Investigaciones Geográficas, Boletín del Instituto de Geografía, UNAM
ISSN 0188-4611, Núm. 74, 2011, pp. 7-18

Landscape changes in a coastal system undergoing tourism development: implications for Barra de Navidad Lagoon, Jalisco, Mexico

Received: 6 October 2009. Final version acepted: 23 April 2010.

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Abstract. In this study, changes in land cover and land use patterns that occurred between 1985 and 2000 in the surrounding basin of the Barra de Navidad coastal lagoon in Jalisco, Mexico are quantified and explained. Two satellite images from 1985 (Landsat TM) and 2000 (Landsat ETM+) were analyzed with supervised classification and ground truthing to evaluate changes in six land use/cover categories: lagoon, agriculture, urban/tourist, tropical dry forest, mangrove and bare substratum. Changes in land use composition were evaluated using a transition matrix and changes to configuration were interpreted using landscape metrics. Results show that urban and tourist areas expanded between 1985 and 2000, mostly at the expense of forested and bare land. Mangroves showed a large relative decrease in area (-39%) and experienced fragmentation. These changes appear to be related to increased sedimentation a fan progradation into Barra de Navidad lagoon. These results may serve as a model for comparison in other systems experiencing multiple stressors, especially changes related to tourism and the intensification of resource extraction.

Key words: Landscape's metrics, land use/cover change, Barra de Navidad.

Cambios en el paisaje de un sistema costero sometido al desarrollo turístico: implicaciones para la Laguna Barra de Navidad, Jalisco, México

Resumen. Por medio de dos imágenes de satélite adquiridas en 1985 (Landsat TM) y 2000 (Landsat ETM+), se analizan cuantitativamente los patrones de cambio de cobertura y uso del suelo ocurridos entre 1985 y 2000 en la laguna de Barra de Navidad, Jalisco, México y su cuenca de drenaje. El análisis de las imágenes se realizó mediante una clasificación supervisada y verificación en campo de seis categorías de uso/cobertura de suelo: lagunar, agricultura, selva seca tropical, manglar y sin vegetación. Los cambios espaciales en la composición del uso del suelo fueron evaluados utilizando una matriz de transición y los cambios de configuración se interpretaron utilizando la métrica del paisaje. Los resultados mostraron que las áreas urbanas y turísticas se expandieron, a costa de la selva baja y suelos sin cobertura. También el manglar mostró un gran decremento (-39%) experimentando una severa fragmentación. Estos cambios parecen estar

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relacionados con el incremento de la sedimentación, resultado de la erosión del suelo aguas arriba y a la progradación de un abanico dentro de la laguna de Barra de Navidad. Los resultados obtenidos pueden servir como un modelo de comparación de otros sistemas que experimentan múltiples factores estresantes, especialmente cambios relacionados con el turismo y la intensificación del uso del suelo.

Palabras clave: Métrica del paisaje, cambios uso/cobertura, Barra de Navidad.

INTRODUCTION

Coastal lagoons are unique environments that are subject to constant changes. These aquatic ecosystems are biologically diverse and highly productive, making them environmentally and economically significant resources in many parts of the world (Morton *et al.,* 2000). Indeed, the preponderance of human development in coastal lagoon areas has been largely due to the potential of those resources (Merino, 1987; Nichols and Boon, 1994). However, due to their partial isolation behind barriers, lagoons often exhibit behaviours characteristic of closed systems, and are thus especially vulnerable to over-exploitation (Laserre, 1979).

The coastal zone of Mexico may be at particularly high risk of severe, potentially irreversible effects from ongoing resource exploitation. The country's long coastline has about 1.5 million hectares of estuarine and lagoon environments (Yañez, 1981). Beginning in the 1970s, recognition of the wealth of marine resources has resulted in rapid, ongoing development in Mexican coastal areas (Merino, 1987). Consequently, sensitive environments such as coastal lagoons have become highly stressed by human activities such as urbanization, the removal of wetlands, and the conversion of forests and prairies into crop and grazing systems (O'Neill *et al.*, 1997)

Geomorphologically, coastal lagoons occupy a transitional position between land and sea and, as such, they are affected by variations in both terrestrial and marine processes. Coastal lagoon ecosystems are affected by landscape-scale factors including land uses and land coverage patterns within the watershed (Berlanga and Ruiz, 2002). Land use activities affect water quality by altering sediment inputs, nutrient loads and watershed hydrology (Basnyat *et al.*, 1999). Loss and fragmentation of natural areas have been cited as major causes affecting hydrologic processes (Jones *et al.*, 2003). Coastal zones represent areas that include high-energy physical stages where geophysical, terrestrial and oceanic process interact. These natural processes permanently model the continental edge and influence the structural features and spatial distribution of ecosystems associated to it (Pannier, 1992). In turn, these territories are influenced by changes in mean sea level, as well as earthquakes, hurricanes and tsunamis, which may give raise to radical physical modifications over geological or historical periods (Correa *et al.*, 2009). Since plant distribution responds to changes in habitat, the modifications induced by geomorphic process can occur regardless of biotic factors (Méndez *et al.*, 2007). Transformations in land cover are seen as cumulative impacts, represented by a change in the spatial pattern of the landscape. While numerous studies have focused on linking landscape pattern and conditions of freshwater systems (Basnyat *et al.,* 1999; Gergel *et al.*, 2002; Jones *et al.,* 2001, 2003; Kearns *et al.,* 2005.), land-water interactions in coastal environments have been less thoroughly explored (Guzmán, 2003).

Science-based management strategies for the coastal zone are based on the analysis of processes that define and regulate this zone (O'Regan, 1996). In order to effectively manage these sensitive environments, there is a need not only to understand how coastal lagoons function and change naturally, but also how human activities modify the landscape and the interaction among processes within that landscape (Guzmán, 2003). However, because of the dynamic nature of coastal zone ecosystems, monitoring change can be difficult using in situ techniques (Berlanga and Ruiz, 2002). Data from remote sensors are extremely useful for analyzing land cover changes, because characteristics of an area may be assessed with enough precision to be used efficiently in the management of natural resources (Dimyati *et al.*, 1996; Grignetti *et al.*, 1997). Classification techniques using satellite imagery have been used successfully to detect landscape changes in many environmental settings (*e.g.*, Dimyati *et al.*, 1996; Maracchi *et al.*, 1996; Nelson *et al.*, 2002; Olson *et al.*, 2000) and have been previously applied to the coastal environments of Mexico (Alonso *et al.*, 2003; Berlanga and Ruiz, 2002; Guzmán, 2003; Ruiz and Berlanga, 1999).

Using satellite imagery and landscape metrics, we document changes to the lagoon and lagoon shoreline of the Barra de Navidad lagoon system in Jalisco, Mexico as well as changes in land use and cover patterns in the surrounding drainage basin. Identified environmental problems in the lagoon are representative of those in many of Mexico's lagoons, and include silt accumulation, pollution and reduction of depth and areal extent (Ortega, 2002). In 1999, the development of a management plan for the restoration of Barra de Navidad lagoon was proposed as part of a larger project for integrated management of the coastal zone of Navidad Bay. The results of the present study, werw used to declare Barra de Navidad lagoon, a Ramsar Site in 2007, a necessary step toward developing a natural resource management strategy. This study show how this approach can be used to enhance understanding of the changes and for improving management and restoration strategies for this and other coastal lagoon systems.

STUDY AREA

The Barra de Navidad lagoon system is located in the southernmost part of coastal Jalisco, bordering on the state of Colima (19º 9.5' N to 19º 17' N and 104º 42' W to 104º 33' W; Figure 1). The study area encompasses 205 km² consisting of coastal plain, mountain and coastal lagoon ecosystems (Méndez *et al.*, 2007). Barra de Navidad lagoon measures approximately 3 km² and is connected to the Pacific Ocean through an inlet at the southeast

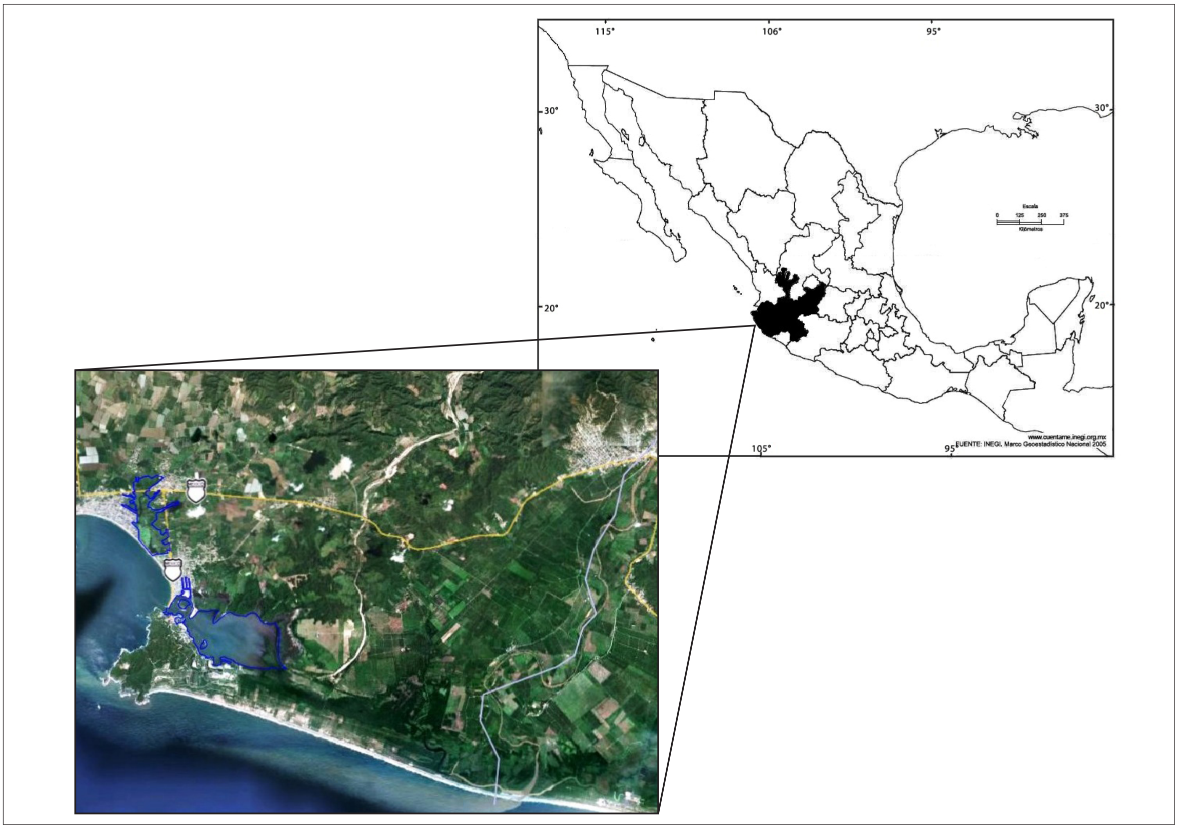

Figure 1. Study area. Navidad Bay, Mexico, and surrounding basin of Barra de Navidad Lagoon.

end of Navidad Bay, which extends 4 km along the coast. The climate is classified as hot, dry sub-humid with an average annual temperature of 23 °C (Rodríguez, 1993). The rainy and dry seasons are well-defined, with the rainy season occurring from June to October.

The natural vegetation types that are predominant in the study area are tropical deciduous forest, woodland and mangrove thickets. There are four species of mangroves in Mexico, all of which are found in Barra de Navidad lagoon: *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove) and *Conocarpus erectus* (buttonwood). The mangrove community structure is well established: *R. mangle* occupies the shallow sub aqueous zone and the bottom part of the littoral zone; *A. germinans* is in the intertidal zone; and *L. racemosa* and *C. erectus* are mostly terrestrial (Rodríguez, 1993; Méndez *et al.*, 2007).

Four watersheds contribute to Navidad Bay hydrology: Marabasco River and Arroyo Seco River feed into Barra de Navidad lagoon (Jiménez, 1980; Méndez *et al*., 2007), Jaluco creek supplies El Tule lagoon, and El Pedregal stream empties directly into the northeast corner of the bay (Ortega, 2002). Arroyo Seco River, with a surface area of 400 km², is an intermittent source of freshwater to Barra de Navidad lagoon, flowing only during the rainy season. The Marabasco River drainage basin has a surface area of 2 200 km², and transports fresh water to the lagoon during six months of the year (Jiménez, 1980). The ocean portion of Navidad Bay is a complex system, affected by the warm Counter Current North Equatorial and cold California oceanic currents. The mixing of these two water masses produces high marine diversity. Barra de Navidad experiences a mixed-diurnal tidal regime with a range of 0.5 m (Meyer *et al.*, 2006).

Six communities occupy the study area: Barra de Navidad, San Patricio Melaque-Villa Obregón, Jaluco, El Aguacate, Cihuatlan and Colimilla. The two towns that are on the shores of the lagoon are Barra de Navidad, which is built on the barrier spit and lagoon shoreline on the northwest side of the inlet, and Colimilla, which is on the southwest shore.

MATERIALS AND METHODS

The satellite images used for this study (path 30, row 47) were acquired in May 1985 and April 2000 by the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+), respectively. All image processing was done using Idrisi32 for Windows Release 2, developed at Clark Labs for Cartographic Technology and Geographic Analysis of Clark University (Eastman, 2001). The original images covered an area of 185 x 172 km, which is much larger than the study area. Therefore, the desired study site with coordinates UTM of quadrant 531 101 and 546 626 northing and 2 117 878 and 2 131 053 easting, was extracted to produce a scene measuring 15.5 km x 13.1 km, with a pixel size of 30 m x 30 m. Because the 2000 images were already geo-rectified to the UTM-13 N coordinate system, the study area was extracted from these images first (bands 1-5). The 1985 scene was rectified to the UTM-13 N coordinate system using seven well-distributed ground control points from the 2000 image, a linear mapping function and the nearest neighbour algorithm for resampling (Avery and Berlin, 1992).

Seven land use and land cover (LULC) classes were identified in the study area: lagoon, agriculture, urban and tourist, tropical dry forest, mangrove, ocean and bare substratum. Supervised classification was used to identify the land use and land cover categories present in each Landsat scene (Alonso *et al*., 2003; Berlanga and Ruiz, 2002; Maracchi *et al*., 1996). This method makes use of ground observations at particular locations in the study area. The 2000 image was the first to be classified, because it could be more closely validated in the field. Training fields for the seven classes were generated by digitizing polygons on a colour composite image. Spectral signatures were then defined for each class. The selection of fields was aided by using a topographic map of the region (1:50 000; INEGI, 1992) and by reconnaissance in the study area, positioning the points of interest with a Garmin Global Positioning System (GPS).

The 2000 scene of the study area was classified using the maximum-likelihood classifier (Alonso *et al*., 2003; Richards, 1986). Once the 2000 image was classified, the accuracy of the classification was assessed using a standard error matrix (Alonso *et al*., 2003; Berlanga and Ruiz, 2002; Foody, 2002). A stratified random sample of 100 points was laid out on a small portion of the study area (~55 km²). Under the assumption that the ocean would not be misclassified, the ocean class was omitted from the sample, leaving 76 points, each of which was located in the field using a Garmin GPS. The true land cover/land use at each location was recorded.

Following the ground truthing an error matrix was produced, presenting a tabulation of the number of sample points found in each possible combination of true and mapped categories (Eastman, 2001). The overall accuracy of the classification is calculated by summing the major diagonal entries, and dividing the result by the total number of sample units for the entire error matrix (Congalton and Green, 1999). The error matrix also tabulates errors of omission, which represent cases where sample points of a particular category are found to be mapped as something different, and errors of commission, which represent cases where locations mapped as a particular category, were found to be truly something else.

In addition to the overall accuracy, the Kappa coefficient was calculated to measure the improvement of the classification over a random assignment of pixels (Berlanga and Ruiz, 2002). The value of K ranges from -1.0 to 1.0 and, when it is significantly close to 1.0, it implies that the classification process used is better than a random classification (Congalton and Green, 1999).

Once the 2000 classification was validated, the 1985 image underwent the same classifying procedure. Because the change in land cover was evident in some cases, it was necessary to adjust some of the training fields by modifying their spatial location. Instead of ground truthing, this procedure was aided by a topographical map of the area (1:50 000; INEGI, 1985).

In order to evaluate changes in the study area landscape over time, landscape composition and configuration were quantified using measures of landscape pattern. Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape mosaics (McGarigal *et al.,* 2001). A patch is defined in this study as a group of contiguous cells with the same land cover, with the minimum patch size being 9 cells, or 0.0081 km². All the metrics used are based on perimeter-area relationships, fractal geometry and information theory. Indices at the landscape and class level were calculated using Fragstats Version 3.3 (*Ibid.*), a public domain spatial pattern analysis program for quantifying landscape structure. Class level indices were calculated for each LULC category, while landscape level indices were calculated for the study area as a whole (Guzmán, 2003).

A total of four indices were calculated for both the 1985 and 2000 land use/land cover maps: class percentage of landscape (PLAND), mean patch size (MPS), number of patches (NP), and patch density (PD). MPS and NP were calculated at both the class and landscape levels, while PLAND and PD, which are class-only statistics, were not calculable for the landscape as a whole. Deforestation Rate is the conversion from forest to another use of land or long time reduction under 10% of forestry covering, this definition consider that lost in this sites must be permanent and changed by other kind of use (agriculture, grass, dams, urban or touristy areas; FAO, 1996).

Changes in land use, coverage patterns and variations in sourronding watershed of lagoon water surface were evaluated using a post-classification change detection analysis. This method involved a separate analysis for each image (1985 and 2000) and contrasting of the assessed area for each of the LULC classes by date (Alonso *et al*., 2003; Berlanga and Ruiz, 2002; Maracchi *et al*., 1996). A cross-classification procedure was employed using Idrisi.

In order to reduce noise in the categorical maps, a 3 x 3 mode filter was applied, which effectively smoothed the classifications (Alonso *et al*., 2003; Berlanga and Ruiz, 2002). Following the smoothing of the classification of both maps, the land use/land cover distribution for the two time periods was calculated and each class was separated. Changes in the total and proportional areas of the cover types were calculated, this translates to a Information regarding whether areas fell into the same LULC class on the two dates or whether a change to a new class had occurred was summarized in a cross-tabulation, or transition matrix. Yearly rate of deforestation were calculated, in according to the method for calculating deforestation proposed by Palacio *et al.* (2004).

$$dn = [s_2 / s_1]^{1/n} - 1 * 100 \quad (1)$$

where dn = rate of deforestation;
s1,2 = areal extent at date 1 and 2;
n = number of years between dates.

RESULTS AND DISCUSSION

Classification accuracy

The error matrix revealed an overall accuracy of 84% between the referenced (ground truth) data and the classification output (Table 1). The Kappa coefficient value obtained was 0.76, with a standard deviation of 0.08 at the 95% confidence interval. The maximum value for the K-coefficient is 1.0, and therefore it was determined that the classification was better than one resulting from chance. Similar studies have accepted Kappa values ranging from 0.61 to 0.80 (Alonso *et al.*, 2003; Berlanga and Ruiz, 2002; Ruiz and Berlanga, 1999).

Transitions among land covers

The most evident changes in land use and land cover categories in the study area can be summarized as follows:

- Considering deciduous tropical forest and mangrove the natural environments of the area, in the 1985 image 62.52% of ground surfaces analyzed was found to be used by anthropogenic activities (69.91 km^2 with transformation versus 111.82 km^2 of deciduous tropical forest and mangrove).
- In 2000, changes on surfaces of land were diminished at 57.73 (61.08 km^2 with transformation versus 105.8 km^2 of deciduous tropical forest and mangrove).
- Rate annual of deforestation between periods was 0.401 km^2/year.
- Tropical dry forest was by a large margin the predominant class in the study area for both dates, but changed in cover to secondary vegetation by 16% between 1985 and 2000.
- Urban and tourist areas showed the largest relative increase in area, from 17.9 to 25.57 km^2, for an increase of 43%.
- Agricultural land also showed a large relative increase in area (22%), from 27.27 to 33.31 km^2.
- Bare substratum experienced the greatest relative reduction in area (-91%) during the study

Table 1. Error matrix used to assess the accuracy of a supervised classification of the 2000 Landsat image of the study area

Referenced Data Classified Data	Lagoon	Agriculture	Urban / Touristic	Forest	Mangrove	Bare substratum	Total	Error committed
Lagoon	6	0	0	0	0	0	6	0
Agriculture	0	2	0	0	0	0	2	0
Urban / Touristic	0	0	11	0	1	0	12	0.083
Forest	0	4	4	35	1	0	44	0.204
Mangrove	0	0	0	2	7	0	9	0.222
Bare substratum	0	0	0	0	0	3	3	0
Total	6	6	15	37	9	3	76 points	
Error by Omission	0	0.667	0.267	0.054	0.222	0		0.158

Overall accuracy = 84.2%; Kappa = 0.76; Kappa standard deviation = 0.08

period. This class declined from covering 12% in 1985 to only 1% in 2000, these areas were substituted for secondary vegetation.
- Mangroves showed the second largest relative decline in area (-39%). Annual Rate of Deforestation of 3.2%.
- The lagoon class, representing predominantly the Barra de Navidad lagoon, decreased slightly in size from 3.41 to 3.14 km² between the two dates.

Table 2 shows the proportion of land transferred from one class to another over the fifteen-year period. There are several notable results:

- Urban and tourist areas increased mostly at the expense of forested areas (33%) and bare substratum (27.3%); *i.e.* 33% of the urban/tourist area in 2000 was forested in 1985, and 27.3% was bare substratum.
- Agricultural and irrigated land also grew at the expense of forested land (27.5%).
- 17.6% of the bare substratum in 2000 was forested land in 1985, and 9.3 % was formerly mangrove thickets.

Changes in composition and configuration through time

The transition matrix and landscape metrics indicated fragmentation of the landscape and urban expansion within the study area, which have had direct effects on the lagoon. The number and size of patches varied from 1985 to 2000 and among the land use/land cover categories (Table 3). The mean patch size (MPS) of the urban and tourist class increased 75%, whereas the number of patches decreased from 88 to 73. This is indicative of the spread of urban and tourist development during the study period. The 75% increase also represents the largest change in mean patch size during the study period. The bare substratum class also showed a small increase in mean patch size (2.78%), but the number of patches declined dramatically, from 68 to 9. This represents an overall loss of bare land over the fifteen-year span. The mean patch size decreased for both the agriculture and forest classes (30% and 11%) while both classes showed an increase in patch number, gaining 17 and 13 patches, respectively. These observations suggest that agricultural land and tropical dry forest experienced fragmentation between 1985 and 2000. The mangrove class was the only land cover type to demonstrate a negative change in both mean patch size and patch number. The number of mangrove patches declined from 78 in 1985 to 56 in 2000, and decreased in size by 15% between the two dates. This translates to an overall loss of mangrove stands in the study area. Although having satellite data from only two years precludes the calculation of a deforestation rate, studies that have been done on similar lagoon-mangrove systems in Sinaloa, Mexico have showed annual rates of mangrove loss ranging from 0.2-2.4% (Berlanga and Ruiz, 2002). It is likely that the Barra de Navidad lagoon rate would be in the higher end of that range with 4.09% per year.

Table 2. Transition matrix showing land use/land cover change. Proportions in the column indicate a transition from the class on the left to a class on the top

2000-1985	Lagoon	Agriculture	Urban / Touristic	Forest	Mangrove	Ocean	Bare substratum
Lagoon	0.838			0.005		0.004	
Agriculture		0.568	0.049	0.056	0.087		0.018
Urban / Touristic	0.039	0.044	0.3	0.067	0.034	0.016	0.222
Forest	0.013	0.275	0.33	0.666	0.383		0.176
Mangrove	0.026	0.079	0.03	0.067	0.458		0.093
Ocean	0.071	0.035	0.008			0.979	0.018
Bare substratum	0.006		0.273	0.136	0.032		0.472

Table 3. Patch number, patch size and density results for the study area in 1985 and 2000

LULC class	Year	Total area km²	Number of patches #	Percent of LAND %	Mean patch Size (km²)	Patch density
Lagoon	1985 2000	3.41 3.14	3 5	1.67 1.54	1.36 0.7	0.015 0.024
Agriculture	1985 2000	27.27 33.31	26 43	13.33 16.28	1.04 0.73	0.127 0.21
Urban	1985 2000	17.90 25.57	88 73	8.75 12.5	0.2 0.35	0.43 0.357
Forest	1985 2000	96.20 111.70	48 61	47.03 54.61	2 1.78	0.235 0.298
Mangrove	1985 2000	15.62 9.60	78 56	7.64 4.69	0.2 0.17	0.382 0.274
Bare substratum	1985 2000	24.74 2.20	68 9	12.1 1.08	0.36 0.37	0.332 0.044
Landscape level	1985 2000		311 247		0.65 0.828	0.153 0.079

Direct changes to the lagoon

A comparison of the classified images (Figure 2) shows clearly that modifications to the borders of Barra de Navidad lagoon between 1985 and 2000 resulted in changes to the shape of the lagoon and sedimentation patterns within the lagoon. The changes were predominantly due to commercialization and tourism development on the lagoon borders, as well as urbanization within the study area as a whole. During the fifteen-year period, the main economic activity in the study area shifted from agricultural livestock and fisheries to tourist services and commerce (Ortega, 2002). In October 1985, Barra de Navidad was designated as a fishing port, by an incentive of the Government of Jalisco and the Department of Fisheries (Rodríguez, 1993). Eighty metres of the barrier spit was dredged to widen the entrance channel to the lagoon, and a jetty was constructed, 155 m long in the direction of the ocean and oriented perpendicular to the existing bar. The creation of Cabo Blanco Marina in Barra de Navidad necessitated the dredging of a series of canals on the northwest side of the lagoon. In 1985, the Grand Bay Hotel was constructed in Colimilla, the grounds of which include an extensive golf course, ornamental landscaping and a marina large enough to dock yachts.

The urban and tourist development on the fringes of the lagoon has enormous actual and potential impacts. Between the two dates of the study, there has been a shift in the perceived resource value of the lagoon. Since 1985, 155 registered boats have been added to the lagoon under the uses of fishing, transportation and aquatic activities (Hernández, 2005). These boats are a source of water and noise pollution.

The expansion of the towns of Barra de Navidad and Colimilla and the construction of the Grand Bay Hotel and golf course were largely at the expense of natural forest and mangrove vegetation. The loss of mangroves can have serious consequences, because they are considered essential to the productivity and natural resource value of the lagoon (Domínguez, 2003). The mangrove ecosystems that are naturally present in the Barra de Navidad lagoon system are breeding and feeding grounds for numerous species of fish, mollusks and crustaceans, many of which are of commercial value. Mangroves are also deemed natural sanctuaries for the protection of endangered species such as crocodiles and rare birds (Yañez, 1981).

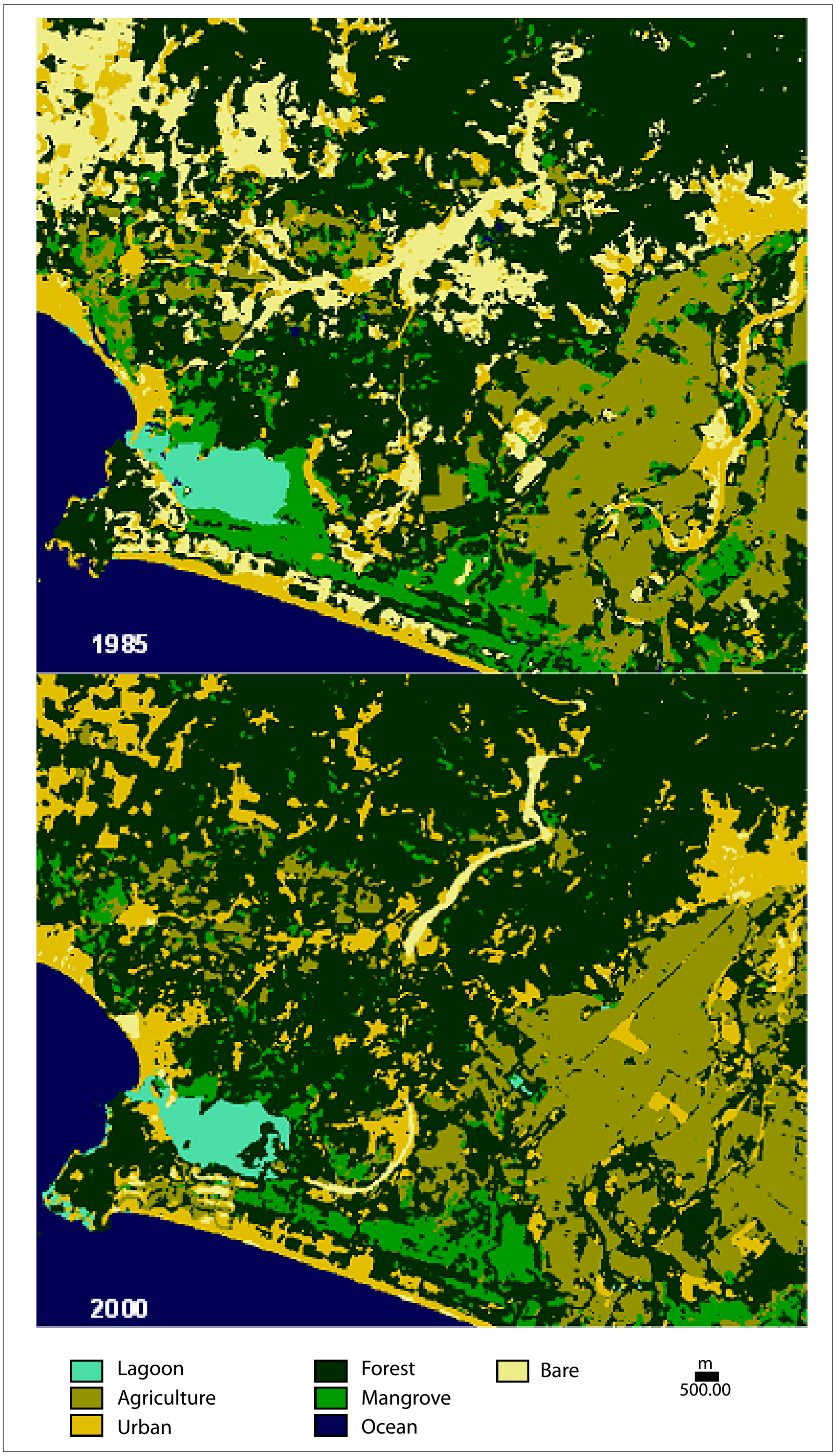

Figure 2. Thematic maps displaying land useland cover classes in the study area for 1985 and 2000.

One of the mangrove species native to the lagoon area, *Rhyzophora mangle* (Red mangrove), is itself listed as an endangered species by Norma Oficial Mexicana NOM-059-ECOL-2001 (Domínguez, 2003). In addition, the golf course is fertilized and irrigated, and the absence of a border of mangroves between the course and the lagoon in many areas increases the runoff of fertilizers directly into the lagoon water.

Sedimentation within Barra de Navidad lagoon shows an anthropogenic influence. In the 1985 satellite image, there is evidence of some sediment build up at the mouth of the Marabasco River, but only below the water surface. In the 2000 scene, however, the fan has built out about 800 m into the lagoon. In some places the sediment has become vegetated. This process of delta progradation is considered typical of microtidal low-latitude coasts. However, despite being a natural process (Méndez *et al.*, 2007), it has been accelerated by anthropogenic influences (Jones *et al.*, 2003). Between 1985 and 2000, there was urban development along the fan of the Arroyo Seco River, which transports freshwater and eroded soils that fall like sediments into the lagoon. Most of the urban expansion was at the expense of bare substratum and forested land.

In addition to the urban development upstream, the sediment load may have been affected by the dredging of the canal that connects Marabasco river to the lagoon. The canal, called Ixtapa Channel, was constructed to aid in the delivery of freshwater to the lagoon. The canal passes through a formerly dense association of mangroves, which would have originally trapped much of the sediment on the way into the lagoon. In 1985, the mangrove stands were still intact, but in 2000 there is evidence of fragmentation of the mangroves surrounding the channel and the head of the lagoon. This would increase the amount of sediment intermittent delivered from Arroyo Seco and Marabasco rivers.

CONCLUSIONS

The results of this study indicate that changes in landscape composition and configuration in the Barra de Navidad coastal lagoon system and surrounding watersheds were prominent in the classes of agricultural land, urban and tourist land, mangroves and forested wetlands, and bare substratum. Urban and tourist land had a large relative increase of area (43%), mostly replacing tropical dry forest and bare substratum. On the fringes of the lagoon itself, tourist development, especially of the Grand Bay Hotel complex, was at the expense of natural forest and mangrove vegetation. Mangroves showed a relatively large decline in area between the two dates (-39%), and became highly fragmented on the lagoon borders.

Natural and anthropogenic pressures are responsible for the sedimentation observed in Barra de Navidad lagoon. Agricultural land, urban development, mangroves and forest vegetation have an influence on water quality and sediment dynamics in the study area. Changes in the composition and configuration of land use and land cover classes in watershed have both direct and indirect accumulative impacts on the lagoon and functioning. At present, the lagoon and its immediate surroundings consist of a landscape with some of its natural covers exhibiting fragmentation. The loss of mangroves is especially worrisome, given the multitude of values that they contribute to the lagoon system.

This study provides evidence of change and baseline data that can be used for forecasting future changes and impacts. It can be used by natural resource managers to develop monitoring and management strategies to identify future threats and to reduce the impact of past and future development on the Barra de Navidad lagoon system. These results are useful not only within this coastal system, but may also serve as a benchmark for comparison in other systems undergoing multifaceted stressors, especially changes for tourism and the intensification of resource extraction.

ACKNOWLEDGMENTS

Many thanks to the staff and faculty of the University of Guadalajara's, Department of Sustainable Coastal Zone Development (DEDSZC) in Melaque, Mexico, where the field work was undertaken for this project. Dr. Elena Bennett of McGill University is also thanked for critical comments on an early draft of this paper.

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