ecosystem vulnerability relative to large-scale natural or man-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 project, which incorporates triplicate Landsat Multi-Spectral Scanner (MSS) imagery from the early 1970s, mid 1980s, and early 1990s, which have been remapped and projected to UTM coordinates with 60-m pixels. It also utilizes 1997 Landsat Thematic Mapper (TM) imagery which has been resampled and mapped at 60-m resolution for comparison.

Little quantitative information on a regional or watershed scale is available about the status of land degradation for rangelands such as those that occur in the San Pedro watershed, yet these represent the most extensive land use type in the world's drylands. Nearly 85% of the North American rangelands are estimated to be in degraded condition; more than any other continent in the world. Landscape composition, connectivity, patch size and patch number were used to evaluate ecosystem resilience and changes in land cover extent over an approximate 25-year period in the San Pedro River basin.

While primary anthropogenic stressors in the project area include urbanization and livestock grazing, they differ in their magnitude and distribution throughout the watershed. Preliminary evaluation of composition, patch size, patch number, and connectivity landscape metrics suggest that these metrics may be useful in evaluating ecosystem resilience and changes in land cover extent. The preliminary results of this project are presented to 1) illustrate both the indicator and change detection strategy and 2) demonstrate the potential application of the approach for developing a regional or watershed program for systematic assessment of ecological condition, especially in regard to land degradation in arid and semi-arid regions of the United States and Mexico.

San Pedro near Lewis Springs

1891 1994

San Pedro near St. David

1890 1962

2. RANGELAND STATUS AND TREND

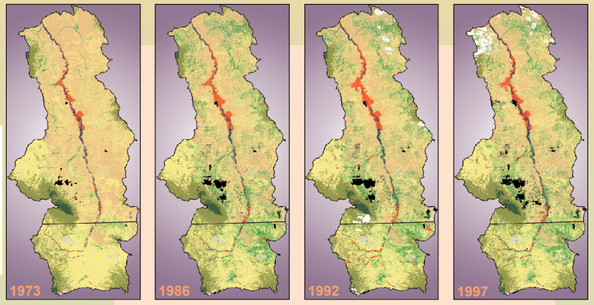
Land managers in the Southwest have traditionally been interested in status and trend in environmental conditions. The principal degradation processes that have occurred throughout the western rangelands involves 1) changes of vegetative cover, i.e. decrease in above ground biomass and compositional 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. Differences in rangeland trend are depicted in the series of repeat photographs for the San Pedro River basin near Lewis Springs and St. David.

3. SITE MAPS - Upper San Pedro Watershed (Arizona/Sonora)

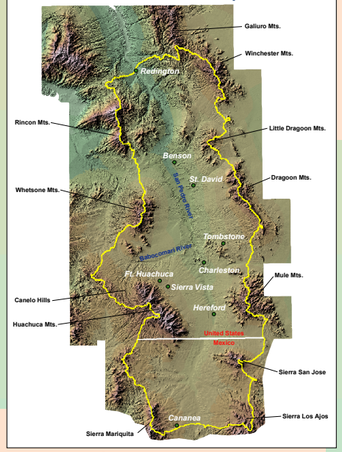
The Upper San Pedro Watershed represents a transition area between the Sonoran and Chihuahuan Deserts and is internationally renown for its biodiversity. It supports the second highest land mammal diversity in the world and provides habitat for almost 400 bird species. The riparian zone has been acquired 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 - 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).

Land Cover LEGEND

- Forest
- Oak Woodland
- Mesquite Woodland
- Grassland
- Desertscrub
- Riparian
- Agriculture
- Urban
- Water
- Barren
- Clouds ('92 and '97 only)



Upper San Pedro Watershed Painted Relief Map



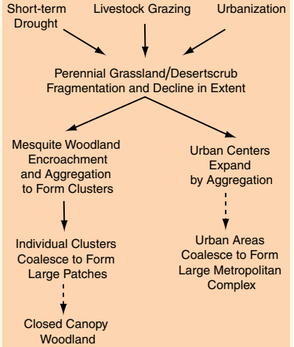
4. LAND COVER

In this project, land cover has been derived from Landsat Multi-Spectral Scanner and Thematic Mapper imagery (5 June 1973, 10 June 1986, 2 June 1992, 8 June 1997) and sampled at 60m pixel resolution. Land cover has been classified into the Brown, Lowe, and Pase (BLP) Biotic Communities Classification System for North America (1979). All vegetation has been classed to the Formation (=biome) level of the BLP system and an urban cover class has been included.

5. LAND COVER TRANSITION

Preliminary 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 389%. 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.

Conceptual Model of Vegetation Phase Transitions in a Semi-arid Watershed



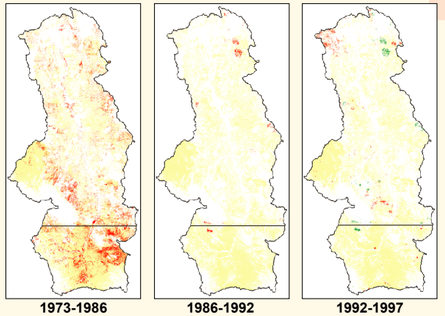
6. CHANGE DETECTION

The following figures depict image differencing for grassland, desertscrub, mesquite woodland, and urban land cover types. The differences in total extent by cover type is displayed for each period (1973-1986, 1986-1992, and 1992-1997) and their difference portrayed as simple gain/loss/no change maps.

Gain/Loss LEGEND

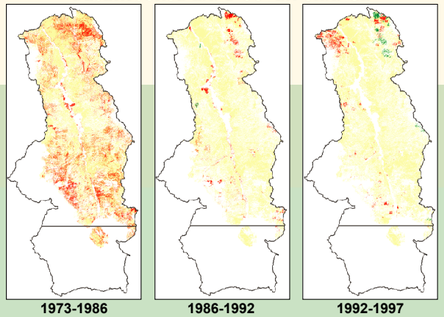
- Loss
- No Change
- Gain

GRASSLAND LAND COVER CHANGE



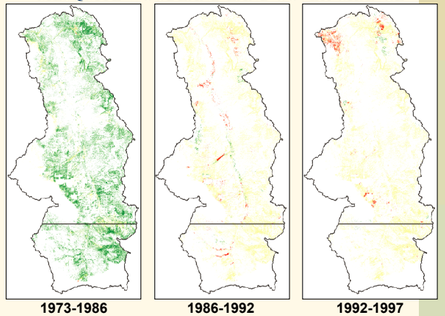
1973-1986 1986-1992 1992-1997

DESERTSCRUB LAND COVER CHANGE



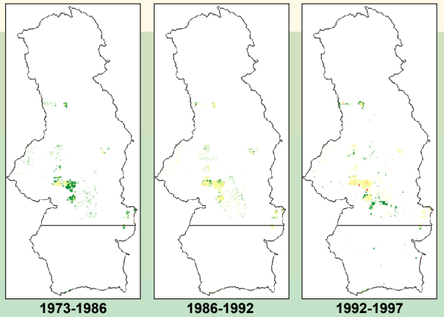
1973-1986 1986-1992 1992-1997

MESQUITE WOODLAND LAND COVER CHANGE



1973-1986 1986-1992 1992-1997

URBAN LAND COVER CHANGE



1973-1986 1986-1992 1992-1997

7. LANDSCAPE CHANGE STATISTICS

Grasslands and desertscrub not only decreased in total extent during the study period but also became more fragmented, i.e. the number of grassland and desertscrub patches increased by approximately 15% and 52%, respectively, and the average grassland and desertscrub patch sizes decreased 27% and 49%, respectively. These two dominant cover types not only dramatically changed in patch size metrics but they each became less connected over time. In stark contrast, mesquite woodland increased in connectivity by 19% and the average patch size and number of patches increased approximately 43% and 243%, respectively.

	Grassland			Desertscrub			Mesquite Woodland			Urban		
	1973	1997	% Rel. Change	1973	1997	% Rel. Change	1973	1997	% Rel. Change	1973	1997	% Rel. Change
Area (ha)	313,614.00	263,979.00	-15.83	296,626.68	230,164.56	-22.41	20,819.88	101,837.88	+389.14	3,286.44	16,705.44	+408.31
% Cover	41.40	34.85	-15.83	39.16	30.39	-22.41	2.75	13.44	+389.14	0.43	2.21	+408.31
# of Patches	50,715	58,142	+14.64	26,260	39,991	+52.29	15,558	53,310	+242.65	418	3,010	+620.10
Largest Patch (ha)	126,258.12	53,173.08	-57.89	201,165.48	37,360.8	-81.43	461.52	3,573.72	+674.34	982.08	4,938.12	+402.82
Ave Patch Size	6.18	4.54	-26.54	11.3	5.76	-49.03	1.34	1.91	+42.54	7.86	5.55	-29.39
Connectivity	0.62	0.56	-9.68	0.66	0.55	-16.67	0.31	0.37	+19.35	0.74	0.69	-6.76

8. CONCLUSION

The present exploratory study was limited to the application of some simple landscape pattern metrics to demonstrate change detection methodology and landscape indicator development to assess watershed vulnerability in a semi-arid environment. The landscape analysis can be enhanced to accomodate more complex diagnostic statistics and can be applied to more detailed land cover maps with finer grain (such as those derived from SPOT satellite imagery or fine-scale aerial photography) and greater classification detail. Application of landscape pattern analysis derived from classified remote imagery, e.g. Landsat-MSS and Landsat-TM, provides an important new approach for environmental managers and policy-makers to measure and assess environmental condition and trend at many scales (site, watershed, region, nation). The process demonstrates a simple procedure to characterize biological systems that are at potential risk from exposure to one or more stressors. Landscape analysis can evaluate environmental problems at multiple scales and can provide interpretive assessments for ecological, hydrological, and selected management or administrative areas. This approach integrates environmental information across all land cover types and provides an important new tool in which to evaluate land management and ecological change over time.

See http://www.epa.gov/crdlvweb/land-sci/san-pedro.htm for more information.