A LANDSCAPE APPROACH FOR DETECTING AND EVALUATING CHANGE IN A SEMI-ARID ENVIRONMENT

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Abstract. Vegetation change in the American West has been a subject of concern throughout the twentieth century. Although many of the changes have been recorded qualitatively through the use of comparative photography and historical reports, little quantitative information has been available on the regional or watershed scale. It is currently possible to measure change over large areas and determine trends in ecological and hydrological condition using advanced space-based technologies. Specifically, this process is being tested in a community-based watershed in southeast Arizona and northeast Sonora, Mexico using a system of landscape pattern measurements derived from satellite remote sensing, spatial statistics, process modeling, and geographic information systems technology. These technologies provide the basis for developing landscape composition and pattern indicators as sensitive measures of large-scale environmental change and thus may provide an effective and economical method for evaluating watershed condition related to disturbance from human and natural stresses. The project utilizes 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 the 1990s. Landscape composition and pattern metrics have been generated from digital land cover maps derived from the NALC images and compared across a nearly 20-year period. Results about changes in land cover for the study period indicate that extensive, highly connected grassland and desertscrub areas are the most vulnerable ecosystems to fragmentation and actual loss due to encroachment of xerophytic mesquite woodland. In the study period, grasslands and desertscrub not only decreased in extent but also became more fragmented. That is, the number of grassland and desertscrub patches increased and their average patch sizes decreased. In stark contrast, the mesquite woodland patches increased in size, number, and connectivity. These changes have important impact for the hydrology of the region, since the energy and water balance characteristics for these cover types are significantly different. The process demonstrates a simple procedure to document changes and determine ecosystem vulnerabilities through the use of change detection and indicator development, especially in regard to traditional degradation processes that have occurred throughout the western rangelands involving changes of vegetative cover and acceleration of water and wind erosion.

Keywords: landscape characterization, remote sensing, change detection, regional vulnerability, accuracy assessment, San Pedro River

1. Introduction

During the twentieth century, dramatic compositional change has occurred in the dominant vegetation throughout the American West (Humphrey 1958, Branson

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1985, Grover and Musick 1990, Bahre 1991, Bahre and Shelton 1993). Most researchers agree that the perennial grasses first encountered by the early explorers have been supplanted by more xerophytic plants, such as mesquite woodland and desertscrub (Brandt 1951, Whittlesey et al. 1997). The factors thought responsible for the major regional shift in land cover are largely attributed to land-use impacts following Anglo-American settlement in the 1870s, however, at least one major cause is attributed to historical change in climate (Hastings and Turner 1965, Neilson 1986). Other hypotheses argue more heavily in favor of overgrazing by domestic livestock (Buffington and Herbel 1965, Bahre 1991) or fire suppression (Humphrey 1958). Although several studies have addressed specific aspects of vegetation change in the Southwest, few have attempted to synthesize the cumulative impacts over a large regional or watershed area (Schlesinger et al. 1990, Grover and Musick 1990).

Information for vegetation change has largely been derived from repeat photography or historic land survey descriptions. Most of the evidence for vegetation change is actually provided from a series of matched photographs beginning in the late 1800s. However, there are serious drawbacks in using this technique to assign change over this period of history. As Bahre (1991) points out, the field of view in ground photographs is usually oblique and covers little total area which limits their usefulness in determining change in plant occurrence over large regional areas. Secondly, the historic photographic series are usually separated by large periods of time and they are often captured more than a decade after the sites were first disturbed by human activity. Lastly, the change photography has largely been used for qualitative comparisons and little progress has been made in quantifying and characterizing vegetation change, especially in regard to determining which systems are most resilient or vulnerable.

Traditional technology has been primarily qualitative in nature and focused on small areas or sites of concern. Today's environmental managers, urban planners, and decision-makers are expected to examine environmental and economic problems in a larger geographic context to: 1) understand the scales at which specific management actions are needed, 2) conceptualize environmental management and planning strategies, 3) formulate sets of alternatives to reduce environmental and economic vulnerability and uncertainty in their evaluation analyses, and 4) to prioritize, conserve, or restore valued natural resources, especially those which provide important ecological goods and services.

This paper presents the results of a study to develop a contemporary change analysis methodology for large geographic areas and to evaluate specific changes within a selected semi-arid watershed. The purpose of the methodology is to document and quantify land cover change and to characterize relative vulnerability of natural resources to cumulative environmental stress. Vulnerability for the study location has been defined as a desired state in which community-type diversity, productivity, and resistance to disturbance are maintained (CEC 1999).

2. Materials and Methods

The study location is the upper San Pedro River basin which originates in Sonora, Mexico and flows north into southeastern Arizona (Figure 1). The San Pedro River is an international basin with significantly different cross border legal and land use practices (Tellman et al. 1997, CEC 1998). The watershed embodies a variety of characteristics which make it an exceptional outdoor laboratory for addressing a large number of scientific questions in arid and semi-arid hydrology, ecology, meteorology, and the social and policy sciences. The Upper San Pedro Watershed represents a transition area between the Sonoran and Chihuahuan deserts and topography, climate, and vegetation vary substantially 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 km^2 (5,800 km^2 in Arizona and 1,800 km^2 in Sonora, Mexico).

Figure 1. *Location of the Upper San Pedro River Basin, Arizona/Sonora.*

Remote imagery was derived from the Landsat Multi-Spectral Scanner (MSS) earth observing satellite (path/row 35/38 and 35/39). Satellite scenes were selected from the North American Landscape Characterization (NALC) project (USEPA 1993). The scenes available in the NALC database are for three pre-monsoon dates for a period of approximately 20 years (i.e., 5 June 1973, 10 June 1986, 2 June 1992). All the imagery in the database is coregistered 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. The cover classes, which are briefly described in Table I, were chosen to improve on earlier work (Mouat et al. 1996) by including some important classes which were not considered, especially Mesquite Woodland and Urban. A decision similar to other studies (Klemas et al. 1993) was made to classify the images separately prior to change detection analysis because of the difficulty in normalizing images derived from different satellite sensors. The landscape changes were analyzed in a geographical information system using ARC/INFO software.

A mosaic of the two scenes is required to cover the entire upper San Pedro basin. This should be a straightforward process since both scenes have the same pixel size and coordinate system. However, it was discovered that the position errors were much larger than expected (up to 7 pixels) and the images and maps derived from them had to be re-registered. This was accomplished by comparison with a precision corrected Landsat Thematic Mapper scene.

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 60 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, mines, tailing ponds, 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 used varied depending on the image being analyzed. Thus the classification of the 1992 image relied heavily on field visits to establish ground control. Five 3-day site visits were carried out from September 1997 to June 1998

Table I
Land cover descriptions for the Upper San Pedro Watershed.

Forest	Vegetative communities comprised principally of trees potentially over 10 m in height and typically characterized by closed or multi-layered canopies. Species in this category are evergreen (with the exception of aspen), largely coniferous (e.g., ponderosa pine), and restricted to the upper elevations of mountains that arise off the desert floor.
Oak Woodland	Vegetative communities dominated (> 30% total cover) by evergreen trees (*Quercus spp.*) with a mean height usually between 6 and 15 m. Tree canopy is usually open or interrupted and singularly layered. This cover type often grades into forests at its upper boundary and into semi-arid grassland below.
Mesquite Woodland	Vegetative communities dominated by leguminous trees (*Prosopis spp.*) whose crowns cover 15% or more of the ground often resulting in dense thickets (30–75% total cover). Historically maintained maximum development on alluvium of old dissected flood plains; now present without proximity to major watercourses. Winter deciduous and generally found at elevations below 1,200m.
Grassland	Vegetative communities dominated by perennial and annual grasses (> 35% total cover) with occasional herbaceous species present. Trees and shrubs do not exceed 20% of the total cover. Generally grass height is under 1 m and they occur at elevations between 1,100 and 1,700 m; sometimes as high as 1,900 m. This is a landscape largely dominated by perennial bunch grasses separated by intervening bare ground (45–50% total cover) or low-growing sod grasses and annual grasses with a less-interrupted canopy. Semi-arid grasslands are generally positioned in elevation between evergreen woodland above and desertscrub below.
Desertscrub	Vegetative communities comprised of short shrubs (>35% total cover) with sparse foliage and small cacti that occur between 700 and 1,500 m in elevation. Within the San Pedro river basin this community is often dominated by one of at least three species, i.e., creosotebush, tarbush, and whitehorn acacia. Individual plants are often separated by significant areas of barren ground (40–45% total cover) devoid of perennial vegetation. Many desertscrub species are drought-deciduous.
Riparian	Vegetative communities adjacent to perennial and intermittent stream reaches. Trees can potentially exceed an overstory height of 10 m and are frequently characterized by closed or multi-layered canopies depending on regeneration. Species within the San Pedro basin are largely dominated by two species, i.e., cottonwood and Goodding willow. Riparian species are largely winter deciduous.
Agriculture	Crops actively cultivated (and irrigated). In the San Pedro River basin these are primarily found along the upper terraces of the riparian corridor and are dominated by hay and alfalfa. They are minimally represented in overall extent (less than 3% total cover) within the basin and are irrigated by ground and pivot-sprinkler systems.
Urban (Low and High Density)	This is a land-use dominated by small ejidos (farming villages or communes), retirement homes, or residential neighborhoods (Sierra Vista). Heavy industry is represented by a single open-pit copper mining district near the headwaters of the San Pedro River at Cananea, Sonora (Mexico).
Water	Sparse free-standing water is available in the watershed. This category would be mostly represented by perennial reaches of the San Pedro and Babocomari rivers with some attached pools or repressos (earthen reservoirs), tailings ponds near Cananea, ponds near recreational sites such as parks and golf courses, and sewage treatment ponds east of the city of Sierra Vista, Arizona.
Barren	A cover class represented by large rock outcropping or active and abandoned mines (including tailings) that are largely absent of above-ground vegetation.

to enable analysts to collect specific land cover data with the aid of Global Positioning System equipment which were incorporated into successive iterations of the classification process. Ideally, site visits should be carried out simultaneously with the satellite pass. In our case, there was a difference of 5 years for the 1992 image and they would have very little value for the earlier images. Fortunately, the 1:250,000 Vegetation and Land Use map produced by INEGI, which covers the Mexican portion of the basin, was produced in the early 1970s so that this could be used as surrogate "ground truth" for the 1973 image. The relation between mapped vegetation and the satellite was encouragingly close. No suitable source of additional vegetation data was found for use with the 1986 image.

The process described above includes many steps where the criteria applied depend on the analyst. While we are fully aware of the many advantages of an entirely objective procedure we believe that the best maps are still produced by a skilled analyst using all the data which are available to him or her. However, the assessment of the quality of that map requires objective application of rigorous statistical techniques.

Digital land cover maps derived from remotely sensed data inherently contain error. Classification accuracy assessment is required for comparing the performance of various classification techniques, algorithms, or interpreters (Congalton and Green 1998). The accuracy of classified images refers to the degree to which the classified images agree with a set of reference data. Most quantitative accuracy assessment methods include an error matrix built from two data sets, i.e., remotely sensed classification map and a reference data set (Congalton and Green 1993). An error matrix was employed to accuracy assess the digital land cover maps generated from the Landsat-MSS imagery. The matrix was used to represent accuracy because the discrete accuracy of each classification category is reported along with both errors of inclusion (commission errors) and errors of exclusion (omission errors) in addition to summary statistics for the entire 10-class matrix (Congalton and Mead 1983, Congalton 1991, Ma and Redmond 1995). The reference condition was determined using U.S. Geological Survey Digital Orthophoto Quadrants (DOQ) at 1:24,000 scale; the error matrix and summary statistics were generated in SYSTAT (SPSS Inc.1998). Allocation of sample points to land cover classes were assigned through stratified (by land cover class) random sampling with a 20-sample minimum for rare classes (i.e., forest, riparian, agriculture, urban, water, and barren).

Overall map accuracy was computed by dividing the total correct (obtained by summing the major diagonal of the error matrix) by the total number of pixels in the error matrix. Accuracy of individual classification categories was computed by dividing the number of correct pixels in a category by either the total number of pixels in the corresponding row or the corresponding column (Congalton 1991). The number of correct pixels in a category divided by the total number of pixels in the corresponding row (i.e., the total number of pixels that were classified in that category) are reported as "user's accuracy" which is a measure of commission error. “User’s accuracy” or reliability is an indicator of the probability that a pixel classified on the map actually represents that category on the ground (Story and Congalton 1986). The number of correct pixels in a category divided by the total number of pixels in the corresponding column (i.e., the total number of pixels for that category in the reference data) are reported as “producer’s accuracy” which is an indicator of omission error.

User’s and producer’s accuracy were determined for the individual land cover classes in addition to the overall (all classes combined) accuracy. The goal in creating the base primary land cover data is to generate digital maps that can be used to detect change, measure landscape pattern, and develop landscape indicators relative to regional vulnerability. Overall accuracy for other projects which have generated land cover maps from satellite data have generally been in the range of 60% to 95% (Jensen et al. 1993, Marsh et al. 1994, Dimyati et al. 1996, Miguel-Ayanz and Biging 1997, and Ramsey et al. 1997).

Mouat et al. (1993) review remote sensing techniques for detecting change by analyzing multi-date imagery. The San Pedro digital land cover maps were transferred into UTM map projection coordinates and incorporated into a geographical information system for change analysis. Change was analyzed using landscape statistical software to produce landscape statistics, including actual 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. This technique has been very useful in identifying semi-arid areas which have undergone change relative to human-induced and natural environmental stress (Pillon et al. 1988) and was employed for this research.

Landsat-MSS 1973 was used for the baseline condition. Change between time intervals, i.e., 1973, 1986, and 1992, 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 (= landscape resilience). Sample size was 2,100,407 pixels (60 m resolution) per digital image map.

3. Results

A total of 457 (3 x 3 pixel, 3.24 ha) DOQ sample points were used for the accuracy assessment with stratification by land cover area. The error matrix showing producer’s and user’s, and overall classification accuracy, and including the Kappa and Tau coefficients is shown in Table II.

An overall classification accuracy of approximately 75% was obtained. A cross-tabulation of the digital land cover and DOQs (Kendall Tau-B and Cohen Kappa statistics) indicated a strong association between the satellite derived land cover and the reference condition derived from DOQs. User’s Accuracy (errors of commission) were acceptable (> 60%) for all individual class categories with the

Table II
Classification accuracy error matrix for land cover map using 1992 Digital Orthophoto Quadrants.

Land Cover Class	92_Map Total	DOQ Total	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
1. Forest	24	22	22	100.00	91.67
2. Woodland Oak	48	55	44	80.00	91.67
3. Woodland Mesquite	62	64	40	62.50	64.52
4. Grassland	103	99	68	68.69	66.02
5. Desertscrub	109	129	89	68.99	81.65
6. Riparian Forest	23	25	20	80.00	86.96
7. Agriculture	23	22	18	81.82	78.26
8. Urban	25	11	11	100.00	44.00
9. Water	20	19	19	100.00	95.00
10. Barren	20	11	11	100.00	55.00
Total	457	457	342		

Overall accuracy (%)	74.836 ± 3.979	
Coefficient	Value	Standard Error
Kendall's Tau-B	0.770	0.025
Cohen's Kappa	0.701	0.025

exception of urban and barren. Although the producer's accuracy for the urban and barren classes was 100%, the user's accuracy is only 44%, and 55%, respectively. This problem is presumably related to the difficulty of discerning low density residential areas in the rural Southwest, i.e., single residences, at 60 m pixel resolution.

Results for land cover extent (total hectares and percent by class) by sample year and relative change for each interval period are presented in Tables III and IV. Results vary over the 19-year period, however, certain land cover types, i.e., forest and oak woodland have changed little over this period relative to other classes.

Three anthropogenic classes (urban, agriculture, and barren) and one natural class, i.e., mesquite woodland, have increased in total extent and dominance during this period. Although urban, agriculture, and barren occupy slightly less than 5 percent of the total landscape in 1992, their growth has increased steadily. Urban growth has been rapid and has increased from 3,254 total ha in 1973 to 12,271 ha in 1992; a relative increase of 277 percent for this period (Table IV). The major surge in urbanization occurred within the first 13-year period from 1973–1986 when urban cover increased nearly three times from the 1973 baseline (Figure 2).

Mesquite woodland, a native tree life-form, has encroached upon the entire watershed. It's total extent increased five-fold between 1973 and 1986 from 20,812 to 107,334 ha (Table III, Figure 3). The baseline extent of mesquite for the watershed in 1973 was 2.75 percent and by 1992 it represented 14 percent of the total land cover.

Decreasing cover types included riparian, desertscrub, and grassland. Although grassland dominates the San Pedro landscape for each of the three sample periods, its total extent has steadily declined. Over 50,000 ha of vegetative communities dominated by perennial and annual grasses were lost between 1973 and 1992. The major decrease for this cover type occurred between 1973 and 1986 (46,025 ha lost) whereas 5,450 ha were lost the following period between 1986 and 1992 (Figure 4).

Table III
Proportional land cover extent as total hectares and percent for the Upper San Pedro Watershed (1973, 1986, and 1992).

	1973		1986		1992	
	Hectares	%	Hectares	%	Hectares	%
Forest	7470	0.99	7479	0.99	7110	0.94
Oak Woodland	92892	12.29	93401	12.35	89447	11.83
Mesquite	20812	2.75	107334	14.19	106240	14.05
Grassland	313104	41.41	267079	35.32	261629	34.60
Desertscrub	296553	39.22	244079	32.28	237539	31.41
Riparian	8674	1.15	6245	0.83	6458	0.85
Agriculture	8785	1.16	13701	1.81	18229	2.41
Urban	3254	0.43	10016	1.32	12271	1.62
Water	262	0.03	85	0.01	376	0.05
Barren	4334	0.57	6728	0.89	7039	0.93

Desertscrub had an identical trend as grasslands. Desertscrub (Sonoran and Chihuahuan species) represents the second most dominant land cover type within the study area. Over 59,000 ha of desertscrub were lost over the 19-year period. Similar to grasslands, most of this loss (89 percent) occurred during the first 13 years between 1973 and 1986 (Figure 5).

Riparian areas initially declined from 8,674 to 6,245 ha between 1973 and 1986. Riparian extent later increased between 1986 and 1992 following acquisi-

Table IV
Percent relative land cover change for the Upper San Pedro Watershed (1973–1986, 1986–1992, and 1973–1992).

	73–86	86–92	73–92
Forest	0.12	-4.93	-4.82
Oak Woodland	0.54	-4.23	-3.71
Mesquite	415.72	-1.02	410.47
Grassland	-14.70	-2.04	-16.44
Desertscrub	-17.69	-2.68	-19.90
Riparian	-28.01	3.41	-25.55
Agriculture	55.95	33.05	107.49
Urban	207.83	22.51	277.14
Water	-67.63	342.57	43.21
Barren	55.23	4.62	62.40

tion of 23,490 ha of riparian corridor in 1986 and subsequent protective status designation by the U.S. Department of the Interior.

Landscape statistics that describe shape and size were used to assess dominance, fragmentation, and conversion matrices for selected cover types and are presented in Tables V and VI.

Mesquite woodland has experienced the most rapid increase in extent during the study period. More than 85,000 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 (Table V). Mesquite patches have increased up to 3,705 ha in size and increasingly become more connected, i.e., the percentage of edges are of identical land cover class, 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 largest patch size from 414 and 982 ha to 3285 and 4,761 ha, respectively. However, average urban patch size and connectivity have actually decreased, likely due to urbanization of the outlying rural areas.

In both cases, the majority of mesquite and urban gain during the 19-year study period were predominantly derived from desertscrub and grassland cover classes (Table VI). During this period 88,508 ha or 97.7 percent of the mesquite and 8,873 ha or 94.5 percent of the urban cover was converted from desertscrub and grassland vegetative cover types combined.

Figure 2. *Urban land cover change for the Upper San Pedro Watershed (1973–1986 and 1986–1992).*

Figure 3. *Mesquite woodland land cover change for the Upper San Pedro Watershed (1973–1986 and 1986–1992).*

Figure 4. *Grassland land cover change for the Upper San Pedro Watershed (1973–1986 and 1986–1992).*

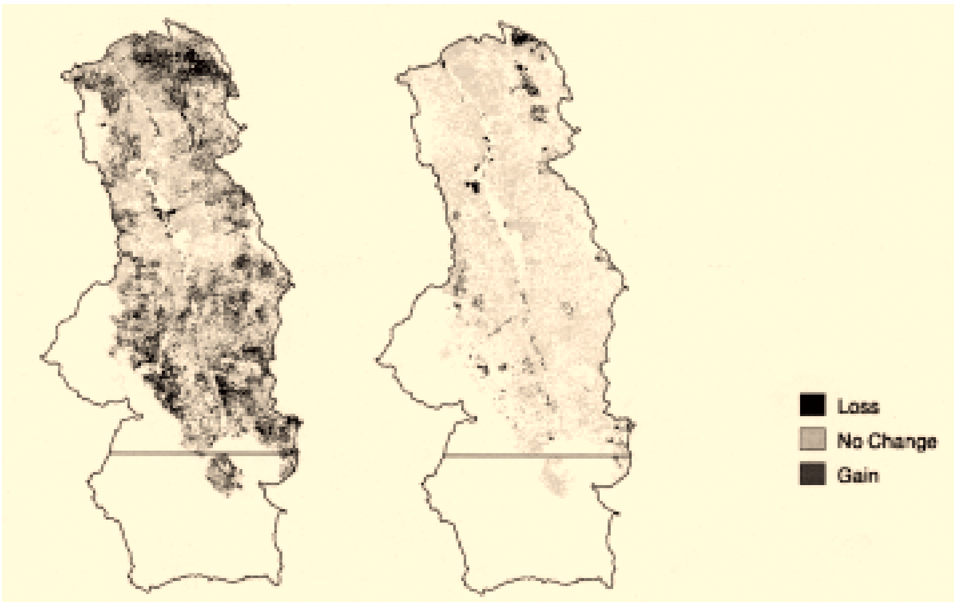

Figure 5. *Desertscrub land cover change for the Upper San Pedro Watershed (1973–1986 and 1986–1992).*

Table V
Landscape statistics for four land cover classes for the Upper San Pedro Watershed (1973, 1986, and 1992).

	Mesquite			Grassland			Desertscrub			Urban		
	1973	1986	1992	1973	1986	1992	1973	1986	1992	1973	1986	1992
Hectares	20812	107334	106240	313104	267079	261629	296553	244079	237539	3254	10016	12271
% Cover	2.75	14.19	14.05	41.41	35.32	34.60	39.22	32.28	31.41	0.43	1.32	1.62
# Patches	15536	54989	52909	50624	59064	57873	26162	39630	39271	414	1670	3285
Largest Patch (ha)	462	3589	3705	125755	52922	78076	201345	42247	38141	982	2521	4761
Ave. Patch Size (ha)	1.34	1.95	2.01	6.18	4.52	4.52	11.34	6.16	6.05	7.86	6.00	3.74
Connectivity	0.308	0.371	0.377	0.62	0.555	0.557	0.66	0.565	0.558	0.74	0.715	0.67

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 6.18 to 4.52 ha and 11.34 to 6.05 ha, respectively and connectivity decreases from the 1973 baseline (Table V).

Table VI
Hectare gains and losses for Mesquite and Urban land cover classes from 1973 to 1992; Upper San Pedro Watershed, Arizona and Sonora.

	Mesquite				Urban			
	Hectares gained		Hectares lost		Hectares gained		Hectares lost	
	Converted from	%	Converted to	%	Converted from	%	Converted to	%
Desertscrub	47998.44	53.0	1579.32	30.7	4947.84	52.7	202.32	54.6
Grassland	40509.36	44.7	1577.52	30.7	3924.72	41.8	114.84	31.0
Mesquite	-----	-----	-----	-----	329.04	3.5	37.44	10.1
Oak Woodland	862.92	1.0	112.68	2.2	104.58	1.1	10.8	2.9
Riparian	892.8	1.0	199.44	3.9	8.64	0.1	2.16	0.6
Agriculture	114.12	0.1	1137.6	22.1	69.12	0.7	1.44	0.4
Urban	37.44	0.04	329.04	6.4	-----	-----	-----	-----
Barren	140.4	0.2	65.16	1.3	2.88	0.03	1.8	0.5
Water	15.84	0.02	6.48	0.1	0.36	0.004	0	0
Total	90571.32		5143.32		9388.08		370.8	

4. Summary and Conclusions

The assessment of land use and land cover is an extremely important activity for contemporary land management. A large body of current literature (Houghton et al. 1983, Turner 1990, McDonnell an Pickett 1993) suggests that human land-use management practices are the most important factor influencing ecosystem structure and functioning at local, regional, and global scales. The type, magnitude, and distribution of land use is a major factor affecting contemporary ecological and hydrological condition related to alteration of species composition, food-web structure, ecosystem carbon storage, and interactions between biota.

Landscape composition and pattern affect key ecological transfer processes which govern the movement or flow of energy, nutrients, water, and biota over time and operate at many scales (Forman and Godron 1986). A landscape framework provides the context 1) to investigate changes in composition, pattern distribution, and process function; 2) to compare conditions across mixed landscapes; and 3) to assess cumulative sources of environmental perturbation (Jensen and Everett 1994).

During the past decade, important advances in the integration of remote imagery, computer processing, and spatial analysis technologies have been applied to the study of distribution patterns of communities and ecosystems, ecological processes that affect these patterns, and changes in pattern and process over time. O'Neill et al. (1997) argue that a landscape approach is practical within current technologies for monitoring environmental quality over large regions and it may represent a less expensive approach than using traditional fine-scaled ground-based surveys. Although not all environmental perturbations can be explained or measured via alterations of land cover, this approach at least supplements existing technologies and improves our ability to measure and understand change and trend over time.

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 (primarily manifested by the introduction of exotic annual species or native woody xerophytic shrubs and trees) and 2) acceleration of water and wind erosion processes. Historically, these have been linked to both human-induced and natural stressors, i.e., livestock grazing and short-term drought (Grover and Musick 1990). However, rapid urbanization in the arid and semi-arid Southwest, within the last 20 years has become an important factor in altering land cover composition and pattern. The purpose of this research was not to determine cause and effect, however, clearly native grassland and desertscrub communities in the upper San Pedro River basin are rapidly declining in the wake of major phase transformation into mesquite woodland and a newly urbanized environment.

The methods employed for this study have been developed 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 advantages of this new approach make it possible to: 1) observe large geographic areas in their entirety, 2) quantify landscape pattern and the areal extent of resources, and to 3) observe changes and trend in large-scale patterns through time. Collectively, this approach provides an opportunity to determine status and trends in landscape pattern and is useful for understanding the condition of our ecological resources through time (Graham et al. 1991, Urban et al. 1987).

The research described herein has been subjected to the Agency's peer and administrative review and approved as an EPA publication. Mention of trade names or commercial products does not constitute endorsement or recommendation by EPA for use.

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