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Land Use Mapping and Change Detection in the Coastal Zone of Northwest Mexico Using Remote Sensing Techniques

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ABSTRACT

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A multitemporal post-classification study with data from the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) was made to detect changes in the landscape of the Majahual coastal system, along the Mexican Pacific. Six land-use classes were used as direct indicators of the landscape condition. Mangrove, lagoon, saltmarsh, dry forest, secondary succession, and agriculture were the categories selected to evaluate the changes by comparing four thematic maps (from 1973 to 1997). The accuracy of the classification (only in the 1997 scene) was calculated from an error matrix, using the overall accuracy assessment (70%) and the Kappa coefficient (0.61). Both values indicate that the agreement in the classification was moderate, but better than one obtained by chance. The analytical comparison of data sets (1973 vs. 1986, 1986 vs. 1990, and 1990 vs. 1997) was done by using a change detection matrix and the Kappa coefficient. Agreement between data sets varied from 61% to 68%, all moderate but enough to determine the general trends of change in the system. These are mainly typified as loss of natural cover (especially dry forest) and the fragmentation of the landscape, with agricultural activities and their subsequent effects (secondary succession, modification of drainage patterns) the main transforming agents.

ADDITIONAL INDEX WORDS: *Multispectral images, remote sensing, supervised classification, Extraction and Classification of Homogeneous Object algorithm (ECHO).*

INTRODUCTION

Data from airborne or space sensors are now an important source of information for monitoring coastal processes. The spectral, spatial, and temporal properties of the information provided by satellites, such as Landsat and SPOT, have been used successfully to help design and update bathymetric charts for clear waters, monitoring of water quality (suspended sediment concentration, chlorophyll concentration, Secchi-disk depth), evaluation of coastline erosion, validation of coastal hydrodynamic numerical models, and identification of flow features in shallow waters (PATTIARATCHI, 1992; PATTIARATCHI *et al.*, 1994).

Management strategies for the coastal zone (CZ), which is defined as the dynamic ecosystem at the interface between land and sea where marine and terrestrial processes interact, should be based on the analysis of the environmental processes that define and regulate this zone (O'REGAN, 1996). However, because of the dynamics of the CZ, monitoring changes is not always easy. The changes occur over several time and space scales, sometimes of great amplitude, and are complicated to follow if only traditional assessment techniques in situ are used. Remote sensing techniques provide a synoptic vision of the Earth that is not possible to obtain other than by exhaustive and expensive field evaluations. Data from remote sensors allow analysis of a region with the sufficient accuracy in an efficient, rapid and low-cost way (DIMYATI *et al.*, 1996; GREEN *et al.*, 1996; 1998a).

For the coastal zone, where the existence of highly productive and sensitive ecosystems, such as estuaries and lagoons, depend on special environmental circumstances, monitoring conditions by means of remote sensing is essential for their future maintenance (KLEMAS, 1993; GREEN *et al.*, 1998b). The special characteristics of these coastal systems rely on factors developed on a landscape scale, such as land uses and coverage patterns (PEARSON, 1994), that have a relevant role on their hydrology, with strong influence on water storage, drainage rates, and biodiversity maintenance. There is also the effect that coverage patterns have on connectivity and mobility of the ecological processes inside the landscape (PEARSON *et al.*, 1995).

Because of the importance that land uses and coverage patterns have in the maintenance of estuaries and lagoons (PEARSON, 1994), they can be used as direct indicators of landscape condition (POUDEVIGNE and ALARD, 1997). Also, remote sensing provides a regular and constant inventory of images to interpret such patterns. The aim of this study fo-

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cussed on the detection of landscape changes in the Majahual system, an estuarine complex in northwest Mexico, using a multitemporal imagery analysis to characterize its present conditions.

STUDY AREA

The Majahual estuarine system lies in the municipality of Escuinapa, south of Sinaloa, between 22°23′ and 22°53′N and 105°30′ and 106°10′W. This system is characterized as type III-C (LANKFORD, 1976), corresponding to strand plain depressions, with multiple sand barriers, salinity highly variable, and may become seasonally dry. The climate is warm-subhumid with average temperature of 26°C and rainfall from 800 to 1500 mm year^{-1} (INEGI, 1995). This coastal system includes the lagoons Laguna Cerritos, Laguna Grande, Las Cañas, and Agua Grande, and the estuaries Agua Grande, Maíz, and Teacapán (Figure 1).

Jointly with the Agua Brava system at Nayarit, to which it is connected through the Puerta del Rio estuary and a series of channels, the Majahual system constitutes the most extensive mangrove forest of the Mexican Pacific. The main mangrove species is *Laguncularia racemosa*, which forms associations with *Rhizophora mangle* and *Avicenia germinans* (FLORES-VERDUGO *et al.*, 1990). *Conocarpus erecta*, the fourth mangrove species recorded in Mexico, is associated with species of xerophitic shrubs and halophytic vegetation. Inside the study area, there are reduced patches of tropical dry forest (BERLANGA, 1999). This vegetal association exhibits radical phenological changes. It completely loses its foliage during the dry season (November -June), appearing dead, changing later to an exuberant appearance once the rainy season starts.

The main economic activities in this municipality are small-scale fishing, with an average production around 1200 t per year, with shrimp the most important item, and seasonal agriculture with almost 60% of the municipality surface devoted to this activity (INEGI, 1995). Shrimp aquaculture is a growing industry that started in the middle 1980s. It is currently composed of 18 farms with 2300 ha of pond surface (RUIZ and HERNÁNDEZ, 1999) and an annual production of about 680 t (BERLANGA, 1999). There are 130 communities and urban areas in the municipality (six inside the study area) with a population of about 50 000 in 1995 and an annual growth rate around 1.5% (INEGI, 1999).

MATERIALS AND METHODS

To make the multitemporal analysis for the study area, four images from the satellite Landsat (path-row: 31–44) of 1973, 1986, 1990, and 1997 were used. All were acquired between February and May during the dry season, the first two with the MultiSpectral Scanner sensor (MSS) and the last two with the Thematic Mapper sensor (TM). Previous to this study, the MSS images were geometrically corrected to 60 m per pixel and geographically rectified, using the Universal Transversal Mercator projection (UTM zone 13 North) based on the ellipsoid of Clarke 1866. To obtain an adequate spatial registration among the MSS and TM scenes, the 1990 and 1997 TM images were adjusted to obtain spatial characteristics similar to the MSS images, with 60m pixels, 924 columns, and 813 lines, fitting to the Lat.–Long. coordinates 22°25′26″ and 22°51′42″ N, and 177°30′26″ and 178°02′57″ W. All the bands were rectified to the UTM system using twelve ground control points, a linear mapping function, and the nearest-neighbour algorithm for resampling (EASTMAN, 1995; CAMPBELL, 1996).

Changes in land use, coverage patterns, and variations in water body surfaces were evaluated using a post-classification change-detection analysis that involves a separate analysis for each image (date) and contrasting of the assessed area for each of the selected class by date (SINGH, 1989; MAS 1998; RUIZ-LUNA and BERLANGA-ROBLES, 1999). As these kinds of methods do not require radiometric data normalization, because each image is classified independently, no attempts to cross calibrate the imagery using "with-in scene" targets were done. The images were classified using supervised methods (CAMPBELL, 1996; RICHARDS, 1993), selecting training fields for six coverage classes; mangrove, lagoon (includes estuarine areas), saltmarsh (also includes exposed and salty soils), dry forest, secondary succession, and agriculture. The 1997 image was the first to be classified because it is the only one with enough recent field information to validate the accuracy of the classification.

The spectral properties for each class were defined by digitizing polygons on the image, and creating spectral signatures from the image values extracted from the polygons. Polygon extents and locations were based on aerial photography (1:35000) taken in October 1995 by the National Institute of Statistics, Geography, and Informatics (INEGI), a topographical chart from the region (F13–15, 1:25000, INEGI 1992), and field identification with the aid of a GPS (Global Positioning System), TRIMBLE Ensign XL. Spectral signatures were developed using bands 2 (0.52–0.60 μ), 3 (0.63–0.69 μ), 4 (0.76–0.90 μ), 5 (1.55–1.75 μ), and 7 (2.08–2.35 μ) of the 1997 TM image.

The supervised classification was done using the Extraction and Classification of Homogeneous Objects algorithm (ECHO), a spatial preprocessing method that assumes that pixels are spatially correlated (LANDGREBE and BIEHL, 1995). This is defined as a context technique that classifies the image based on the individual spectral properties of each pixel, but takes into account the spectral properties of neighbour pixels (RICHARDS, 1993). ECHO divides the image into small groups of spectrally homogeneous pixels called cells. After this, individual cells are compared with adjacent fields and annexed if they are statistically similar. Finally, the homogeneous objects are classified using maximum likelihood criteria (KETTIG and LANDGREBE, 1976).

Once the 1997 image was classified, the accuracy was assessed through overall accuracy and the Kappa coefficient ($\hat{K}$), both indices based on the error matrix (sometimes referred to as the confusion matrix). The error matrix includes all the categories in the classification in a $n \times n$ array, where n represents the number of categories. The cell values are the number of sampling units assigned to these categories in both the classification and the reference data. The reference data used to build the matrix were randomly selected, located on the ground, and the land cover documented. The lagoon class was excluded from the accuracy assessment, assuming

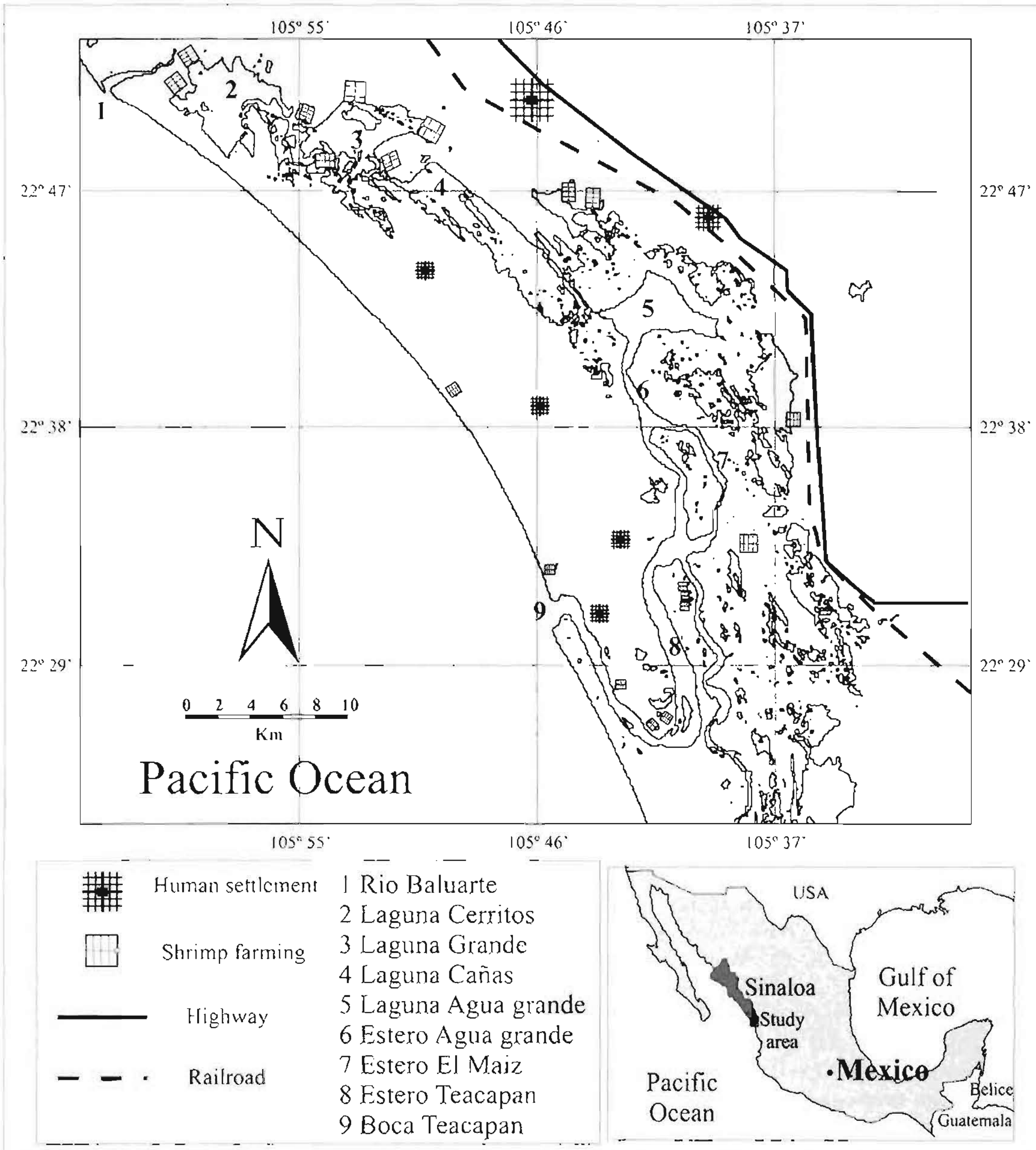

Figure 1. Study area of Majahual system, northwest Mexico.

that this class does not cause confusion with other classes. The major diagonal of this rectangular array includes the pixels classified correctly, and the overall accuracy is estimated as the division between the sum of the diagonal and the total number of pixels in the array.

The $\hat{K}$ coefficient is a discrete multivariate technique that determines the level of agreement between two maps using the results of the error matrix. This coefficient takes values from −1.0 to 1.0 and, when it is significantly close to 1.0, implies that the classification process used is better than a random classification (ROSENFIELD and FITZPATRICK-LINS, 1986; CONGALTON and GREEN, 1999). Besides a general assessment of the accuracy of the classification through $\hat{K}$ or the overall accuracy, the error matrix allows a more detailed estimation of the inaccuracy in the classification of individual categories by means of the assessment of errors of commission and omission. Errors of commission are produced when a pixel is assigned to a different category than it belongs to. Conversely, errors of omission occur when pixels are excluded from a category to which they really belong (CONGALTON and GREEN, 1999). Because the earlier scenes did not have aerial photographs or coincident field data to select the training fields, they were selected with criteria similar to those for the 1997 scene.

Table 1. *Overall accuracy, Kappa coefficient, and error assessment for a supervised classification of 1997 Landsat TM image of the Majahual system, Sinaloa.*

	Referenced data					
Classified data	Mangrove	Saltmarsh	Dry forest	Secondary succession	Agriculture	Total
Mangrove	16	0	0	0	0	16
Saltmarsh	0	11	0	4	4	19
Dry Forest	2	0	12	1	0	15
Secondary succ.	1	1	5	10	1	18
Agriculture	1	1	3	5	15	25
Total	20	13	20	20	20	93

Overall accuracy = 70%; Kappa = 0.61; Kappa standard deviation = 0.06

To reduce noise in the output maps, a 3 × 3 mode filter was used. This procedure removes isolated pixels and is useful when there is interest in gross tonal variations rather than details (GIBSON and POWER, 2000). Subsequently, pixels corresponding to the ocean and human settlements were masked and excluded from the change detection analysis. Once the classifications were achieved, change detection matrices with sets of two different dates (1973 vs. 1986, 1986 vs. 1990, and 1990 vs. 1997) were constructed to make the multitemporal analysis (EASTMAN *et al.*, 1995; JENSEN *et al.*, 1998).

The change detection matrix allows the calculation of the logical conjunction of all possible combination of categories on two maps. When the maps correspond to different dates, numbers in the major diagonal of the matrix represent the pixels that are the same on both dates (no change). Those away from the major diagonal represent changes from one class to another between dates. Also, this matrix is useful in evaluating other indicators of change, as the Kappa coefficient, whose values range from −1 (total change) to 1 (total agreement). When $\hat{K}$ is not significantly different from 0, all the changes are produced by chance (EASTMAN *et al.*, 1995). The image processing routines were completed with IDRISI for Windows 2.0 by Clark Labs for Cartographic Technology and Geographic Analysis of Clark University (EASTMAN, 1995), with the exception of the supervised classifications that were done with the algorithm ECHO included in MultiSpec 1.2, developed by the School of Electrical Engineering, Purdue University (LANDGREBE and BIEHL, 1995).

RESULTS

The spatial registration obtained between TM and MSS images was highly precise, obtaining a total sum of the residual mean error (RMS) around 35 m for the 1990 and 1997 scenes, which represents less than 1 pixel error, adequate for comparison analyses (SINGH, 1989). The final outputs for all dates maintained ocean and human settlement areas as constant (covering 39% of the total area), and were displayed as background without value for the accuracy assessment. Validation for the 1997 image, the most recent date available, was done using a total of 93 points that were confirmed by ground verification (Table 1). From these, 64 were positioned on the major diagonal of the error matrix. This represents an agreement around 70% (overall accuracy) between the reference data (ground data) and the classification output.

Individually, the class most accurately defined was mangrove, classified without commission errors, and only four test points of 20 were omitted (Table 1). The secondary succession class displayed the lowest accuracy and the highest number of commission errors (8 of 18) and omission errors (10 of 20). Using the same data, we obtained a $\hat{K}$ coefficient value of 0.61 with standard deviation variance of 0.06. Such a result indicates that the hypothesis H_o: $\hat{K} = 0$ could be rejected ($Z = 7.91$, $P < 0.05$), and consequently the classification results better than one caused by chance.

Under the assumption that the classifications were reasonably accurate, results derived from the change detection analysis by class indicates that mangrove and lagoon classes were the most stable covers (Table 2, Figure 2a). The mangrove, a significant class because of the functions and services it offers to coastal ecosystems, represented around 10% of the terrestrial area evaluated. This proportion remained stable during the period of study, maintaining an area around 17500 ha, with a slight reduction close to 13% from 1973 to 1986, although to subsequent dates the area was similar to that assessed in 1973. Comparably, the lagoon class area decreased around 50% from 1973 to 1986, but recovered most of this loss from 1990 to 1997.

In contrast, dry forest and secondary succession decreased jointly around 35000 ha, whereas saltmarsh and agriculture classes increased their areas at the end of the 24-year period (Table 2, Figure 2b).

The most important changes are associated with reductions of the dry forest coverage and increasing agricultural cover. Dry forest had one of the most notable changes, losing gradually the original area assessed for the 1973 image. By 1986 this reduction reached around 10% and by 1997 almost 60% of the original 45980 ha evaluated was lost. By contrast, agriculture increased more than 100% from 1973 to 1990 and maintained an area near 45000 ha in 1997.

Similar to agriculture, saltmarsh increased considerably. Considering the total area, this class had the highest relative growth, increasing over 150% of the original assessed area in 1973 (20000 ha). Finally, secondary succession did not follow a regular trend, showing at the end of the period a reduction of nearly 20% of the area assessed for 1973.

Following the pixel by pixel comparison, mangrove, lagoon, and agriculture classes displayed less discrepancies among dates (Table 2). The number of pixels assigned to the mangrove (around 36000) and lagoon classes around (30000) were similar in all the scenes. However, there were variations in the associated landscape (Figure 2a,b). The agriculture class continuously increased, but most of the associated error was assigned to the commission error.

From 1973 to 1997, nearly 20% of the mangrove area changed to the secondary succession class. Also, mangroves were displaced by saltmarsh and agriculture classes. In contrast, mangrove class grew over lagoon and secondary succession classes, mainly. Comparing results from 1990 to 1997, mangroves mainly interchanged areas with saltmarsh, lagoons, and agriculture.

Table 2. *Change detection matrix (number of pixels) and Kappa coefficients to assess the landscape change between classified LANDSAT scenes in sequential dates for Majahual system, Sinaloa.*

	1973						
	Mangrove	Lagoons	Saltmarsh	Dry forest	Secondary succession	Agriculture	Total
Mangrove	35599	4096	267	74	1196	873	42105
Lagoons	398	31353	949	183	413	206	33502
Saltmarsh	1141	27044	19711	319	5861	676	54752
Dry forest	163	547	72	102712	8823	2095	114412
Secondary succ.	10212	9672	8773	18901	82543	22162	152263
Agriculture	713	1125	2985	5536	118812	41335	63506
Total	48226	73837	32757	127725	110648	67347	460540

Overall accuracy = 68%; Kappa = 0.60; Kappa standard deviation = 0.001

	1986						
	Mangrove	Lagoons	Saltmarsh	Dry forest	Secondary succession	Agriculture	Total
Mangrove	33565	1488	3958	57	9089	333	48490
Lagoons	1947	26610	3196	129	546	31	32459
Saltmarsh	1310	4325	45095	541	36207	1426	88904
Dry forest	21	84	98	85439	4481	87	90210
Secondary succ.	898	104	325	23050	26740	55	51172
Agriculture	4364	891	2080	5196	75200	61574	149305
Total	42105	33502	54752	114412	152263	63506	460540

Overall accuracy = 61%; Kappa = 0.53; Kappa standard deviation = 0.001

	1990						
	Mangrove	Lagoons	Saltmarsh	Dry forest	Secondary succession	Agriculture	Total
Mangrove	38768	924	4119	9	575	3749	48144
Lagoons	6625	30614	25106	114	188	1283	63930
Saltmarsh	1844	766	49282	1294	8409	24178	85773
Dry forest	5	4	162	46259	3016	3531	52977
Secondary succ.	370	45	4018	40240	33735	8373	86781
Agriculture	878	106	6217	2294	5249	108191	122935
Total	48490	32459	88904	90210	51172	149305	460540

Overall accuracy = 67%; Kappa = 0.59; Kappa standard deviation = 0.001

Changes in the lagoon class were principally related to variations in the surface of saltmarsh class. From 1973 to 1986, an equivalent surface of lagoon class was classified as saltmarsh, and 13% to secondary succession, represented by halophytes and herbaceous vegetation (*Salicornia, Heliotropium, Batis, Portulaca*) and shrubs (*Conocarpus erecta, Prosopis juliflora*) that grow successfully in saltmarsh-like soils. Later, during the 1990–1997 period, a reversal in this process occurred and a high proportion of saltmarsh appeared as lagoon class.

Another natural cover, dry forest class, was reduced more than 50% from the coverage in 1973, mainly changing to secondary succession and agriculture classes. Dry forest class gained around 10% of its surface area from other classes, formerly secondary succession and agriculture. Finally, the agriculture class grew more than 100% from 1973 to 1997, mainly by conversion of secondary succession and saltmarsh classes.

DISCUSSION

The quantitative analysis of classification results indicated that the overall accuracy for the 1997 classification reached a value close to 70%. Considering procedures, similar values are expected for the remaining outputs. The Kappa analysis also reflected relatively low values, but it proved that the classification obtained was better than would be expected if a random assignment of the pixels were done. Besides that, considering the proposal of LANDIS and KOCH (1977) that classifies $\hat{K}$ values in three groups as a measure of accuracy or agreement (values greater than 0.80 represent strong aggregation; values between 0.4 and 0.8 moderate aggregation, and values smaller than 0.4 represent little aggregation), the results correspond to a moderate aggregation, which is acceptable. Finally, covers catalogued as nonconflict areas (lagoon and human settlements) did not include test points for the accuracy assessment.

The output classifications show that landscape in the study area was dominated by agriculture (around 30% of the area), although dry forest dominated the landscape in 1973. Results show it is being rapidly converted to secondary succession and finally to agriculture. By 1997, the dry forest covered only a small percentage of the landscape (around 10%) and was distributed in small patches, reducing the ability of nat-

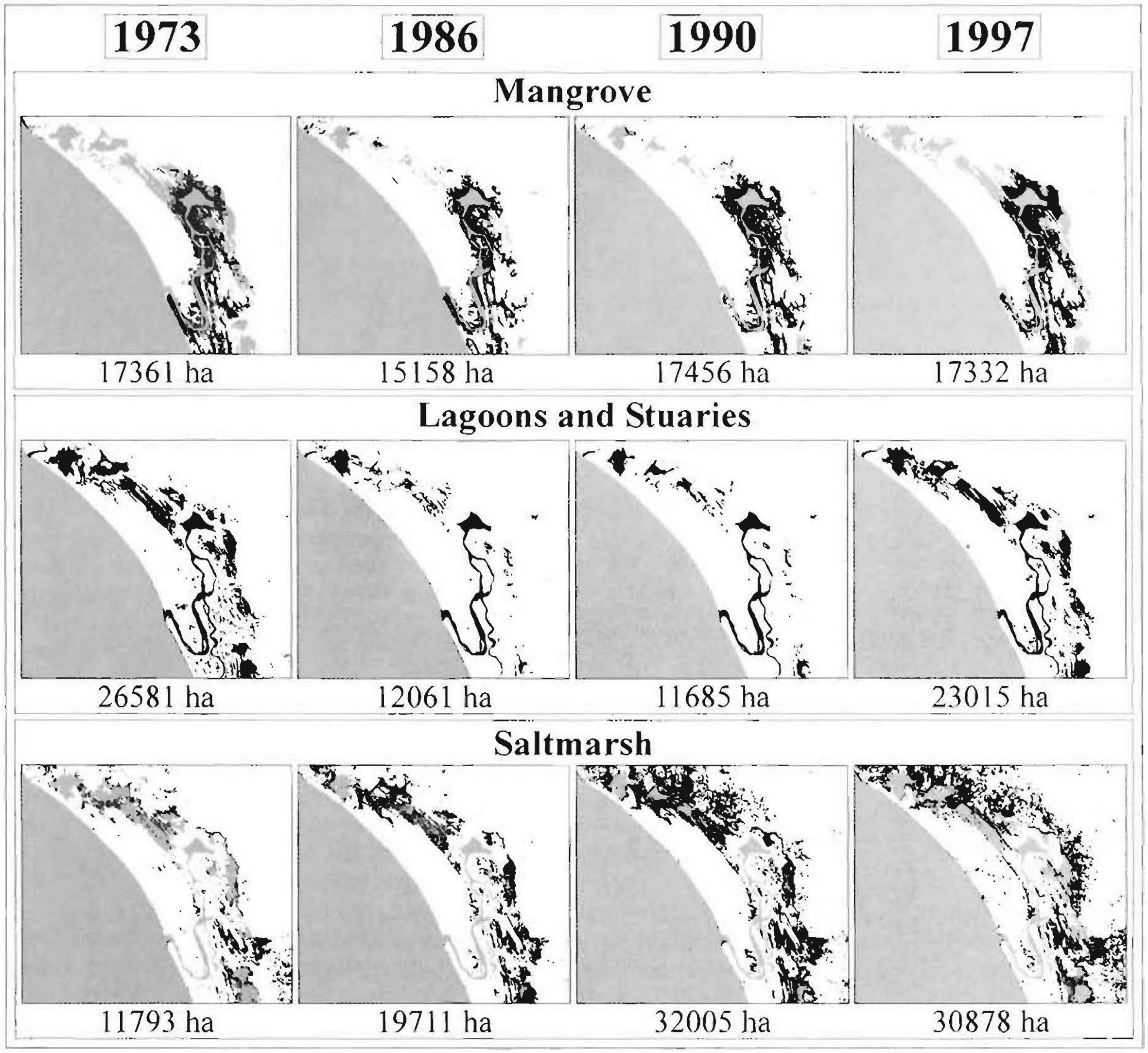

Figure 2a. Change of land use-cover extension in the landscape of Majahual system, from 1973 to 1997.

ural populations to move through the landscape. The fragmentation also reduced the regenerative capacity of the natural communities allowing the invasion and development of secondary succession (BARBOUR *et al.,* 1987). The replacement modified the hydrologic patterns and the nutrient cycles in the watershed (PEARSON 1994), and altered the landscape connectivity and therefore the sequence of some ecological processes (PEARSON *et al.,* 1995). Connectivity is considered a structural component of the landscape and its reduction is associated with reduction of species diversity and energy flow (GOOSSENS *et al.,* 1993; ESTRADA and COATES-ESTRADA 1994; TAYLOR, 1997).

Another natural cover, mangrove, displayed a deforestation rate of 0.2, less than the other systems in southern Sinaloa. For instance, Marismas Nacionales, a large estuarine system to which Majahual is connected, has an annual deforestation rate of 2.4% (PANTOJA *et al.,* 1991). The Huizache-Caimanero system and Estero de Urías, north of the study area, have annual rates of 1.9% and 0.6% (RAMÍREZ *et al.,* 1997; RUIZ and BERLANGA, 1998; RUIZ-LUNA and BERLANGA-ROBLES, 1999). The most extensive mangrove forest in Mexico, Laguna de Términos, in the Gulf of Mexico, has an annual deforestation rate of 1.1% (PÉREZ and PÉREZ, 1991).

Comparing variations observed in the lagoon class, there was an evident reduction in the intermediate dates (1986–1990). This reduction probably can be associated with natural variations of freshwater inputs, a common process in coastal aquatic systems, especially in lagoons with temporary openings to the sea. Three of the four scenes were acquired during El Niño events, in 1972–1973, 1986–1987, and 1997–1998 (TORRENCE and WEBSTER, 1999). This oceanic and atmospheric phenomenon has a great influence on the interannual climatic variability, with changes in the rain and flood patterns as some of the most appreciable effects. In the study

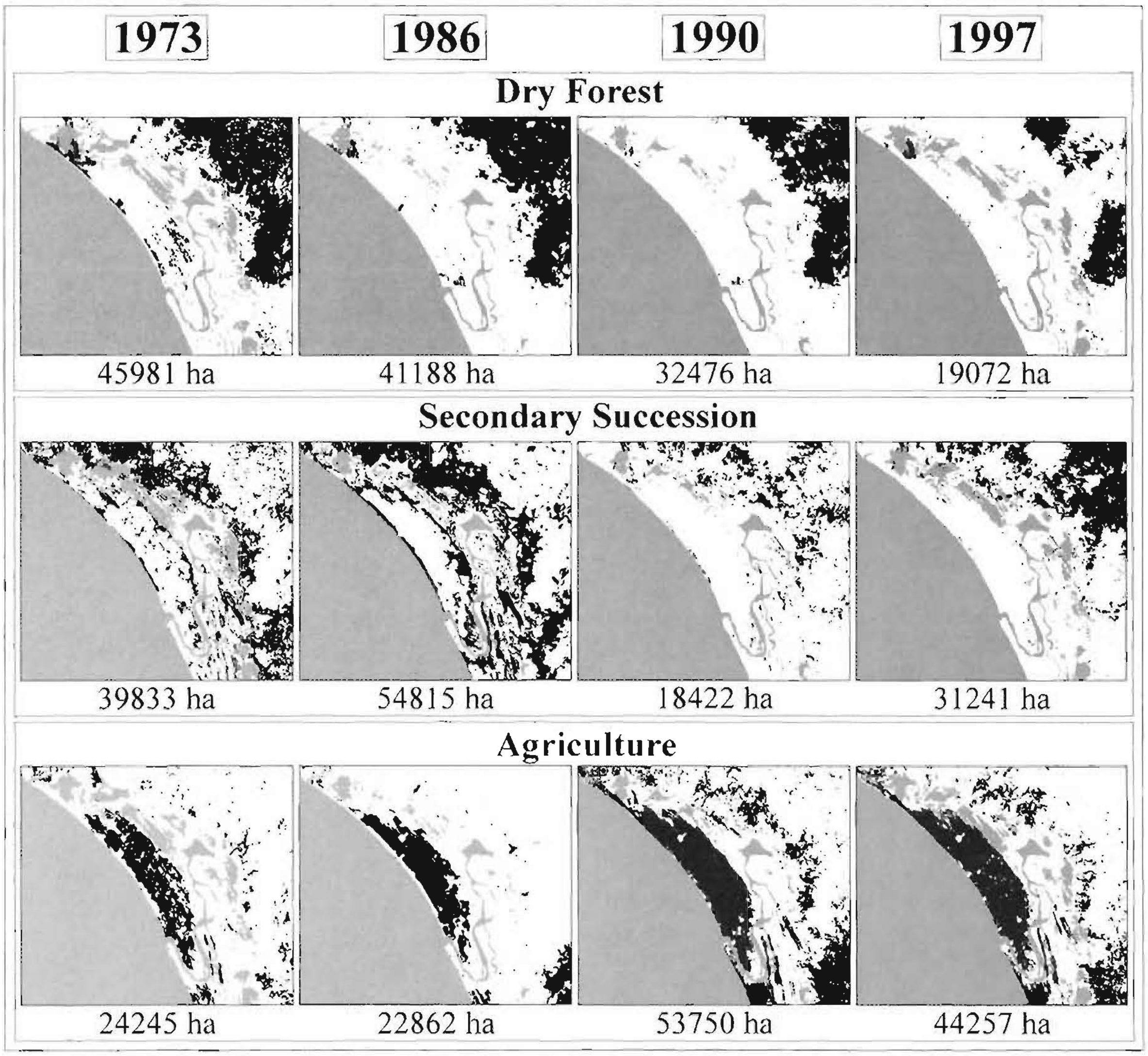

Figure 3a. Change of land use-cover extension in the landscape of Majahual system, from 1973 to 1997.

area, these changes would be reflected in the images and therefore in the results obtained.

BERLANGA (1999) analyzed the rainfall records for the rainy season previous to the acquisition of the images and the subsequent dry season and found that, except for 1996–1997 when precipitation increased to 1942 mm, precipitation was around 1000 mm. This could increase the availability of freshwater, giving an increase in the lagoon surface for the 1997 image.

Variations in the lagoon class surface could also be related to deforestation rates. From 1973 to 1997, the dry forest area decreased more than half its original area, a loss of 2.4% per year. This process occurred jointly with increasing human development. Consequently changes in land uses possibly altered water storage capacity and drainage patterns reducing the residence time of water in the inner basins and accelerating the loss rates by flood.

As a consequence of variations in the lagoon class surface, and the increase in deforestation patterns, especially related to dry forest, the saltmarsh class varied inversely. This class could be considered as the dry phase of coastal wetlands, because when the water level of lagoons and estuaries decreases, temporarily or permanently, there remain salty soils where some kinds of vegetation (halophytes) are established.

With the addition of shrimp aquaculture as part of the surrounding activities, the saltmarsh and lagoon covers are being changed rapidly to shrimp ponds (integrated as background in the output classification), modifying the hydrological patterns. Specifically for the Majahual system, there are 18 farms, of which 30% to 40% are part of small lagoons or are located inside them (RUIZ and HERNÁNDEZ, 1999). Even during 1990–1997, when the lagoon area began recover (28% from flooding of saltmarsh), the saltmarsh class did not decrease, but maintained its expansion, growing 16% from secondary succession and similar amount from agriculture.

In general, some of the observed changes could be explained by the occurrence of natural processes, but specially they were generated by man-induced practices, such as deforestation, construction of hydraulic infrastructure, as well as urban development and changes in land uses. Here, we are considering that the accuracy levels obtained are not enough to discriminate boundaries between classes with high precision, but it is sufficient to characterize the landscape in the study area and to determine trends of change followed by the main land covers and land uses, especially if changes are evaluated at a regional scale.

CONCLUSIONS

Multitemporal remote sensing analysis determined that the landscape of the Majahual system is dominated by natural land covers (saltmarsh, lagoon, mangrove, and dry forest), which amount to more than half of the study area. Although classification accuracy was moderate, general trends suggested that the system is changing rapidly to a fragmented landscape, dominated by agriculture, secondary succession, and other man-induced covers (human settlements, shrimp aquaculture).

These are mainly typified as loss of natural cover (especially dry forest) and the fragmentation of the landscape, with agricultural activities and their subsequent effects (secondary succession, modification of drainage patterns) being the main transforming agents. Possible freshwater deficits caused surface area reduction in lagoons and estuaries temporarily restricting communication to the sea. In contrast with the dry forest cover, the mangrove coverage in Majahual appears as one of the less deforested systems in Mexico, and some actions should be planned to preserve it.

In conclusion, there is evidence to support the idea that anthropogenic activities in the Majahual system are generating a highly fragmented landscape that is contributing to the degradation of the environment. To conserve ecological processes and the productive potential of this coastal system, this trend should be reversed and restoration mechanisms should be implemented.

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SUMARIO

El sistema litoral Majahual, al noroeste de Mexico, está formado por una serie de lagunas, esteros y marismas que se comunican con el sistema Agua Brava, Nayarit y juntos conforman el bosque de manglar mas extenso del Pacífico mexicano. Con el fin de detectar cambios en el paisaje en este sistema, se realizo un estudio multitemporal post-clasificatorio con cuatro imagenes multiespectrales de los satelites Landsat MSS, y Landsat TM (path/row: 31/44), que incluye fechas de 1973 a 1997. Se seleccionaron seis clases de cobertura del terreno como indicadores directos del paisaje: manglar, lagunas y esteros, marismas, selva (bosque tropical caducifolio), vegetacion secundaria y agricultura. Las imagenes fueron clasificadas por separado, utilizando un proceso de clasificacion supervisada con el algoritmo de Extracción y Clasificacion de Objetos Homogéneos (ECHO). El análisis cuantitativo del cambio del paisaje se realizó por comparacion de los mapas tematicos resultantes de la clasificación (1973 vs. 1986, 1986 vs. 1990 y 1990 vs. 1997), a través de matrices de error y el calculo del coeficiente de Kappa. Ambas técnicas fueron utilizadas para evaluar la exactitud de la clasificación de la imagen de 1997. La exactitud general y el coeficiente de Kappa para la clasificación de 1997 fueron de 70% y 0.61, respectivamente, lo que representa una clasificacion con exactitud moderada. Las comparaciones entre los mapas temáticos indican que las actividades humanas han provocado cambios en el uso del suelo, que junto con ontras actividades en la cuenca han inducido transformaciones radicales en los componentes acuaticos y terrestres del paisaje. El bosque de manglar en el Majahual aparece como uno de los menos deforestados de Mexico. Por el contrario, la cobertura de selva caducifolia mostro una reducción considerable en los 24 años que abarca este estudio. Actualmente, la vegetación natural esta reducida a parches aislados localizados sobre terrenos donde las actividades económicas no son viables. Como una de las consecuencias de lo anterior, se presentan niveles deficitarios de agua dulce y con ello la reducción del espejo de agua de las lagunas que tienen comunicacion temporal o restringida con el mar. Además los canales y estanques de algunas granjas camaroneras y otras obras hidraulicas han modificado la comunicación entre las lagunas, reduciendo el flujo natural de un número indeterminado de especies acuaticas que viven en el sistema. A pesar de que la exactitud de las clasificaciones resulto moderada, los metodos utilizados permitieron establecer las tendencias generales de cambio del sistema, que podrían tipificarse como la pérdida de coberturas naturales y la fragmentacion del paisaje, identificándose a la agricultura como el principal agente transformador.