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POSGRADO EN CIENCIAS BIOLÓGICAS

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"Productividad y alteración de los manglares y la percepción social sobre los mismos en el Noroeste de México"

T E S I S

QUE PARA OBTENER EL GRADO ACADÉMICO DE

DOCTOR EN CIENCIAS

P R E S E N T A

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Dr. Isidro Ávila Martínez
Director General de Administración Escolar, UNAM
P r e s e n t e

Por medio de la presente me permito informar a usted que en la reunión ordinaria del Comité Académico del Posgrado en Ciencias Biológicas, celebrada el día 6 de septiembre del 2010, se acordó poner a su consideración el siguiente jurado para el examen de DOCTOR EN CIENCIAS del alumno **XAVIER LÓPEZ MEDELLÍN** con número de cuenta **96533233,** con la tesis titulada: **"Productividad y alteración de los manglares y la percepción social de los mismos en el Noroeste de México"**, bajo la dirección del **Dr. Exequiel María Ezcurra Real de Azua.**

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Sin otro particular, quedo de usted.

A t e n t a m e n t e
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CONTENIDO

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RESUMEN

Los manglares del noroeste de México tienen una notable importancia biológica, ya que al encontrarse en una zona cubierta casi en su totalidad por ecosistemas xéricos, su follaje puede ser la única cobertura vegetal disponible para muchas especies que lo usan para alimentarse y/o refugiarse; sus raíces proporcionan hábitat a especies marinas, muchas de importancia económica. La interacción con la marea permite que su producción orgánica fluya hacia aguas adyacentes, donde se transforma en nutrientes para varias tramas tróficas. Actúan como filtros naturales, pues sus tejidos y los suelos donde se encuentran tienen la capacidad de absorber e inmovilizar contaminantes y protegen las costas de la erosión eólica y marina. Finalmente, juegan importantes papeles sociales y económicos, pues muchas comunidades costeras subsisten de la pesca en las regiones de manglar o en sus inmediaciones.

Sin embargo, a pesar de la importancia que estos ecosistemas tienen para la región y el país, su conservación se ve cada vez más comprometida por el avance acelerado y sin control de la población humana. Este desarrollo ha sido promovido por políticas públicas dirigidas a incrementar el crecimiento económico, favoreciendo inversiones privadas para maximizar la producción y obtener grandes ganancias en el corto plazo.

A través de un enfoque ecológico, histórico, social y geográfico, en esta tesis se describe y la dinámica ecológica, socioeconómica, política y cultural de los manglares de Sonora y Baja California Sur. Asimismo, se proponen estrategias que consideran tanto el entorno biofísico, como también los valores de la sociedad para obtener un manejo integral y controlado de las actividades humanas y así mantener, e incluso mejorar la salud de estos ecosistemas de manera que no se vean comprometidos en el futuro.

Como primer capítulo, se realizó un meta análisis de nueve trabajos científicos que evalúan la productividad de los manglares de la región. Se analizan los efectos de variables bióticas y abióticas sobre la producción de material orgánico y se evalúan las consecuencias que tendría una reducción substancial de los manglares para el intercambio de material en la zona entre la tierra y el mar, así como para las comunidades biológicas y poblaciones humanas. Los resultados indican que a pesar de encontrarse en una región árida, la producción orgánica es muy elevada, comparable con los manglares localizados en los trópicos. Estos manglares pueden convertir eficientemente los nutrientes disponibles en biomasa, gracias a comunidades de hongos, bacterias, protozoarios y algas que viven en su rizósfera que les permiten retener nutrientes. Este mantenimiento y ciclado de nutrientes es una de las principales funciones de los manglares en la bioquímica de las regiones costeras del noroeste de México.

Posteriormente, cuantificamos los cambios en la superficie de manglar en el Océano Pacífico de Baja California Sur, ocasionados por efectos globales como el aumento del nivel del mar y anomalías oceanográficas como El Niño. Para ello se comparó la respuesta espectral de manglares en imágenes de satélite entre 1986 y 2001; el análisis de los registros históricos del nivel del mar; fotografías aéreas históricas con imágenes actuales; el levantamiento topográfico y florístico de transectos en la costa; y el análisis isotópico de C^{14}. Evidenciamos que el manglar ha ampliado su extensión tierra adentro a una tasa anual promedio de 1.16% entre 1986 y 2001. Identificamos también que el nivel medio del mar ha aumentado a una tasa de 2.2 mm por año y que en El Niño puede crecer mucho más. Esto permite la colonización por manglares de nuevos espacios que antes estaban ocupados por vegetación halófita y suelos híper salinos, donde el aumento del nivel del mar empuja las semillas tierra adentro y reduce la concentración de sal. Sin embargo, este aumento no calma la preocupación sobre la conservación de estos ecosistemas, pues aunque los manglares están respondiendo al aumento del nivel del mar, los beneficios del nuevo crecimiento no son comparables con la pérdida del manglar de borde que es el que provee mayores servicios ambientales.

A continuación se presenta un estudio de ecología histórica donde se evalúa la influencia de diferentes patrones y procesos humanos históricos en las costas del noroeste de México. Comparando fotografías aéreas históricas con imágenes modernas, se examina cómo el crecimiento acelerado ha ido ocupado cada vez más ambientes costeros y se analizan las repercusiones ambientales, económicas y sociales. Se incluye también un análisis de las condiciones ambientales actuales en las localidades de manglar de Sonora y Baja California Sur, para complementar la exploración de los cambios antropogénicos y los respectivos impactos ambientales.

Finalmente, presentamos un estudio social que explora las percepciones, opiniones e intereses de pescadores, gobierno, ONGs y científicos con respecto a los manglares. Con la aplicación de entrevistas semi-estructuradas, identificamos las ideas principales, percepciones y prioridades de cada grupo, analizando cómo la oposición de intereses y la divergencia de opiniones están produciendo conflictos en la conservación y el manejo de las regiones costeras del noroeste de México.

En conjunto, estos capítulos proporcionan distintos elementos que permiten analizar la interacción histórica y actual entre el ser humano y los manglares en las regiones costeras del Noroeste de México, identificando aquellas áreas de conflicto aparente o potencial para la aplicación de medidas que promuevan un planeamiento eficiente que involucre la conservación del ecosistema, de sus procesos biológicos y el desarrollo económico local y regional.

ABSTRACT

Mangroves in northwestern Mexico have a remarkable biological importance, because their foliage in an area almost completely covered with xeric vegetation can be the only vegetative cover available for many species that use it for food and/or shelter; its roots provide habitat to different marine species, many of which are economically important. The interaction with the tide allows the flow of its organic production towards adjacent waters, where it is transformed into nutrients for many trophic chains. They act as natural filters because their tissues and the soils where they are have the ability to absorb and immobilize pollutants. They also protect the coast from wind and tide erosion. Finally, they play important social and economic roles, because many coastal communities live from fishing in the areas adjacent to mangroves.

However, despite the importance these ecosystems have for the region and the country, their conservation is compromised because of an accelerated and uncontrolled growth of human population. This development has been promoted by public policies directed towards increasing economic growth, thus favoring private investments in order to maximize production and obtain large economic profit in the short term.

Through ecological, historical, social and geographical approaches, this thesis describes the ecological, socio-economic, politic and cultural dynamics of the mangroves in Sonora and Baja California Sur. We also propose strategies that consider the biophysical environments as well as society values in order to obtain an integrated and controlled management of human activities, and thus improve the health of these ecosystems so their presence is not compromised in the future.

In the first chapter, we performed a meta analysis of nine scientific studies that evaluate the productivity of the mangroves in the region. We analyze the effect that biotic and abiotic variables have on the production of organic matter and we evaluate the consequences that a substantial reduction of mangrove surface will have on the exchange of organic matter in the sea-land transition zone, as well as for the biological communities and human population. The results indicate that even though these mangroves are in arid regions, their organic production is very high, comparable to other mangroves in tropical regions. These mangroves can efficiently convert the available nutrients into biomass because of fungi, bacteria and algae communities associated to their rhizosphere, that allow them to retain and cycle nutrients. This nutrient cycling is one of the main functions of these mangroves in the biochemistry of the coastal regions in northwestern Mexico.

We then quantified the changes in the surface of mangroves located on the Pacific Ocean coast of Baja California Sur that are derived from global changes such as sea-level rise and oceanographic anomalies such as El Niño. We compared the spectral signature of mangroves in satellite images from 1986 and 2001; analyzed the historical records of sea level; historic aerial pictures with modern images; topographic chart and floristic transect in the coast; isotopic analysis of C^{14}. We evidenced that the mangrove has extended its surface landward at a mean rate of 1.16% between 1986 and 2001. We also identified that the sea level has increased 2.2 mm per year and that in El Niño events it can grow much more. These allows the mangrove colonization of new areas that were previously occupied by halophytic vegetation and hyper saline soils, where the sea level rise drive the seeds inland and reduces the saline concentrations. However, this increase in surface does not ease the concerns on the conservation of mangroves, because even though these ecosystems are responding to sea level rise, the benefits of the new expansion are not comparable with the loss of mangrove fringe, which is the one that provides most of the environmental services.

A historical ecology study follows, where we evaluate the influence of different historic human patterns and processes in the coasts of northwestern Mexico. By comparing historic aerial photographs with modern images, we examine how the accelerated growth has been occupying more coastal environments and we analyze the environmental, economic and social impacts. We also include an analysis of the current environmental conditions of the mangrove localities from Sonora and Baja California Sur, in order to complement the exploration of anthropogenic changes and their respective environmental impacts.

Finally, we present a social study that explores the opinions and interests of fishermen, government officers, NGOs and scientists regarding mangroves. By applying semi-structured interviews, we identified the main ideas, perceptions and priorities of each group, analyzing how the opposing interests and the divergence in opinions are producing conflicts in the management and conservation of the coastal regions in northwestern Mexico.

Together these chapters provide different elements that allow the analysis of historical as well as current interaction between humans and mangroves in the coastal regions of northwestern Mexico, identifying those areas that might be in conflict to apply measures to promote an efficient planning that involves environmental conservation, its biological process, as well as the local and regional economic development.

INTRODUCCIÓN GENERAL

Décadas de investigaciones en diversas disciplinas científicas de los ecosistemas de manglar han demostrado su importancia como proveedores de infinidad de bienes y servicios ambientales que son fundamentales para el sostenimiento de la biodiversidad y las poblaciones humanas en las costas tropicales y subtropicales del planeta (Lugo 1974; Woodrofe 1982; Robertson 1991; Jennerjahn e Ittekkot 2002; Primavera 2005, Nagelkerken 2008).

En el Océano Pacífico los manglares alcanzan el límite norte de su distribución en las regiones áridas del noroeste de México, las cuales están cubiertas casi en su totalidad por ecosistemas xéricos. Con poco más de 33,000 hectáreas distribuidas en los estados de Sonora y Baja California Sur (CONABIO 2008), estos manglares tienen una notable importancia biológica, ya que su follaje puede ser la única cobertura vegetal disponible para muchas especies terrestres que lo usan para alimentarse y/o refugiarse; sus raíces proporcionan hábitat a especies marinas, muchas de gran importancia económica (Tovilla 1994; Palacios y Mellink 1995; Whitmore et al. 2005; Holguín et al. 2006; Aburto-Oropeza et al. 2008). Asimismo, la constante interacción entre los manglares y la marea permite que la elevada producción orgánica de estos ecosistemas fluya hacia aguas adyacentes, donde es rápidamente transformada en nutrientes vitales para varias tramas tróficas, manteniendo así la biodiversidad y la productividad marina, costera y terrestre (Flores-Verdugo et al. 1992; Félix-Pico et al. 2002). Los manglares también actúan como filtros naturales, pues sus tejidos y los suelos donde se encuentran tienen la capacidad de absorber e inmovilizar contaminantes, lo cual ayuda a mantener la calidad del agua en esteros, lagunas y costas (Rivera-Monroy et al. 1999; Páez-Osuna et al. 2003). Su presencia protege las costas de la constante erosión eólica y marina, por lo que es fundamental para mitigar efectos de huracanes, inundaciones y tsunamis que de otra forma causarían severos daños (Holguín et al. 2006; Walters et al. 2008).

Los manglares también juegan importantes papeles sociales y económicos, pues muchas comunidades costeras subsisten de la pesca en las regiones de manglar o en sus inmediaciones. Los tallos, raíces y hojas son también utilizados por las comunidades ya sea como leña, medicinas, tinciones, o para la construcción y elaboración de herramientas como arpones y postes (Young 2001; Basurto 2006; De la Cruz-González et al. 2006). Asimismo, su presencia favorece el desarrollo de la industria acuícola, que es una importante fuente de recursos económicos para muchas comunidades y empresas en la región. Por un lado, proporcionan nutrientes y semilla natural para los cultivos, y por el otro, ayudan a absorber los deshechos de los estanques (Páez-Osuna 2001; 2005). Otro importante servicio provisto por los manglares es su belleza escénica y la fauna asociada a los mismos, lo que resulta muy atractivo para el turismo y ha contribuido al desarrollo de esta industria tanto a nivel comunitario como empresarial (De Sicilia-Muñoz 2000; Presenti y Dean 2003). Finalmente, los manglares forman parte de la cosmogonía de algunos grupos indígenas en Sonora como los Seri y los Mayos desde tiempos ancestrales (Yetman y Van Devender 2002; O´Meara y Bohnemeyer 2008).

Sin embargo, a pesar de la importancia biológica, económica y social que estos ecosistemas tienen para la región y el país, su conservación se ve cada vez más comprometida por el avance descontrolado de la población humana (Enríquez-Andrade et al. 2005). La tasa de crecimiento de población alrededor del Mar de Cortés está entre las más altas del país, particularmente para los estados de Baja California y Baja California Sur, con tasas de crecimiento anual porcentual de 4.3% y 3% respectivamente, lo que aumenta las presiones ambientales derivadas del desarrollo de actividades económicas de una sociedad en crecimiento (INEGI 2000; Enriquez-Andrade et al. 2005, Azuz-Adeath y Rivera-Arriaga 2007). Este acelerado crecimiento y desarrollo ha sido promovido por políticas públicas dirigidas a incrementar el crecimiento económico, favoreciendo inversiones privadas para maximizar la producción y obtener grandes ganancias en el corto plazo. Estas decisiones se hacen por lo general sin considerar las repercusiones ambientales de estas prácticas, lo que ha resultado por un lado, en una notable degradación del medio ambiente y en la disminución de la capacidad de los ecosistemas para proveer sus servicios ecológicos, y por el otro, en el incremento en los niveles de marginación económica e inequidad social (Young 2001; Gonzalez et al. 2003; Basurto 2005; Luers et al. 2006; Duke et al. 2007).

La presente tesis es un estudio holístico que analiza el estado ambiental actual o la salud de los ecosistemas de manglar, evaluando el grado en el que las funciones del manglar se mantienen o se han visto interrumpidas y/o afectadas por las actividades humanas (Rapport et al. 1999). A través de un enfoque ecológico, histórico, social y geográfico, se describe y evalúa en los cuatro capítulos que forman esta tesis, la dinámica ecológica, socioeconómica, política y cultural de los ecosistemas de manglar de los estados de Sonora y Baja California Sur. Asimismo, se proponen estrategias que consideran tanto el entorno biofísico, como también los valores de la sociedad para obtener un manejo integral y controlado de las actividades humanas y así mantener, e incluso mejorar la salud de estos ecosistemas de manera que no se vean comprometidos en el futuro (Farnsworth 1995; Rapport et al. 2005).

En el primer capítulo, se realiza un meta análisis de nueve trabajos científicos que evalúan la productividad primaria de los manglares de la región. Se analizan los efectos que tienen variables bióticas y abióticas sobre la producción de material orgánico y se evalúan las consecuencias que tendría una reducción substancial de los ecosistemas de manglar para el intercambio de material en la zona de transición entre la tierra y el mar, así como para las comunidades biológicas y poblaciones humanas.

Posteriormente, se cuantifican los cambios en la superficie de manglar en el Océano Pacífico de Baja California Sur, ocasionados por efectos de escala global como el aumento del nivel del mar y anomalías oceanográficas como El Niño. Para ello se comparó la respuesta espectral de manglares en imágenes de satélite entre 1986 y 2001; el análisis de los registros históricos del nivel del mar; fotografías aéreas históricas que datan de 1960 con imágenes actuales de alta resolución; el levantamiento topográfico y florístico de transectos lineales en la costa; y el análisis isotópico de C^{14} en muestras de manglares obtenidas a diferentes distancias.

A continuación se presenta un estudio de ecología histórica (Swetnam et al. 1999) donde evaluamos la influencia que han tenido los diferentes patrones y procesos humanos históricos en las costas áridas del noroeste de México. Comparando fotografías aéreas históricas con imágenes modernas de alta resolución, se examina cómo el crecimiento acelerado de la región ha ido ocupado cada vez más ambientes costeros y se analizan las repercusiones ambientales, económicas y sociales para la región. Se incluye también un análisis de las condiciones ambientales actuales en todas las localidades de manglar de Sonora y Baja California Sur, para complementar la exploración de los cambios antropogénicos y los respectivos impactos ambientales que se han ido dando a lo largo del tiempo.

Finalmente, la cuarta sección representa un estudio social que explora las percepciones, opiniones e intereses de pescadores, personal de gobierno, organizaciones no gubernamentales y científicos con respecto a los ecosistemas de manglar. Mediante la aplicación de entrevistas semi-estructuradas y su posterior análisis, se identificaron las ideas principales, percepciones y prioridades de cada grupo, analizando cómo la oposición de intereses y la divergencia de opiniones que están actualmente produciendo conflictos en la conservación y el manejo de las regiones costeras del noroeste de México.

En conjunto, estos capítulos proporcionan distintos elementos que permiten analizar la interacción histórica y actual entre el ser humano y los manglares en las regiones costeras del Noroeste de México, identificando aquellas áreas de conflicto aparente o potencial para la aplicación de medidas que promuevan un planeamiento eficiente que involucre la conservación del ecosistema, de sus procesos biológicos y el desarrollo económico local y regional.

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CAPÍTULO I

La productividad de los manglares en el Noroeste de México.

The productivity of mangroves in Northwestern Mexico: A meta-analysis of current data.

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Key Words: Baja California Sur, Sonora, litter production, northernmost mangrove distribution.

Abstract

Mangroves are highly productive ecosystems that export organic material to the surrounding environments through their interaction with tides, and provide nutrients and energy for coastal and even open ocean food webs. These ecosystems reach their northernmost distribution in the arid and semi arid regions of northwestern Mexico, where they grow under suboptimal conditions. Nevertheless, they maintain high rates of productivity that are similar to those located in humid zones, and therefore their presence has important ecologic and economic implications. However, these mangroves are being threatened by the accelerated development of a region with the highest population growth rate in the country. In order to apply generality to the importance of mangroves in producing organic material, we performed a meta-analysis of the scientific studies that evaluate their primary productivity in northwestern Mexico. Our results fully support the idea that the production of organic material is higher at lower latitudes and it decreases linearly as latitude increases. Some mangroves presented high levels of litter productivity that are only comparable with the maximum values reported for mangroves closer

to the equator. Thus, primary productivity can be added to the other ecological roles of the northernmost mangroves of the North American Pacific coast, including the provision of habitat, food and shelter for many economically and ecologically important marine and terrestrial species. The substantial reduction of mangroves in the region will certainly have consequences for the exchange of material at the land-sea transition, which will be detrimental to many biological communities and human populations.

Introduction

Mangroves are among the most productive ecosystems in the continental margins of the tropical and subtropical regions, with annual biomass yields comparable to those of highly productive agricultural crops such as sugar cane (Flores-Verdugo et al. 1992; Day et al. 1996; Jennerjahn and Ittekot 2002). Mangroves shed large amounts of organic material in the form of leaves, branches, flowers, and fruits that when fallen from the tree are exported to the surrounding environments via the constant interaction with tides (Day et al. 1987).

Some of the organic matter produced by mangroves is directly consumed by grazers, while most of it is incorporated as detritus into the rich flux of energy that moves to adjacent areas, providing food and energy source for a myriad of marine and terrestrial food webs (Flores-Verdugo et al. 1992; Bano et al. 1997). For such reasons, the reduction or disappearance of these ecosystems can drastically alter the biochemical cycling of nutrients and disrupt many trophic chains (Flores-Verdugo et al. 1987; Jennerjahn and Ittekot 2002).

Mangroves of the Pacific coasts of America reach their northernmost distribution in the arid and semi arid regions of northwestern Mexico, where they cover a total surface of 105 thousand hectares distributed in the states of Sinaloa, Sonora and the peninsula of Baja California (CONABIO 2008). Due to the arid character of the region and the lack of flows from large rivers, mangroves grow here under suboptimal conditions, evidenced by a less developed forest structure and smaller tree heights (Flores-Verdugo et al. 1992; Holguín et al. 2001; Whitmore et al. 2005).

However, even though different studies have showed that factors like geographic localization, hydrology, nutrient availability, salinity, soil type, and light, among others determine mangrove biomass and productivity (Woodroffe et al. 1988; Arreola-Lizárraga et al. 2004; Méndez-Alonso and López-Portillo 2008), some mangroves in northwestern Mexico are able to maintain high rates of productivity that are similar to those located in humid and sub humid zones (Flores-Verdugo 1987). For these reasons, their presence has important ecological and economic implications, as mangroves contribute precious nutrients into the coastal environments that are the principal source of energy for coastal food chains, some of which support valuable open-sea fisheries in the region (Félix-Pico et al. 2006; Holguín et al. 2006; Aburto et al. 2008). Furthermore, in areas of extreme aridity, these ecosystems may be the only green vegetation available as habitat for terrestrial and avian organisms during migrations or dry seasons (Flores-Verdugo et al. 1990; Whitmore et al. 2005).

Despite their importance, mangroves in northwestern Mexico are being threatened by accelerated development in a region that has the highest population growth rate in the country (INEGI 2005). This rapid and unplanned growth is causing considerable degradation on the coastal environments, threatening the provision of important nutrients, goods and services, like those supplied by these productive ecosystems, which have not yet been fully evaluated for this region but that are vital in maintaining coastal ecosystems healthy (Enríquez-Andrade et al. 2005; Whitmore et al. 2005; Aburto et al. 2008).

In order to explore and describe large-scale patterns on the role and importance of mangrove ecosystems in producing organic material in northwestern Mexico, we performed a meta-analysis of the scientific studies and reports that evaluate the primary productivity of mangroves in the region. This is the first attempt to make a statistical synthesis of research results from a varied set of original studies, and to assess the effects of biotic and abiotic variables on the productivity of mangroves.

Methods

We included total of five published articles (Flores-Verdugo et al. 1987; Flores-Verdugo et al. 1990; Flores-Verdugo et al. 1992; Arreola-Lizárraga et al. 2004; Félix-Pico et al. 2006) and four unpublished manuscripts and data (Espinoza et al. 1981; Sandoval-Castro 2005; Chávez-Rosales 2006; Melling-López et al. unpublished data), which constitute the only available studies that estimate the productivity of mangroves in northwestern Mexico. All these studies analyzed the yearly amount of litterfall produced by mangrove trees by placing baskets below the canopy to collect fallen organic material along transects on different mangrove localities in the states of Sinaloa, Sonora and Baja California Sur between 1981 and 2004 (Table 1, Figure 1).

A database was constructed with the results of these studies and also with biotic and abiotic variables that have been reported to influence the productivity of mangroves, including species composition, precipitation, temperature, evaporation, salinity, and latitude (Flores-Verdugo et al. 1992; Twilley and Day 1999). The abiotic information was obtained from the

Mexican National Meteorological System website (http://smn.cna.gob.mx/, February 2010) (Table 2).

We used standard linear regression analyses to explore and model the relationships between the selected variables and evaluate their quantitative effect on the overall primary productivity of mangroves in northwestern Mexico.

Results

The results of the regression analyses showed that latitude was the environmental variable that best predicted the regional production of organic matter in the mangroves of northwestern Mexico (r^2=0.62, *P*=0.0004; Figure 2). Evaporation also showed a significant relation with litter productivity (r^2=0.31, *P*=0.01). We found no significant relation between litter productivity and the rest of the environmental variables (Table 3).

Additionally, the different species of mangroves also showed significant relationships with litter productivity (*Rhizophora mangle* r^2=0.48, *P*=0.0006; *Laguncularia racemosa* r^2=0.26, *P*=0.022 and *Avicennia germinans* r^2=0.27, *P*=0.175; Table 3).

These results suggest that there might be a different contribution by the different species to the overall litter productivity of the mangrove forest. Therefore we calculated the mean litter production in ecosystems with the presence of *R. mangle* (*n*=8, mean=1053, SE=105) and compared it with the mean litter production in ecosystems without *R. mangle* but with *L. racemosa* and/or *A. germinans* (*n*=8, mean=503, SE=85; *Laguncularia* and *Avicennia* forests did not differ between themselves; Figure 3).

Discussion

It has been estimated that litter production in mangrove forests around the world ranges from 200 to 1600 g m^{-2} yr^{-1}. (Twilley and Day 1999). These ecosystems show a high diversity of structural patterns as well as of functional roles within regions, and these varying traits are reflected on their productivity (Lugo and Snedaker 1974). Saenger and Snedaker (1993) found that productivity varies locally but that in a broader scale it declines as latitude increases; they also found a strong correlation between latitude and tree height, suggesting that latitude influences the elevation of vegetation through insolation, temperature and water availability which is reflected in the amount of organic matter that is produced. Additionally, patterns of litter productivity can also be affected by the species composition in mangrove ecosystems because some plants have growth rates that are intrinsically higher than others (Twilley and Day 1999).

The results of our analysis of litter production in several mangroves supports the conceptual model that within the regional mangrove community in northwestern Mexico the production of organic material is higher at lower latitudes and it decreases linearly as latitude increases. The highest productivity values were reported for the state of Sinaloa (1100-1263 g m^{-2} yr^{-1}) at latitudes 22–23°N, while the lowest production values are in the state of Sonora (185-197 g m^{-2} yr^{-1}) at the northernmost limit of mangroves between 28°N and 30°N.

Some of the reported values from mangroves in Sonora that are almost completely covered by *A. germinans* fall below the minimum worldwide estimations (Saenger and Snedaker 1993). Some authors attribute such low productivity to the combined effects of minimal tidal flooding and the scarce availability of fresh water in localities where evaporation rate is greater than rainfall (Arreola-Lizárraga et al. 2004).

On the other hand, a study conducted with *R. mangle* in Baja California Sur reported values that are among the highest for mangrove ecosystems worldwide (1634 g m^{-2} yr^{-1}). It is important to note that this study was performed on an estuary that was impacted by the construction of a highway by disrupting the natural water flow between the estuary and the bay. The authors mention that such amounts of litterfall might result from the poor environmental conditions of the estuary, which is reflected in the large decay of organic material (Espinoza et al. 1981). However, other mangroves in the region also presented high levels of litter productivity (1010-1263 g m yr), particularly those with *R. mangle,* that are only comparable with the maximum values reported for lagoons closer to the equator where conditions are more suitable for the development of mangrove forests (Flores-Verdugo et al. 1992; Saenger and Snedaker 1993).

In these arid and semi-arid regions were water and nutrients are scarce, mangroves grow under sub optimal conditions, often evidenced in their stunted growth. Nevertheless, they present high production levels of organic matter. Alongi and collaborators (2005) mentioned that in environments were nutrients are low, plants are generally more efficient in converting nutrients into biomass, and that the trees in arid zones exhibit rapid rates of net primary production, nutrient cycling, and litterfall. The nitrogen-use efficiency in mangroves worldwide varies from 48 to 294 g DWg^{-1} , and the phosphorous-use efficiency from 600 to 4900 g DWg^{-1}, however in some arid regions in Western Australia this same authors found a nutrient-use efficiency of 167 to 322 g DWg^{-1} for Nitrogen and 2905 to 5053 g DWg^{-1} for Phosphorous. A possible explanation of such nutrient-use efficiency in arid environments may be found in a highly effective nutrient recycling system formed by fungi, bacteria, protozoa and algae associated to the roots of mangroves (Holguín et al. 2001). Such communities help to retain scarce and important nutrients such as phosphorus and nitrogen, which have been proved to limit the productivity of these ecosystems (Twilley and Day 1999; Holguin et al. 2001), within the mangrove roots. This nutrient balancing is a very important function of mangroves in terms of the biogeochemical cycling of elements in the coastal areas of northwestern Mexico.

The amount of litter produced by these mangrove ecosystems represents a major source of organic matter and nutrients that flow into adjacent communities and nurture the coastal food chain, as the high content of water-soluble compounds makes dissolved organic matter released from leaves an easily accessible energy source for bacterial growth and filter feeders (Jennerjahn and Ittekkot 2002). The high primary productivity of the mangrove forests can be added to the other ecological roles of the northernmost mangroves of the North American Pacific coast, which include the provision of habitat for breeding, as well as refuge, food and shelter for many economically and ecologically important marine and terrestrial species (Whitmore et al. 2005; Holguin et al. 2006).

For these reasons, the conservation of these mangroves is critical. Any substantial reduction of these ecosystems will almost certainly have consequences for the exchange of material at the land-sea transition, which will be detrimental to many biological communities (Jennerjahn and Ittekkot 2002).

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Figure 1. Localities with litter productivity studies in northwestern Mexico. *= Estuaries with *Rhizophora mangle.*

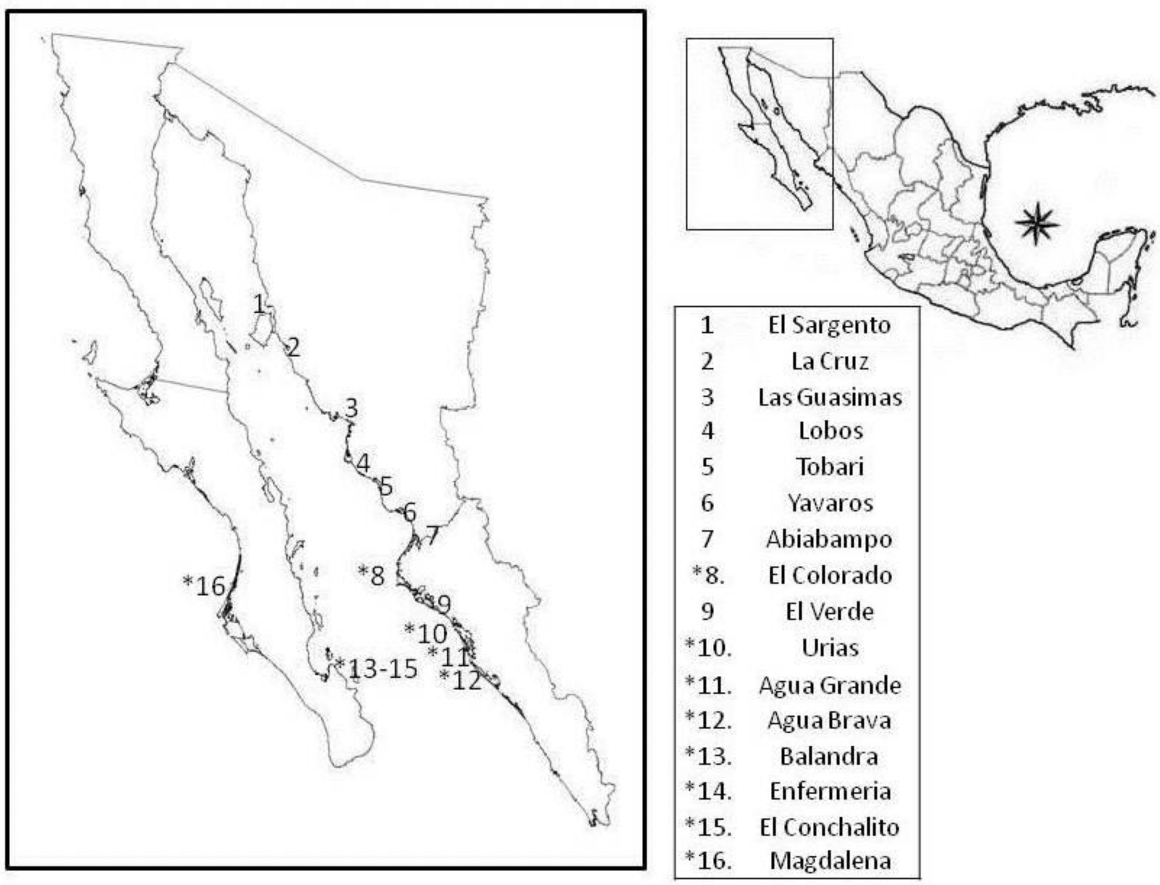

Figure 2. The relationship between latitude and productivity in mangroves of northwestern Mexico. ▲= Mangroves with *Rhizophora mangle* ●= Mangroves with *Avicennia germinans* and/or *Laguncularia racemosa* (t=-5.37, *P*=0.00004, r^2=0.62).

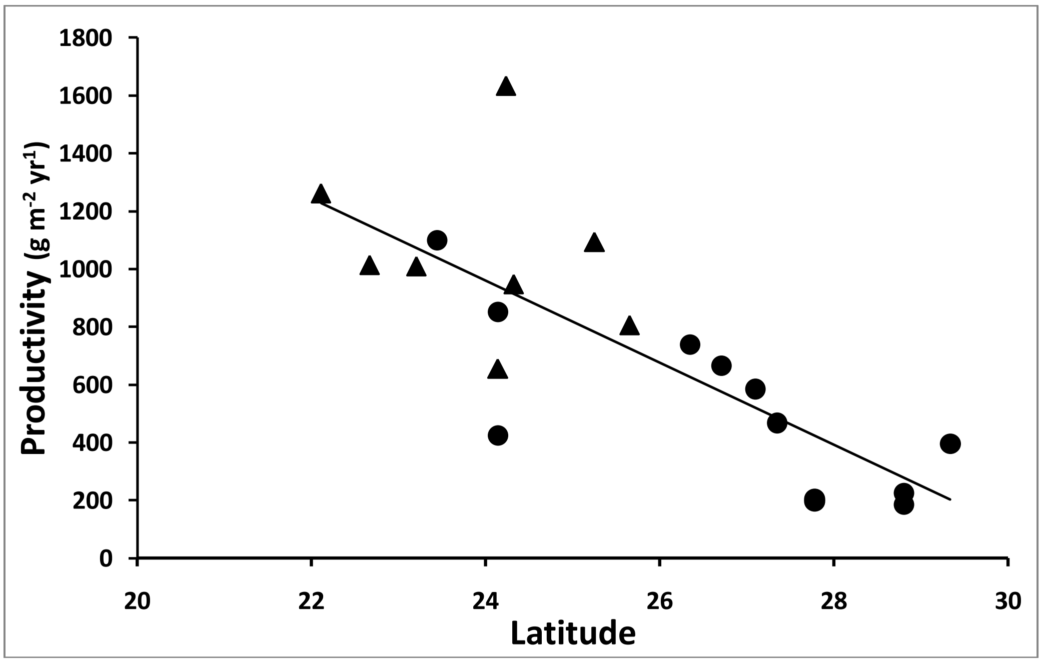

Figure 3. Mean litter productivity of mangroves with *Rhizophora mangle* and those with *Avicennia germinans* and/or *Laguncularia racemosa.*

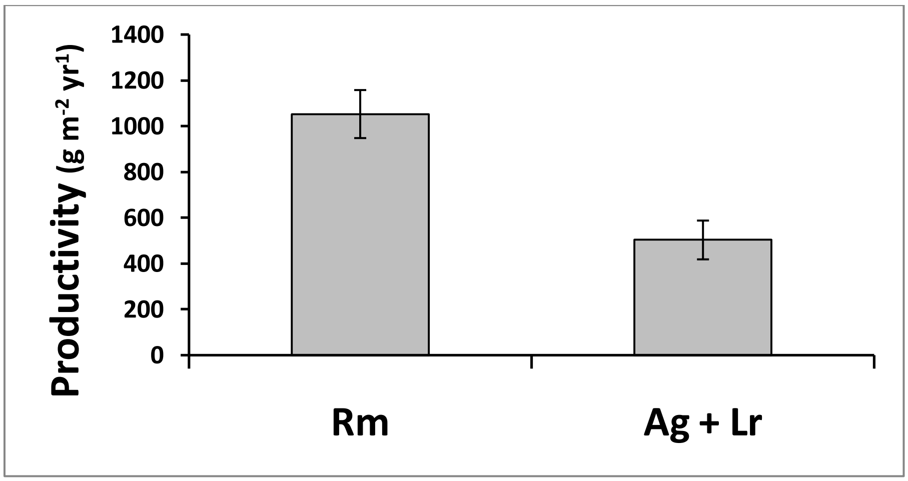

Table 1. Studies selected and sampled localities included in our analysis.

Locality	State	Latitude	Longitude	Source
Agua Brava	SIN	22.668	105.710	Flores Verdugo et al. 1990
El Colorado	SIN	25.654	109.286	Sandoval-Castro 2005
Estero de Urías	SIN	23.207	106.395	Flores-Verdugo et al. 1992
Agua Grande	SIN	22.110	105.510	Flores Verdugo et al. 1990
El Verde	SIN	23.442	106.562	Flores-Verdugo et al. 1987
Enfermería	BCS	24.235	110.306	Espinoza et al. 1981
Bahía Magdalena	BCS	25.254	112.123	Chávez-Rosales 2006
Balandra	BCS	24.322	110.324	Espinoza et al. 1981
El Conchalito	BCS	24.143	110.351	Félix-Pico et al. 2006
El Conchalito	BCS	24.143	110.351	Félix-Pico et al. 2006
El Conchalito	BCS	24.143	110.351	Félix-Pico et al. 2006
Agiabampo	SON	26.352	109.159	Meling-López et al. NP
Yavaros	SON	26.708	109.544	Meling-López et al. NP
Tobari	SON	27.100	109.970	Meling-López et al. NP
Lobos	SON	27.353	110.454	Meling-López et al. NP
El Sargento	SON	29.340	112.276	Meling-López et al. NP
La Cruz	SON	28.807	111.920	Meling-López et al. NP
La Cruz	SON	28.807	111.920	Meling-López et al. NP
Las Guásimas	SON	27.781	110.580	Arreola-Lizárraga et al. 2004
Las Guásimas	SON	27.781	110.580	Meling-López et al. NP

Table 2. Data matrix of litter productivity values (gr m yr) and abiotic and abiotic variables that were selected for this study.

Locality	**State**	**Prod.**	**Rm**	**Lr**	**Ag**	**Precip. mm**	**Max. T°**	**Min. T°**	**Med. T°**	**Evap. mm**	**Salinity**	**Latitude**
Agua Brava	SIN	1,015	1	1	1	853.5	32.7	18.5	25.6	1736	35	22.668
El Colorado	SIN	806	1	0	1	421.8	30.4	20.5	25.4	1833.8	42.5	25.654
Estero de Urías	SIN	1,010	1	0	0	846	32	14	24.1	2146	34	23.207
Agua Grande	SIN	1,263	1	1	1	853.5	32.7	18.5	25.6	1736	32.5	22.110
El Verde	SIN	1,100	0	1	0	541.1	29.4	18	23.7	1333.3	34.5	23.442
Enfermería	BCS	1,634	1	0	0	182.6	30.7	16.4	23.3	1996.5	42.5	24.235
Bahía Magdalena	BCS	1,094	1	1	1	111.7	29.5	14.1	19.3	2000	36.5	25.254
Balandra	BCS	948	1	0	0	182.6	30.7	16.4	23.3	1996.5	39	24.322
El Conchalito	BCS	852	0	1	0	182.6	30.7	16.4	23.3	1996.5	39	24.143
El Conchalito	BCS	657	1	0	0	182.6	30.7	16.4	23.3	1996.5	39	24.143
El Conchalito	BCS	424	0	0	1	182.6	30.7	16.4	23.3	1996.5	39	24.143
Agiabampo	SON	740	0	0	1	400	32.6	18	25.3	2650	40.5	26.352
Yavaros	SON	666	0	0	1	300	43	17	30	1750	21	26.708
Tobari	SON	585	0	0	1	259.2	31.2	15.5	23.3	2124.3	35	27.100
Lobos	SON	467.3	0	0	1	297.7	24.7	18	22	2591.5	26.5	27.353
El Sargento	SON	396	0	0	1	137.5	33	11	21	2000	40	29.340

La Cruz	SON	226	0	0	1	139.6	27	13.8	20.4	2159.5	37.5	28.807
La Cruz	SON	185	0	0	1	139.6	27	13.8	20.4	2159.5	37.5	28.807
Las Guásimas	SON	197	0	0	1	253.4	31	17	24	2712	38	27.781
Las Guásimas	SON	204	0	0	1	253.4	31	17	24	2721	38	27.781

Table 3. Linear regression results of the abiotic and biotic variables used to predict primary productivity. The best predictor was latitude, which had an inverse slope with productivity. The second best predictor was the simple presence of the black mangrove *Rhizophora mangle*, which increased primary productivity in around 550 g m^{-2} yr^{-1} (SE ± 135).

	Rm	***Lr***	***Ag***	**Prec**	**Tmx**	**Tmn**	**Tmd**	**Evap**	**Salinity**	**Latitude**
r^2	**0.48**	**0.26**	**0.27**	0.19	0.03	0.08	0.05	**0.31**	0.00	**0.62**
P	**0.0006**	**0.022**	**0.018**	0.05	0.46	0.22	0.34	**0.011**	0.84	**0.00004**

CAPÍTULO II

Anomalías oceanográficas y aumento del nivel del mar aumentan la superficie de manglares tierra adentro en las costas del Pacífico de México.

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Oceanographic anomalies and sea-level rise drive mangroves inland in the Pacific coast of Mexico

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Keywords
Bahia Magdalena; Baja California; Coastal lagoons; Coastal vegetation change; El Niño; Sea-level rise

Abbreviations
ENSO, El Niño Southern Oscillation; MEI, Multivariate ENSO Index

Nomenclature
The International Plant Names Index (2008). Available at http://www.ipni.org

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Abstract

Question: Although mangrove forests are generally regarded as highly threatened, some studies have shown that mangrove canopies in the Pacific coast of Mexico have been increasing in recent decades. We investigated the possible causes driving this reported mangrove expansion.

Location: The mangrove lagoons of Magdalena Bay in Baja California, Mexico.

Methods: We used 50-year-old aerial photographs and 24-year-old satellite images to compare long-term vegetation change, surveyed a coastal vegetation transect to analyse flooding levels, compiled six decades of tidal and oceanographic information, as well as hurricane data to analyse changes in storm frequency or sea-level conditions, and used isotopic analysis to date the age of trees along the gradient.

Results: A significant increase in mangrove cover has occurred in backwaters of the lagoons during the last 40 years, and especially during the El Niño anomalies of the 1980s and 1990s, while at the same time the mangrove fringe has been receding.

Conclusions: The observed change can be attributed to the combined action of the warm surface waters of El Niño events and sea-level rise. Jointly, these two effects are sufficient to flood large areas of previously non-flooded salt flats, dispersing mangrove seedlings inland. The inland expansion of mangroves, however, does not ease conservation concerns, as it is the seaward fringes, and not the inland margins, that provide the most valuable environmental services for fisheries and coastal protection.

Introduction

Recent studies have ranked mangrove forests among the most threatened ecosystems on Earth (Valiela et al. 2001; Alongi 2002; Duke et al. 2007; FAO 2007). In agreement with this view, Mexican governmental agencies have reported that the mangrove area in the nation has been decreasing in the last decades at an annual rate of around −2% (INE 2005). Some large-scale remote-sensing studies in northwest Mexico, however, suggest that mangrove cover in many lagoons, despite common perception, is not being lost. Comparing satellite images, some regional reports have argued that the area covered by mangrove forests has in fact been increasing during the last decades in some lagoons of the Pacific coast of Mexico (de la Fuente & Carrera 2005; Hernández-Cornejo et al. 2005; Hak et al. 2008). Looking at these remote sensing studies in detail, an additional pattern seems apparent: mangrove stands near the open waters, in seaward places such as sand bars or lagoon fringes, have decreased in the last decades, while landward mangrove cover, in the topographically higher edge of the forest, seems to have increased. Furthermore, the different lagoons where this mangrove forest increase has been reported lie in the coastal edge of flat sedimentary coastal plains, where a small change of just a few centimeters in sea-levels could flood large areas of coastal mud flats.

The rate of forest loss is of environmental concern, as mangroves produce vitally important environmental services, such as coastal protection (Badola & Hussain 2005; Costanza et al. 2008), pollution trapping and regulation of water dynamics in estuaries (Tam & Wong 1997; Ewel et al. 1998; Gilbert & Janssen 1998) and nursery habitat for commercially important fisheries (Costanza et al. 1997; Gilbert & Janssen 1998; Aburto-Oropeza et al. 2008). Cumulatively, the annual value of these services for 1 ha of mangrove forest can add up to tens of thousands of dollars and, in consequence, the long-term discounted value of a hectare of mangrove can reach estimated values of hundreds of thousands of dollars (Costanza et al. 1997; Rönnbäck 1999; Aburto-Oropeza et al. 2008; Hussain & Badola 2008). Thus, when an area of mangrove forest is destroyed, resources that provide valuable services for society may be irreversibly lost. Understanding the balance between mangrove loss and mangrove expansion is of utmost importance for coastal conservation. Thus, the research question driving our study was whether rising sea-levels have induced visible changes in the cover of mangrove forests during recent decades, thus explaining the observed long-term increase in mangrove cover.

Because the existing studies have been done using remote sensing techniques at a regional and relatively large scale, in order to test our hypothesis, we decided to analyse mangrove distribution at a more local scale, where local sea-level, micro-topography and establishment patterns could be measured in detail. For this purpose, we studied the mangrove forests of Magdalena Bay, a 200-km long complex of coastal lagoons in Baja California, Mexico, separated from the Pacific Ocean by a chain of islands and sand bars that keep the bay protected from ocean swells. The inland area east of the bay is formed by a large expanse of desert sedimentary plains that gently slope eastwards for around 50 km, into the foothills of the Sierra de La Giganta.

We explored our hypothesis using five different methods: (a) a comparison of the mangrove spectral signature in satellite images of 1986 and 2001; (b) a time-series analysis of tide levels from long-term recorded data; (c) a comparison of aerial photographs from 1962 against modern high-resolution images; (d) a detailed topographic and floristic field survey along a transect in the coast of the lagoon; and (e) an isotopic analysis of mangrove ages along the fringe–upland gradient.

Methods

Comparison of mangrove spectral signature in satellite images

We used seven-band LANDSAT images from 1986 and 2001 for Magdalena Bay, with a pixel size of 28.5 m × 28.5 m, classified into different vegetation categories according to the spectral signature of the dominant ground cover. The images were kindly provided by NatureServe and Pronatura Noroeste, two conservation agencies from the US and Mexico, respectively. The image classification algorithms used the CART (Classification and Regression Tree) software tool (Hansen et al. 1996; Pal & Mather 2003) to model and map the mangrove-dominated community types. Image registration between data sets consisted of 678 co-registration points identifiable on both images. Field surveys were done in March 2007, March 2008 and April 2009 to register community structure and composition of the dominant species, and to verify the results of the classification algorithm. Sites covered by clouds were marked on both images as a polygon shape and removed from the analysis. Adding all pixels that showed a spectral signature attributable to mangrove cover, we estimated the surface area covered by mangrove canopies in 1986 and 2001, and from these values, we estimated the change in mangrove cover in the whole Magdalena Bay from 1 year to another. At a more detailed scale, an image showing mangrove change was developed for Boca de Santo Domingo, one of the flattest plains of the whole region and one of the least impacted by direct human activity.

Time-series analysis

We downloaded sea-level data from 1950 onwards from the Permanent Service for Mean Sea Level (PSMSL), Proudman Oceanographic Laboratory in Liverpool, UK, (http://www.pol.ac.uk/psmsl/), for three stations in the Californian Pacific: Scripps Pier in La Jolla and San Diego Bay, both in Southern California, and Cabo San Lucas in Baja California Sur, Mexico. All monthly tide levels were re-calculated as deviations from the mean tidal level of 1950, which was taken arbitrarily as zero. Although all the stations had missing values for some months, there were no months in which all three stations had missing values simultaneously.

To obtain an estimate of sea-surface temperature change during the last half-century we downloaded the monthly Multivariate ENSO Index (MEI) from NOAA's Earth System Research Laboratory (http://www.cdc.noaa.gov/people/klaus.wolter/MEI/) from January 1950 (the first available datum) to the present.

Using time-series analysis techniques, we regressed the mean monthly tidal level against individual predictor variables. Because tide levels have an arbitrary origin in each station, we converted all tidal values to deviations from the station's mean. To model the seasonal trends in tide levels (the lowest mean tides are observed around March, when the water is coolest, maximum mean flooding occurs around September, when the water is

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warmest), the first harmonic term in a Fourier analysis was used to model seasonal variations in tidal levels. To capture and quantify the amount of variation that can be attributed to warm water expansion during the warm phase of the Pacific Oscillation (known as ENSO or El Niño Southern Oscillation), we used the MEI values as additional predictors of mean sea-level. In order to detect possible systematic effects of rising sea-levels on the flooding of the coastal mud flats, we used time, measured in years from 1950, as a direct linear predictor. Finally, in order to detect possible differences between stations, we tested for statistical interaction terms between the stations and the three linear predictors (seasonality, MEI and time).

Hurricane data

In order to test whether extraordinary continental run-off flowing into the lagoon after hurricane storms may have an influence in increased seedling establishment, we obtained the past hurricane tracks in the Pacific coast of North America since 1950 from NOAA's National Hurricane Center (http://www.nhc.noaa.gov), to correlate the occurrence of extraordinary hurricanes with periods of mangrove expansion.

Evidence from aerial photography

We visited the archives of *Ingenieros Civiles Asociados* (ICA) in Mexico City, the largest collection of aerial orthophotographs in the country, and selected and digitized 53 black and white aerial photographs of the Magdalena Bay region, scale 1:20 000, and taken between 1959 and 1962 (Job 562, Flights 109 and 110). All photographs were scanned at a resolution of 600 dots per inch and saved as JPEG files. Recent (August 2006) high-resolution colour images were downloaded from GoogleEarth Pro. Using ARC MAP software (ESRI, Redlands, CA, USA), images were geo-rectified to correct geometric and spectral distortions using a minimum of ten control points between older images and current INEGI base maps and modern images. The resulting images were projected in the Universal Transverse Mercator co-ordinate system. We used visual interpretation and a simple digital image processor (Adobe Photoshop) to compare geo-rectified past and current images, and to identify changes in mangrove cover. Although we obtained images for the whole estuary, we concentrated our analysis around Boca de Santo Domingo, where a detailed field verification survey was also done.

Field survey

In April 2009, we established a 425-m transect from a tidal channel to an elevated shell-midden occupied by coastal desert vegetation (25°27′16.5″N, 112°04′20.0″W). With a precision surveyor's level (SOKKIA model C22, Topcon Corp., Japan), we mapped the topographic profile of the lagoon-to-desert gradient, surveying a total of 13 stations. We collected all plants found along the transect, identified them in the lab, and deposited them in the herbarium of the San Diego Natural History Museum as voucher specimens.

On 7 April 2009, at 16:21 h we measured the level of the lowest tide of that day, and on 8 April, at 10:13 h we measured the level of the high tide. Comparing these two values with those from the nearby Port of San Carlos (obtained from CICESE, Laboratorio del Nivel del Mar; http://nivelmar.cicese.mx/), we were able to refer the topographic levels of our transect to those of the coast of the Pacific and thus calculate the mean tidal level for April 2009. Correcting for the effects of season, time and the Pacific oscillation, we then calculated the maximum flooding level in spring 1950, and the maximum flooding levels during the ENSO event of 1997. Finally, we plotted the results in the form of a topographic profile chart.

Isotope analysis

On 7 April 2009, we collected 2-cm thick stem sections from the base of nine mangrove trees: three were cut from *Avicennia germinans* saplings established in the higher part of the landward hinterland, three from *A. germinans* saplings in the lower part of the hinterland, and three from *Rhizophora mangle* trees in the flooded mud flat forest. In the each of the two hinterland samples, two of the saplings were randomly selected (to get an idea of the modal establishment time), and one additional individual was non-randomly chosen for its larger size with respect to the population (to estimate the establishment time of older saplings). In the mud flat, stem slices were cut from two randomly selected trees, and one was cut from a small tree that looked younger than the rest (to estimate the range of age variation in the mud flat forest). All cross-section slices were oven dried at 60°C until constant weight, and then the stem segments were sliced longitudinally in order to separate the pith from the secondary wood. Because the pith at the base of the stem is the result of primary stem growth, an analysis of ^{14}C in the pith cellulose provides an estimate of the plants establishment age.

Holocellulose isolates were prepared from the pith samples and analysed for radiocarbon content. Sample preparation was done at the Facility for Isotope Ratio Mass Spectrometry at UC Riverside and radiocarbon analysis was performed at the Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory at the University of California, Irvine. Because open-air nuclear explosions in the 1950s and early 1960s produced a large increase in atmospheric ^{14}C, which peaked in 1963-1964 and has been continuously decaying since, radiocarbon samples were classified into pre-bomb pulse and post-bomb pulse. Owing to the availability of aerial photographs of Bahia Magdalena from 1960, where the hinterland mangrove saplings are not visible, we could infer that all bomb pulse-labelled mangroves in the salt flats were established on the falling limb of the atmospheric ^{14}C-CO_2 pulse, i.e. after 1963.

Results

As reported in other studies from throughout Mexico's northwest, the spectral signature of the mangrove canopy in LANDSAT images increased significantly between 1986 and 2001 (Fig. 1 and Table 1). The net increase concentrates mostly in the landward fringe, where the mangrove forest meets the desert. During the two decades of the study period, a significant area of salt flats became colonized by new mangrove growth.

Mean tidal levels varied ($r^2 = 0.72$) with season and ENSO conditions, and tended to increase linearly with time (Table 2). Each year shows minimum tidal levels around March and maximum levels around September. Additionally, mean tidal levels are also strongly and linearly related to the Multivariate ENSO Index (MEI), a measure of the intensity of the warm El Niño phase in the Pacific Ocean. Finally, mean tidal levels have been increasing since 1950 at a fixed background rate of ca. 2 mm

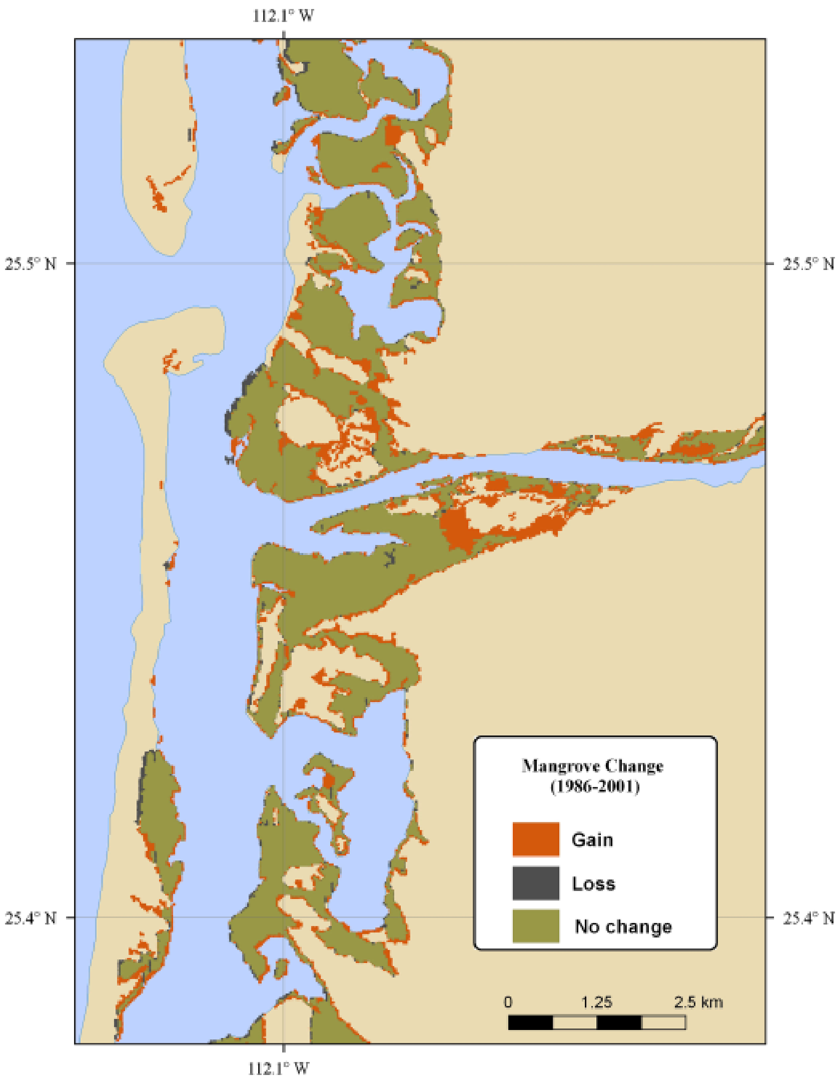

Fig. 1. Change in the spectral signature of mangrove canopies between 1986 and 2001, detected in Landsat images near Boca de Santo Domingo, one of the flattest coastal plains in Magdalena Bay and one of the areas least disturbed by direct human action. A trend for mangrove reduction is observed in the lagoon's fringes, while cover tended to increase in the landward edges of the forest.

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per year (Fig. 2). In particular, it was found that during the peak of the El Niño seasons of 1982-1983 and 1997-1998, the tidal levels in the Pacific coast of Baja California were ca. 35 cm above the 1950 baseline level. No significant interaction terms were found between the three tide stations and the predictors, indicating that seasonal variations, El Niño anomalies, and sea -level rise all have a similar effect on each station.

The number of hurricanes and tropical storms reaching the Baja California peninsula since 1950 has oscillated between zero and six per decade (Table 3). There was no visible trend towards increased incidence of tropical storms in recent decades.

Historic black-and-white aerial photos of 1962, compared against modern high-resolution GoogleEarth 2006 images, showed a marked increase in mangrove cover in many flat parts of the lagoon (Fig. 3), basically confirming the results of the satellite image analysis. Because of the fine detail in the aerial images, the error that could potentially be introduced in the satellite images by the large pixel size, or by confusing the spectral signature of mangrove forests with that of halophytes, is much lower in this method. The results showed a marked increase in mangrove cover towards the lagoon's landward fringes.

A topographic transect in the coast of the lagoon showed a narrow association between vegetation types and flooding levels (Fig. 4). The lower mud flat, occupied by high trees of red (*Rhizophora mangle*), white (*Laguncularia racemosa*) and black mangrove (*Avicennia germinans*), was regularly flooded during high tide in 1950. The upper mud flat, occupied by barren, salt-encrusted soils and a sparse community of halophytes, lies above the current level of maximum floods. The band between these two habitats was above the maximum flood level in 1950, but has been undergoing frequent

Table 1. Mangrove cover in Magdalena Bay as estimated from the canopy spectral signature in Landsat images 1986–2001.

Category	area (ha)
1986 – total	21 081
2001 – total	25 730
Unchanged	19 354
Lost	1727
Gained	6376

Table 2. Significance of different time-series variables driving mean monthly tidal level along Southern California and Baja California. Seasonality was predicted using the first harmonic of a Fourier transform, the intensity of the El Niño phenomenon was derived from the Multivariate ENSO Index (MEI), and the effect of continuous sea level rise was estimated using time as a linear predictor. No significant differences were found between the three tide stations.

	SS	df	MS	F	P	r^2
Seasonality	4 614 347	2	2 307 174	1221	< 0.00001	0.43
El Niño anomalies	2 267 594	1	2 267 594	1200	< 0.00001	0.21
Global sea level rise	819 650	1	819 650	434	< 0.00001	0.08
Full model	7 701 591	4	1 925 398	1019	< 0.00001	0.72
Error	2 982 112	1578	1890			

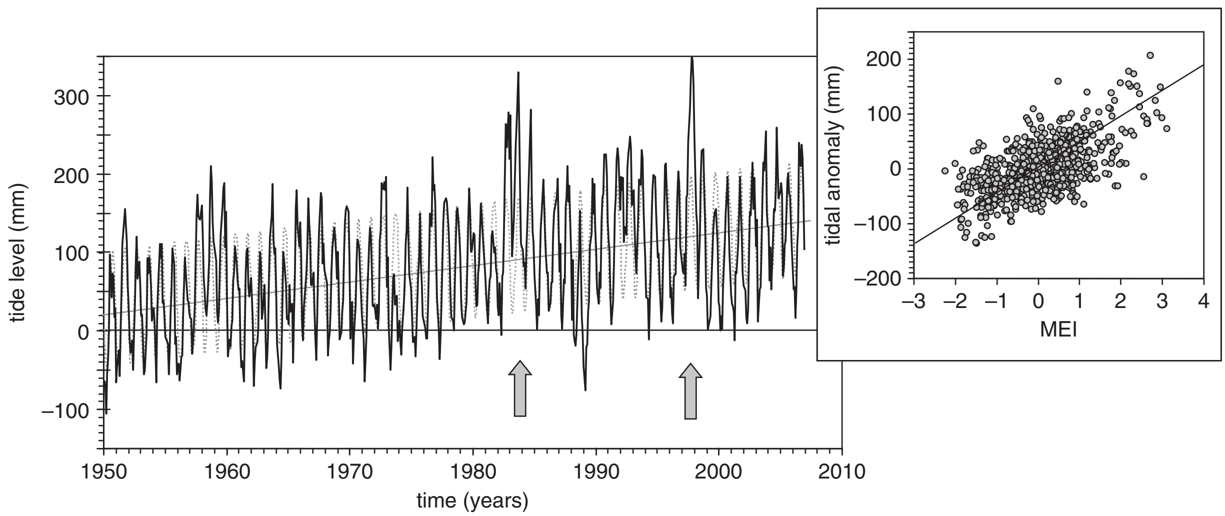

Fig. 2. Monthly mean sea-level values for the Pacific coast of Baja California. The data line in black shows the averaged values of the three tide stations (Scripps, San Diego and Los Cabos), arbitrarily taking the mean tidal level for 1950 as the baseline origin. The straight line in grey indicates the general trend for sea-level rise, the sinusoidal broken line shows the harmonic function describing seasonal variation. The deviations from these two predictors, shown in the insert to the right, were highly correlated with the Multivariate ENSO Index, a measure of oceanographic conditions in the Pacific Ocean (see Table 2 for significances). The vertical arrows show the El Niño years of 1982 and 1997, when the tidal anomaly reached extremely high values, ca. 20 cm above the predicted trend, flooding large expanses of the desert coastal salt flats.

Table 3. Number of hurricanes and tropical storms hitting the Baja California peninsula and generating increased continental runoff into the Magdalena plains.

Decade	Storms
1950–1959	5
1960–1969	3
1970–1979	2
1980–1989	0
1990–1999	2
2000–2009	6

inundations since, as sea-level has gradually risen. This band is now colonized mostly with young saplings of black mangrove, whose canopies show up in the satellite images as new mangrove cover.

The results of the isotopic analyses (Table 4) were strongly consistent with those of the photographic analysis and the field survey. The randomly selected plants sampled in the upper hinterland, the highest part of the transect, showed contemporary establishment times (the pith was formed after the 1998 ENSO event), while saplings in the lower hinterland showed piths formed after 1987 (following the 1983 ENSO event). In contrast, the randomly selected trees in the mud flat forest were 80 to 135 years old, with a younger, selectively chosen individual reaching ca. 37 years of age.

Discussion

During the last two decades, the area covered by mangrove canopies has increased in Magdalena Bay by more than 20%. Mangrove saplings are now growing in the landward stretches of the mud flats, which were occupied decades ago by salty soils and a halophytic desert scrub. It is clear from our transect data that microtopography is a major factor in the response of vegetation to changes in sea-level. Inland colonization by mangrove saplings will chiefly happen in gently sloping coastal plains, where a slight increase in sea-level may significantly drive the intrusion of seawater inland.

The process of inland colonization necessarily demands extraordinary tidal levels flooding the coastal salt flats, as flooding depth is one of the main factors defining the establishment of the viviparous propagules of mangroves (Rabinowitz 1978). The larger propagules of the red mangrove tend to become established in the deeper parts of the intertidal mud flats, while the smaller propagules of the black mangrove can drift inland into shallow waters. Thus, maximum tidal level defines the vegetation composition of any given point within a mud flat. In congruence with this, the newly colonized salt flats in Magdalena Bay contained saplings of black mangrove, the species with the smallest propagules.

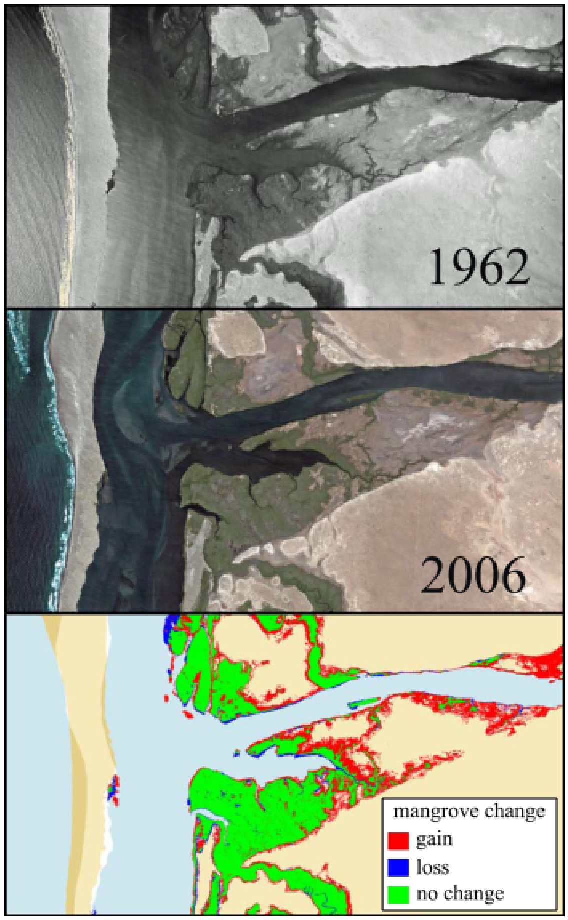

Fig. 3. Boca de Santo Domingo in high-resolution images. The top plate shows an aerial photograph taken in 1962, the middle one is a GoogleEarth image from August 2006. The image at the bottom highlights the differences between the two timed photos.

The new colonization of the previously mangrove-bare salt flats may be triggered by at least three different phenomena: (a) extraordinary continental run-off flowing into the lagoon after hurricane storms; (b) very strong ENSO warm-phase anomalies; or (c) continuously rising sea-levels. Hurricanes, however, have occurred regularly in the past (Table 3), and there is no strong evidence of increased continental run-off during the last three to four decades, the period in which new mangroves have colonized the mud flats. Furthermore, there is good evidence that hurricane-driven floods were in the past as strong as they are today: in 1906 the American explorer Edward W. Nelson documented an extraordinary flood that inundated the whole of the Magdalena plains and the surrounding desert vegetation: "*for two days we had the strange experience of riding through desert vegetation immersed in water as though growing in a marsh*" (unpublished notebook, Smithsonian archives). Remarkably, during the decade 1980-1989, a period where according to isotopic

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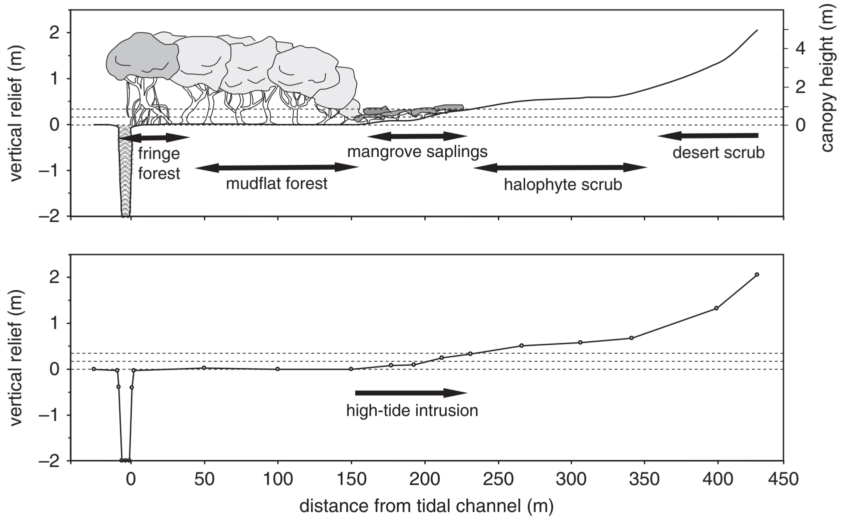

Fig. 4. Top: Vegetation profile of the mangrove community in Boca de Santo Domingo, Magdalena Bay. The fringe forest is formed by linear stands of the stilt-rooted red mangrove (*Rhizophora mangle*); the mud flat forest is composed of old-growth stands of red, black and white mangroves (*Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa*, respectively), and the saplings in the landward edge are mostly small individuals of black mangrove. Bottom: The same profile with the topographic stations. The lower dotted line shows the high-tide flooding levels in 1950, the middle dotted line shows the high-tide levels observed in April 2009, and the upper dotted line shows the levels of high-tide inundation during the El Niño season of 1997. The distribution of mangrove saplings, which were not seen in the 1962 aerial photograph, is concentrated in the upper landward edge that was flooded in recent decades.

Table 4. Carbon age of nine trees along the sampling transect, classified by their landform position along the topographic gradient, and the sampling criterion used to select them.

species	Landform	sampling criterion	year
Avicennia germinans	upper hinterland	older plant	1986
Avicennia germinans	upper hinterland	Random	2007
Avicennia germinans	upper hinterland	Random	2007
Avicennia germinans	lower hinterland	older plant	1973
Avicennia germinans	lower hinterland	Random	1990
Avicennia germinans	lower hinterland	Random	1988
Rhizophora mangle	Mudflat	Random	1929 ± 20
Rhizophora mangle	Mudflat	Random	1874 ± 20
Rhizophora mangle	Mudflat	Sapling	1972

observations mangrove seedling establishment in the mud flat was intense, there were no recorded hurricanes or tropical storms in the region.

Seedling establishment in the newly colonized areas has occurred mostly since the 1970s, in coincidence with a period of frequent and strong El Niño events. Thus, it is likely that these oceanic warm-phase anomalies had a strong influence on the inland colonization by mangrove seedlings. It is likely, however, that all three causes may be working in a synergistic fashion. Williams (2009) described how extraordinary oceanic anomalies and unusually strong hurricanes can set the stage for sea-level rise to drive rapid changes in coastal landforms delivering a "combination punch" to the coastal systems.

Following this idea, and based on our establishment data, it is likely that mangrove inland expansion progressed in pulses, driven by the warm phase of the ENSO anomaly, which can episodically add 20 cm or more to the background trend for sea-level rise. During the ENSO seasons of 1982-1983 and 1997-1998, the lower salt flats of Magdalena Bay became regularly flooded with the high tides, and mangrove establishment followed. Continuous sea-level rise, on the other hand, has kept these mud flats wetter than they were only a few decades ago, allowing the newly established seedlings to survive. At the same time, a significant amount of mangrove fringe has been lost (Fig. 5).

The inland expansion of mangroves as a result of rising sea-levels, however, does not ease concerns for the future of these ecosystems. An area occupied by new-growth mangrove saplings may have a canopy spectral signature similar to that of a mature forest, but ecologically it does not have the complexity of an old-growth stand. At the same time, many areas of fringe mangrove have been suffering considerable loss (Whitmore et al. 2005) as a result of forest clearing, dredging, sedimentation, increased wave action from motorboats and, as this paper now shows, also as a result of increased sea-levels. Recent papers have demonstrated that these seaward fringes provide the most valuable environmental services, such as fisheries or coastal protection (Barbier et al. 2008; Koch et al. 2009). A recent study by our research group (Aburto-Oropeza et al. 2008) showed that the annual

Fig. 5. Top: Receding seaward fringe of the mangrove forest (exposed black mangrove root system near Puerto López-Mateos). Bottom: High desert hinterland becoming colonized by black mangrove saplings (salt-flat near Boca de Santo Domingo).

value of the fisheries services provided by fringe mangroves can be of the order of US$37 000 per ha. Because a large part of the 1727 ha of mangroves that have been lost in Magdalena Bay during the last decades corresponds to fringe mangrove, it is likely that many millions of dollars in fishery habitat have been lost or degraded as a result of rapid changes in the mangrove forests.

The on-going colonization by small black mangrove saplings in the landward part of the tidal flats does not necessarily compensate for the loss of old-growth mangrove forest in the seaward fringe. Mangroves have been clearly responding to sea-level rise, but the benefits of increased mangrove establishment in the landward salt flats, compared to the loss of valuable services as a result of mangrove destruction in the seaward fringe, are dubious.

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CAPÍTULO III

El límite noroccidental de los manglares en México: Lecciones ambientales de un acelerado desarrollo costero.

THE NORTHWESTERN LIMIT OF MANGROVES IN MEXICO: ENVIRONMENTAL LESSONS FROM ACCELERATED COASTAL DEVELOPMENT.

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ABSTRACT--The northwestern region of Mexico is one of the most productive and biodiversity rich areas of the world. It has provided ecological services to humans since pre-Hispanic times and continues to provide them today. Mangroves in this region are fundamental to maintaining coastal environmental quality. They provide nutrients that sustain marine and terrestrial species, many of which have economic importance. However, mangroves and their surrounding environments are being impacted by the growth of coastal populations and the development of economic activities. To observe and understand how human patterns and processes have affected mangrove ecosystems through time and evaluate the consequences of unplanned development activities in Sonora and Baja California Sur, we integrated historical information, aerial photography and field surveys. We observed how the landscape in these regions has gradually changed over the last century as human development has progressed. In areas that have been developed for longer periods of time, like the southern region of Sonora, mangrove ecosystems have been drastically modified and important ecological functions provided by these ecosystems have vanished. On the other hand, in areas where development is still scarce, like some areas in the Pacific coast of Baja California Sur, mangrove ecosystems manifest suitable environmental conditions and continue to provide vital services to human populations.

RESUMEN--El noroeste de México es una de las áreas más productivas y ricas en biodiversidad del mundo. Ha proveído servicios ecológicos a los humanos desde tiempos pre-Hispánicos y actualmente continúa proveyéndolos. La presencia de manglares en la región es fundamental para mantener la calidad ambiental costera. Proveen nutrientes que mantienen a muchas especies marinas y terrestres, algunas de ellas con importancia económica. Sin embargo, los manglares y su entorno están siendo severamente impactados por el crecimiento de las poblaciones costeras y el desarrollo de actividades económicas. Para observar y entender cómo los patrones y procesos humanos han afectado a los ecosistemas de manglar en el tiempo y poder evaluar las consecuencias de un desarrollo acelerado en Sonora y Baja California, integramos información histórica, fotografía aérea y muestreos en campo. Con ello observamos cómo estas regiones han ido cambiando durante el último siglo a medida que el desarrollo humano ha progresado. En áreas que han sido desarrolladas por más tiempo, como la región sur de Sonora, los ecosistemas de manglar han sido drásticamente modificados e importantes funciones ecológicas de estos ecosistemas han desaparecido. Por el otro lado, en áreas donde el desarrollo es aún escaso, como algunas áreas en la costa del Pacífico de Baja California Sur,

estos ecosistemas mantienen condiciones ambientales favorables y continúan proveyendo servicios vitales para las poblaciones humanas.

The arid northwestern region of Mexico is formed by the states which surround the Sea of Cortés: Sonora, Baja California Norte and Baja California Sur. This area is one of the most productive and biodiverse areas of the world (Sala et al., 2004; Enriquez-Andrade et al., 2005), and it has provided environmental goods and services to the human populations that have inhabited these coastal areas for milennia (Almada, 2000; del Rio and Altable-Fernández, 2000).

Mangroves in these arid regions play key functions to maintain the environmental quality of coastal ecosystems (Twilley and Day, 1999; Holguín et al., 2006): their roots and stems provide habitats for many fish and invertebrate species, many of which sustain fisheries (Aburto-Oropeza et al., 2008); their canopy provides stopover sites for migrating species (Palacios and Mellink, 1995; Whitmore et al., 2005; Holguín et al., 2006); their high productivity contributes organic material and nutrients to both land and sea (Flores-Verdugo et al., 1992; Holguín et al., 2001; Félix-Pico et al., 2006); they remove contaminants by incorporating them in their tissues or immobilizing them in sediment (Feller et al,. 1999; Rivera-Monroy et al., 1999); they also provide suitable environments for aquaculture (Páez-Osuna et al., 2003); and constitute scenic landscapes suitable for tourism activities (Presenti and Dean, 2003).

The rich waters of the Sea of Cortés and its coastal environments are ideal for the development of economic activities which sustain the large population growth on its coasts. Presently almost ten million people inhabit certain areas in the region, which has the highest population growth in the country (INEGI www.inegi.org.mx). This is also the result of waves of immigration from regions where people previously practiced agriculture and/or livestock activities; these new residents settle in some coastal areas searching for labor alternatives. As this expansion continues, human activities are exerting development pressures which have transformed natural environmental conditions (Enriquez-Andrade et al., 2005; Glenn et al., 2006).

In Mexico, the urgency to generate rapid economic growth has historically promoted policies that focus on economic gain by encouraging the development of hastened practices to maximize short-term yield, rather than harvesting them sustainably (Young, 2001; Basurto, 2005). This situation has had negative impacts on both coastal ecosystems and human populations, because it threatens the different ecological functions, services and economic values from which the region and its population benefit (York et al., 2003; Enriquez-Andrade et al., 2006). It is of the outmost importance that the degradation of natural environments is reduced or even reversed, so that the future population can enjoy the benefits of these coastal ecosystems.

In order to understand and assess how human patterns and processes have influenced mangrove environments through time, and also to inform land management decisions, we used historical information and photography to illustrate the development of the region and provide reference frames of times when natural ecosystems were less affected by humans (Swetnam et al., 1999; Axelsson and Östlund, 2000). Combining historic data with current information and local environmental and socioeconomic assessments can serve to illustrate the environmental consequences of unplanned development activities (Swetnam et al., 1999).

This study provides a summary on the history of the human population and the economic development in the coasts of the arid territories in northwestern Mexico. By comparing historic aerial photographs with modern imagery, we examined how the accelerated development has claimed coastal environments; and by performing assessments of the current environmental conditions of all mangrove localities in Sonora and Baja California Sur (BCS) we explored the long-term anthropogenic changes and their impacts on natural habitats.

In order to organize our work, we divide the area as Doode (2001) suggest into three regions according to the historical development of human population and economic activities (Figure 1):

1. South-central Sonora. Has a higher population density that has practiced agriculture, cattle, mining, fishing and trade since the 18th century. Has large wetlands influenced by deltas of large rivers. Mangroves are distributed from Guaymas (N 27°57' 19.47" W 111° 3' 50.28") to the southern limit of the state in Estero Agiabampo (N 26°21' 18" W 109° 09' 13.2") (Figure 2).
2. Northern Sonora. Has a lower population density, its development largely related to a fishing expansion in the 20th century. Mangroves are distributed between Isla Tiburón and Bahía de Kino and reach north to Estero El Sargento (N 29°19' 24.43" W 112° 21' 56.64"). (Figure 3).
3. Baja California Sur. Has the lowest population density, few merchant ports and small settlements that were created in the 20th century with the expansion of fishing. Mangroves occur along the Pacific coast from Punta Abreojos (N 26°48' 15.3" W 112° 21' 56.64") to Estero Rancho Nuevo (N 24°18' 47.1" W 111° 24' 01.1"). In the Sea of Cortés mangroves are present in isolated patches from San Lucas (N 27°13' 12.9" W 112° 13' 05.3") to Playa Balandra (N 24°18' 45.9" W 110° 19' 05.8") (Figure 4).

MATERIALS AND METHODS--The historical development of human activities in the states of Sonora and BCS was summarized after extensive literature review. This information was complemented with current data about the type and size of human population, as well as current development activities, taken mostly from Instituto Nacional de Estadística, Geografía e Informática (INEGI).

We researched two archives with historical aerial photographs, Ingenieros Civiles Asociados (ICA) and INEGI and scanned 160 photographs from Sonora and BCS taken between 1950 and 1970 with a flat-bed scanner at 600 dpi.

Photographs were geometrically corrected and rectified using modern UTM ortho photographs as base maps (http://antares.inegi.gob.mx). Then, we compared the historical photography with high resolution images from Google Earth and visually registered the human development around all mangrove ecosystems in both states.

We conducted field visits in Sonora and BCS between 2007 and 2009 to survey the intensity of human activities and assess their effects on the mangrove ecosystems and their surrounding environments.

RESULTS—*History of development in South-central Sonora*--The region that extends from the city of Guaymas to southern Sonora has been occupied by humans since well before the arrival of Europeans. For millennia, native tribes like the Yaqui and the Mayo harvested corn, beans, squash, and cotton and also used marine resources (Hrdlicka, 1904; González-Bonilla, 1941; Doolitle, 1984).

In the 16th century, Europeans explored the region by sea and land, searching for gold, pearls and other commodities. However, all attempts to establish settlements failed. It took until the early 18th century before missionaries finally started settlements and initiated the first economic activities. With the lethal combination of hard labor and epidemics, they pressured native groups and reduced their population (Treutlein, 1939; Almada, 2000).

By the end of the independence movement in 1821, products from local farms, ranches and mines were being gradually incorporated into the national commerce. The period of President Porfirio Diaz (1883-1911) promoted foreign investments, particularly from the US, designed to enhance communication systems and create better public works. These attracted migrants from all over the country to these coastal areas, accelerating the population growth and the development of economic activities (Coerver, 1977). However, the regional economic boost became vulnerable to the fluctuating cycles of the US economy. During the crisis of 1908, for example, high unemployment forced many to return to the valleys (Almada, 2000).

In the 1930s the government promoted a new land distribution scheme based on the ejido, distributed territories to local communities, and fostered the development of agriculture, cattle growth and fishing in order to promote economic growth. Large investments were directed to construct dams, channels and roads to promote irrigation-based agriculture and enhance cattle production in the valleys of the Mayo and Yaqui rivers (Almada, 2000).

The resources from the ocean were plentiful then, and by the end of WWII the US was again interested in food and raw materials produced in Sonora. The first fishing cooperatives and processing plants were established during this period to capture and process oyster and shrimp, and new investments were directed toward massive production without considering the environmental consequences (Almada, 2000). The introduction of outboard motors, nylon nets and larger boats in the 1950s accelerated the exploitation of marine resources, which were soon decimated. Furthermore, the pesticides and fertilizers used in the agriculture of the valleys washed down towards lagoons and estuaries, threatening the fishing cooperatives' income (McGoodwin, 1980).

Consequently, by the beginning of 1970, soil productivity was severely reduced and fish captures diminished drastically, resulting in lower revenue and greater debt in the region. The drop of oil prices in 1982 and other market changes shifted investments out of the country, severely affecting the regional economy (Almada, 2000).

As a strategy to expand the economic alternatives of the ejido sector, aquaculture was introduced in Sonora in 1983 (Luers et al., 2006). However, limited access to credit and a lack of material and technical resources stopped rural communities from developing this industry. During the 1990s, new privatization and liberalization policies were created to integrate rural communities into the global economy. However, some of these reforms changed the ejido laws, enabling their members to transfer their lands, and also encouraged partnerships with the private sector to create credit opportunities (Luers et al., 2006). This allowed the private sector to enter the aquaculture industry freely, growing tremendously: in 1993 there were 1000 ha of ponds and between 1994 and 2003 a total of 18,904 ha were constructed, most of these financed by private entrepreneurs (Luers et al., 2006). These transformations placed Sonora as one of the fastest growing states; it was a time of productivity growth, with cities growing in extent and population, but also a time of severe overexploitation.

Present state of mangrove ecosystems in south-central Sonora--The first mangrove estuary in southern Sonora is the Yavaros-Moroncarit system (N26 41 31.5 W109 32 29.4). The town of Yavaros (population 4,000) borders the estuary (INEGI www.inegi.org.mx). The urban settlement is next to the mangroves, where large depositions of trash and other construction and liquid waste attest to the popularity of these areas as waste disposal sites. In the 1960s a road was constructed to connect Yavaros with Huatabampo, the largest city in southern Sonora (population 30,000) (INEGI www.inegi.org.mx). This road blocked the natural water flow and caused severe sediment deposition, killing many mangrove trees. In 1985, because sardine fishing was a profitable activity, industrial and fishing ports, as well as several fish processing plants, were established in Yavaros (Cisneros-Mata et al., 1995). However, in recent times the area is undergoing severe environmental problems: sediments and contaminants come down from the Mayo River valley through large drainage channels, polluting the waters and transforming the estuary by blocking the natural flow of water. This situation is aggravated by the direct disposal of liquid and solid wastes from processing plants into the estuary. Finally, the long-term overharvesting of resources has depleted populations of marine species that sustain fisheries (Mora, 1997). Figures 5A and 5B illustrate the expansion of agriculture and aquaculture around Yavaros, as well as the waste channels directed into the estuary.

Estero Tóbari (N27 06 03.9 W109 58 56.6), one of the most productive estuaries in Sonora, is located north of Yavaros. Its mangrove and marine environments are suitable for the reproduction of mollusks, crustaceans and fish, and it creates an important stopover site for migrating species (Balderas et al., 1994). The area was severely modified in the 1960s by the construction of a road to Isla Huivulai, which cut the estuary in half and blocked the natural water flow. This estuary also receives pesticides and fertilizers from adjacent agricultural developments through a draining channel, which results in heavy pollution, eutrophication and sedimentation. Figures 6A and 6B show the road construction, the expansion of agriculture, aquaculture and salt works around the estuary, and the draining channels directed to the estuary.

South from Guaymas, there is a large system of coastal lagoons that begin in Las Guásimas (N27 53 40.6 W110 37 14.4) and end in Estero Lobos (N27 17 33.1 W110 25 54.4). Mangroves are located in the coastal limit of the fertile Yaqui river valley, an area where the Yaqui have exclusive fishing rights. These mangroves are impacted by drainage channels that spill residues into the estuaries, blocking water flow, and resulting in high pollution, biodiversity loss and economic consequences, because fishermen cannot access the estuary. Aquaculture ponds have also been constructed in the area, adding pressure to these threatened coastal environments.

The next mangroves are located around Guaymas (N27 55 26.1 W110 52 13.2) and are highly impacted due to the accelerated development of the second largest Mexican port in the Pacific. The economy of Guaymas (population 101,507) (INEGI www.inegi.org.mx) was based on fishing products and their processing (Almada, 2000). The local fishing industry contributed 70% of the state's fishing productivity, including sardines, shrimp and squid. However, in recent times the decline of fisheries by overharvesting and the increasing pollution switched economic activities over to assembly plants and tourism. Today, Guaymas keeps growing without control. Urban settlements and industrial facilities are being developed all over the bay, increasing human pressure on coastal environments (Figures 7A and 7B). There is, however, a growing initiative by environmental NGOs to protect natural ecosystems, and recently the state has declared a large mangrove population (Estero El Soldado) as a protected area.

History of development in Northern Sonora--For more than 2000 years, the northern part of Sonora was inhabited by semi-nomadic tribes like the Seri, who lived from hunting, fishing and gathering, moving regularly according to resource availability, due to the aridity of the region. By the 18th century the Seri population was concentrated on Isla Tiburón, but it also dominated the coastal continental areas from the Yaqui River to the south, and to the Altar desert to the north (González-Bonilla, 1941; Almada, 2000).

Early European explorations consisted on military reconnaissance missions in the mid 16th century without attempts to settle. The first contact with natives occurred in the end of the 17th century, when Jesuit Eusebio Kino established the first settlement in what now is Bahia de Kino. However, with the foundation of the city of Hermosillo in 1700, the northern territory was consolidated. However, the arid environment and the belligerent nature of the Seri culture slowed down the development of the region. Not until the 1970s was the territory of the Seri formerly recognized. At that time they were granted the exclusive fishing rights of Canal del Infiernillo, a region with great fishing because there are no developments to pollute the marine environment. The Seri have created a traditional guard to survey their area in search for unauthorized fishermen (Wong, 1999).

In the early 20th century, a small fishermen settlement existed in Bahia de Kino, now called Kino Viejo, which was dedicated to the capture of totoaba (*Totoaba macdonaldii*). Fifteen years later the first fishing cooperative was formed, increasing the population to 500, and the capture of species like sharks and shrimps began (Moreno et al., 2005).

From 1965 to 1990 fiber boats, faster motors, nylon nets and diving gears allowed a faster extraction of resources and broaden the fishing area to the west coast of Baja California (Doode, 1999). In 1980 a public company created to support the fishing cooperatives at Bahía de Kino, constructed warehouses, and provided work opportunities. The number of fishermen increased as new waves of people migrated to the coast from the adjacent valleys in search of work (Basurto, 2006). Soon, the intense harvesting of resources abated natural populations and captures decreased, causing the company to stop operations by 1984 (Basurto, 2006). Conflicts which continue to the present day started within the community in a struggle for resources between industrial and artisanal fishermen (Moreno et al., 2005).

Aquaculture started in the area as a small experimental and research unit of the Universidad de Sonora in the 1980s. However, several changes in privatization policies during the 1990s promoted its quick development, and in 2002 thirteen farms produced more than 2500 tons of shrimp which exceeded the captures of the fishing industry (Moreno et al., 2005).

Fishing opportunities also attracted tourism since 1930s, when the first sport fishermen arrived from the US. In 1950 the government promoted tourism in Bahia de Kino by constructing a highway to Hermosillo and expanding electricity and water services, making the city a vacation destination for national and international tourists.

Present state of mangrove ecosystems in northern Sonora--The first mangroves, going from south to north, are located in Estero Tastiota, where one of the largest aquaculture developments has almost completely removed all mangrove vegetation, with just a few surviving patches left. Sixty kilometers to the north is the next mangrove community, surrounding the Estero Santa Cruz in the vicinity of Bahía de Kino, a town with 5,000 inhabitants (INEGI www.inegi.org.mx), and structures comprised of fishermen and tourism houses, restaurants and large aquaculture complexes.

Damage to the mangroves comes from trash and construction and liquid wastes disposed directly in the estuary by people. Aquaculture ponds also deposit large quantities of organic matter and sediments that are polluting the waters and blocking their flow. The consequences are noted by the fishermen, whose captures have been reduced by overharvesting and pollution.

Figures 8A and 8B show the large construction of roads, aquaculture ponds and draining channels connected to the estuary.

The best preserved mangroves in Sonora are in the land of the Seri between Isla Tiburón and the mainland, the northernmost limit of their distribution. Human development is scarce here, with only two Seri settlements: Desemboque and Punta Chueca, with a total population of 658 mostly dedicated to fishing and/or crafts (INEGI www.inegi.org.mx). The channel between mainland and Isla Tiburón, known as Canal del Infiernillo, has a series of small mangrove estuaries (Punta Arenas, Punta Víboras, Punta Onah and Punta Tortuga), the largest being Punta Arenas (N29 10 49.3 W112 13 40.7). Further north is the last mangrove ecosystem in Sonora, Estero Sargento (N29 20 20.9 W112 16 38.1), which is the largest estuary, with more than 5 kilometers of a large mangrove ecosystem. These ecosystems are in very good conditions since the Seri acknowledge their importance for the fisheries in their fishing area and protect them.

History of development in Baja California Sur--Researchers estimate that before Europeans arrived, Baja California had a native population of forty to fifty thousand that moved seasonally across the peninsula hunting, fishing and gathering (Del Rio and Altable-Fernández, 2000).

The first European exploration started in the 1530s, but all attempts to establish a settlement failed because of the extreme arid conditions and the lack of permanent water sources. It wasn't until the late 17th century that the missionaries started colonizing the area by establishing a series of missions that started in the coastal region of Loreto. Missionaries and soldiers gathered the natives in these missions and developed a few agriculture and cattle activities, as well as scarce mineral and pearl extraction. After the Jesuits were expelled in 1767, the crown was barely interested in the mineral deposits of the peninsula, and the only activities developed were those necessary to provide the mines with transportation, raw materials and food. The resources needed to sustain these settlements were supplied by mainland Mexico through the increasingly important port of San José del Cabo (Del Rio and Altable-Fernández, 2000).

By the first half of the 19th century, the agriculture, cattle and mining activities practiced by this population were becoming more important, and their production reached not only regional, but national and international markets. Trade became a profitable activity and the port city of La Paz grew quickly. By 1830 the government moved from Loreto to La Paz (Del Rio and Altable-Fernández, 2000).

In the beginning of the 20th century, Porfirio Diaz secured large investments from foreign companies to exploit mineral resources in Baja California and distributed large portions of land; some of these companies widened their activities to include agriculture and cattle growing in order to guarantee local supply. These investments also improved the cities, with the development of infrastructure, and schools, and by 1910 the population grew to 42,000 (Wyllys, 1933). The enlargement of human population and economic activities also brought the overharvesting of resources and the pollution of water bodies by industrial and urban waste (Del Rio and Altable-Fernández, 2000).

The Mexican revolution started in continental Mexico in the first decade of the 1900s, but its effects were hardly felt in the peninsula. However, resources from mainland became scarce, which greatly slowed the local economy. The population growth slowed, and by 1929 there was a total population of 47,000 people who worked in the mining colonies and agriculture/cattle settlements. In response to this lack of expansion, the federal government promoted surveys between 1930 and 1960 to identify available natural resources. These explorations identified areas suitable for agriculture, but the reports indicated that due to the water scarcity, it could not be practiced intensively. Nevertheless, a series of agriculture policies were created in order to advance the economy, and the government distributed large territories to ejidos and private parties tripling the farming surface in the state (Del Rio and Altable-Fernández, 2000).

In the 1960s, the southern region of Baja California underwent a large process of industrialization, and fat credits were granted to farm large surfaces of land. Furthermore, the ferry to communicate the peninsula with mainland was introduced and in the '70s the peninsular highway was finished, connecting the entire peninsula from north to south. This contributed to the development of commerce and tourism, increasing the population to 130,000 inhabitants (Del Rio and Altable-Fernández, 2000).

Between 1971 and 1980 the federal investment in BCS increased more than 100%. Mining, construction, electricity, communication, transport and fishing industries grew, however commerce and tourism presented the largest growth, becoming the principal activities (Del Rio and Altable-Fernández, 2000). Hotels, condominiums, restaurants, fishing fleets and other tourism services were intensively developed in La Paz and Los Cabos, and by 1980 the economic income generated by tourism represented 27% of the total state incomes (Del Rio and Altable-Fernández, 2000). From 1995 on, the tourism industry has been a major socioeconomic factor in the peninsula. The construction of large urban developments around the Sea of Cortés are increasing water demands, restricting access to valuable resources and polluting their surrounding ecosystems with residual waters and improperly treated wastewater (Del Rio and Altable-Fernández, 2000; Beltrán-Morales, 2005; De Sicilia-Muñoz, 2000).

The marine resources from the rich waters of Baja California have provided additional sources of profit. In the 1930s fisheries policies were created to support small and large fisheries (Young, 2001), and to date a total of 650 species have been identified as exploitable for human consumption and industrialization (Cortés-Ortiz et al., 2006). On the Pacific coast, species with high commercial value, such as abalone and lobster, represent profitable targets. To this end, large investments have been directed towards new technology and transportation (Chenaut, 1985; Vega-Velázquez, 2004). The Sea of Cortés coast has less valued species, and most of the fishing here is done basically by small groups (Young, 2001). However, since 1993 the massive-capture fishing activities of less valued species have been largely promoted, contributing to the development of this industry (Felix-Uraga et al., 1996). By 2000, BCS ranked fifth among states with plants for transforming fishing products and seventh in the number of cooperatives. To date the fishing industry continues to grow, and in 2002 it contributed more than 12% of the national captures (Cortés-Ortiz et al., 2006).

Present state of mangrove ecosystems of Baja California Sur--The coast of the Sea of Cortés— Mangroves in this coast are distributed on different coves and inlets in small to medium size patches. Bahía Balandra (N24 19 2.5 W110 18 54.4) is the southernmost mangrove locality on this shore, where a coastal lagoon is surrounded by mangroves in good condition. This bay, near the city of La Paz, has recently been declared a protected area. Further north is another estuary called El Merito (N24 18 7.5 W110 19 36.2) that is in good condition, however, the access has been closed by a private owner and the area is soon to be developed for tourism. Bahía Pichilingue (N24 14 56.8 W110 18 48.4) is an area with high tourism and industrial developments, with constructions that include a shuttle port, fuel and cement factories, universities and tourism facilities. Embedded in the city of La Paz there is a small coastal lagoon called Enfermería (N24 13 47.77 W110 18 26.33), which has been severely polluted and damaged by road construction and aquaculture development (Figures 9A and 9B).

Other mangroves are embedded in La Paz (N24 9 2.27 W110 19 31.75), a city of 189,176 inhabitants who live mainly from tourism (INEGI www.inegi.org.mx). The city has a large port, and airport, as well as several industries and tourism facilities that contribute important profits to the city. However, due to its arid location, water scarcity is a critical problem, and since more hotels are being constructed, local water supplies and environmental quality are being compromised. These mangroves show signs of disturbance like surface oil and trash and construction debris deposition. In front of the Bahía de La Paz, there is a large mudflat called El Mogote (N24 09 24.7 W110 20 48.3), with some mangrove populations facing the bay. These mangroves are in good condition; however, the area is undergoing rapid tourism development inlcuding golf courses, a large marina and several buildings, which represent a threat to their conservation (Holguin et al. 2006). Figure 10A and 10B shows the growth of La Paz, with a notable urban and industrial expansion, as well as the construction of roads around the bay and on El Mogote sand bar.

Just north of La Paz is the Espíritu Santo Island, which was declared as a protected area in 2001. The west side of the island has eight sites with mangroves in excellent condition: El Mesteño (N24 30 56.2 W110 23 21.6), La Raza (N24 28 32.7 W110 22 35.7), El Gallo (N24 27 52.6 W110 22 10.8), La Gallina (N24 27 13.8 W110 22 02.3), El Erizoso (N24 26 23.4 W110 22 20.8), Bahía San Gabriel (N24 25 36.2 W110 21 09.0) and La Despensa (N24 24 45.7 W110 21 04.1). In 1903, some facilities were built on the island for the production of oyster pearls, opening channels through the mangroves. However, the facility was abandoned in the ‘70s due to production failure. Presently there are no settlements on the island, and the impact of tourism is very low.

Some small mangrove patches are located along the coast to the north up to Loreto. The first population is located in Puerto Escondido, a marina that projects to have hotels, condominiums, golf courts, ferry areas and a commercial port (De Sicilia, 2000). Some mangroves were removed during the construction of the port, but a few patches are still left. However, the environmental conditions in the area will soon be modified by the projected development that has already changed the morphology of the port, as it is evident in Figures11A and 11B.

A couple of kilometers north, in the Loreto-Nopoló area, another series of mangroves located in the vicinity of Ligüi (N25 44 40.0 W111 15 41.6), were severely damaged during the 2003 hurricane season. Some other small mangrove stands are present around the fishing community of Ensenada Blanca (N25 43 31.5 W111 14 48.5), where a luxury hotel is being developed, and conflicts with fishermen are already occurring by restriction of their access to the beach. A couple of miles north from Ensenada Blanca, a medium size mangrove estuary was completely covered with sand in 1976-77 by the National Fund for Tourism Encouragement to develop the Loreto-Nopoló-Puerto Escondido corridor.

The next mangrove population to the north is located in a series of coves along the west coast of Bahia Concepción. The first is Ensenada El Manglito (N26 32 59.2 W111 45 51.4), a large mangrove stand in good condition and with a small fishing community in its surroundings that captures clams, snails, manta and snappers. The next is Playa Armenta (N26 37 33.5 W111 48 53.5), a small mangrove area next to a hotel and an RV camp. These populations are in poor condition, since construction and debris have blocked and changed the water flow. Santa Barbara (N26 42 03.2 W111 52 53.1) has two patches of mangroves with no signs of human presence.

However, an ongoing large project is expected to construct golf courses, marinas, hotels and houses in this area. El Burro (N26 43 57.7 W111 54 30.2), has a medium-sized mangrove patch bordering a lagoon, and small houses distributed along the shore. The lagoon is being filled in by the local inhabitants to reduce its surface and eventually kill the mangroves, which represents nuisance vegetation to them. The last mangrove area is the largest population and is located in Playa Santispac (N26 45 44.4 W111 53 30.8), where little tourism development is still present. However, during the vacation season tourists fill the area leaving trash and waste along the seashore that accumulates in the roots of mangroves.

Continuing to the north is the town of Mulegé (N26 53 53.7 W111 58 02.4), with 3,317 inhabitants. Mulegé is an important tourist destination, with hotels, trailer parks, restaurants, a bus station and a small airport (INEGI www.inegi.org.mx). The city is located next to a large estuary that flows into the Sea of Cortés. The mangroves in the inner part of this estuary show disturbance by urban development and road construction, which have partially blocked it with rocks and other debris. Fishermen concentrate their activities in the sea and almost no fishing is practiced in the estuary, because they consider it a natural refuge for fish and birds. Figures 12A and 12B show the construction of roads, urban and tourism developments in Mulegé. Another impact to mangroves in the area is the occurrence of hurricanes, which damage this vegetation periodically.

The last mangrove stand along this shore in BCS is located 50 kilometers north of Mulegé in a small settlement called San Lucas (N27 13 05.6 W112 12 49.1), which has tourist houses, RVs and military barracks. A thin bar of sand forms a small inlet, where mangroves are distributed in well conserved patches. Among the population of 203 inhabitants (INEGI www.inegi.org.mx) fishermen capture squid and fish from the sea, and clams, crabs, oyster and octopus in the mangroves.

The Pacific coast --The first mangrove locality from north to south is located in a 15 kilometers estuary named La Bocana (N26 45 29.5 W113 38 30.5), flanked by two fishing communities with a total of 2,000 inhabitants: Punta Abreojos and La Bocana (INEGI www.inegi.org.mx). The population here relies upon lobster and abalone, which are highly valued species in the market and sustain the local economy. However, some others capture clams, oyster and some fish from the estuary for local consumption (Cortés-Ortiz et al. 2006). Southeast from Punta Abreojos is El Coyote estuary (N26 48 36.8 W113 28 09.6) (Figures 13A and 13B), formed by a series of channels and islets covered by mangroves in excellent condition. Here, there is a small lodging facility with cabins and latrines that was constructed in 1980, as well as a couple of fishermen's houses and two oyster farms.

The next mangrove populations are distributed around the Bahía de San Ignacio, an area that was designated as a World Heritage site by UNESCO (INE-SEMARNAP, 2000). This ecosystem is in good condition and occupy large areas around Estero El Cardón (N26 49 15.5 W113 10 53.8), which continues south to Estero El Dátil. The population is distributed in three settlements: the first two are the ejidos Luis Echeverría and El Cardón with 1,000 inhabitants in total; the third, El Dátil, is located adjacent to the estuary of the same name with less than 100 inhabitants (N26 32 39.5 W112 56 17.5). Fishing is the principal activity of the local population, however there is a growing number of people working in oyster farms. The area receives a great number of temporary visitors who come from December to April to see the southern migration of the Gray whales (*Eschrichtius robustus*), therefore different tourism developers employ seasonal workers.

Further south, the area of Bahía Magdalena-Bahía Almejas, is the largest mangrove ecosystems of BCS distributed in a complex set of estuaries and channels covering more than 130 kilometers. The cooler conditions of the California current meet here with the subtropical effluents coming from the south, which creates an area of great productivity and biological diversity (Mathews, 1974; Hernández-Trujillo et al., 2004; Amador et al., 2006). This region is one of the most important coastal zones in northwest Mexico and contributes with 65% of the BCS fishery production (Lluch-Belda et al., 2000). Human population is distributed mainly in two port cities: Puerto Adolfo López Mateos and Puerto San Carlos, and the rest lives in a small fishermen camp called Puerto Chale, as well as in small temporal isolated fishing camps along the system.

Puerto Adolfo López Mateos is a town of 2,200 inhabitants (INEGI www.inegi.org.mx), who live mainly from fishing or work in cannery industries, plus whale watching services. A smaller portion works in commerce, education and health centers (Tovar-Vázquez, 1997; Gardner and Chávez-Rosales, 2000). Mangrove ecosystems are all over the channel and estuaries and are, in general, in a healthy condition of conservation, though in the vicinity of a cannery many dead mangroves were evident, probably due to the residual waters that are discharged at very high temperatures from the factory.

The port of Puerto San Carlos, 45 km. to the south, has a large drought that serves the fishing industry, supplies tourist ships, and helps transport goods from nearby agriculture developments (Tovar-Vázquez, 1997). The town has 3,600 inhabitants, which work in fishing, agriculture, and tourism, as well as in one of the several industries, such as canneries and thermoelectric plants.

Dead mangroves were observed close to these cannery industries probably due to the discharges. In some areas where mangroves are adjacent to the city, the accumulation of construction debris and household trash block the natural water flux and kill mangroves. Figures 14A and 14B show how in Puerto San Carlos, the most evident changes were due to the growth of the city, the expansion of the roads and bridges that connect it, and the development of the port.

Mangroves continue south of Puerto San Carlos to the bays of Almejas and Santa Maria. The population in this area is distributed mainly in Puerto Chale, a fishing locality with a resident population of 300 highly marginalized inhabitants that harvest crabs, scallops and fish. In the shrimp and clam seasons more fishermen arrive to this area, reaching a population of 1,200 temporary residents (Tovar-Vázquez, 1997). Formerly in this region, there existed a large sea farming complex owned by an ejido; however, the ejido recently sold these lands to foreigners who are developing tourism facilities. Presently two private shrimp farms were also established here. Rancho Bueno is the last of the estuaries with mangroves in healthy condition in BCS. Here, only one settlement running a small oyster farm has been in operation for 10 years.

DISCUSSION—In the last century, the landscape of northwestern Mexico has changed gradually along with the intensification of economic alternatives; and today changes keep occurring at accelerating rates. Many of these transformations have affected the environmental conditions of coastal ecosystems, diminishing their capacity to provide valuable goods and ecosystem services, as well as having detrimental effects on the flora and fauna associated with mangroves (Enríquez-Andrade et al., 2005; Whitmore et al., 2005).

In the arid northwestern regions of Mexico, these damages can be identified following the historical development of human populations. The degree of human damage to mangrove ecosystems also varies depending on the type, frequency, and intensity of the development activities (Adeel et al., 2002; Duke et al., 2007).

In the central-southern region of Sonora, humans have been present and active for a longer time, and the mangrove ecosystems show evident signs of deterioration. Agriculture and cattle practices in the upper valleys dispose of large quantities of chemicals and fertilizers through draining channels where they merge with municipal wastewaters and are finally emitted as coastal discharges. All are conducted to coastal and estuarine areas by large draining channels, resulting in sediment accumulation and severe environmental pollution. Resource overharvesting has decimated the populations of valuable plant and animal species, having deleterious impacts on local and regional fisheries.

Some mangrove populations in this region have been almost completely removed for the construction of aquaculture complexes, like those of Estero Tastiota, and some others are so severely damaged that their recovery seems very difficult if not impossible. Thus, some mangrove ecosystems have been disturbed by the construction of urban and tourism developments and by the direct disposal of their solid and liquid wastes. It is imperative that the construction of these complexes is properly planned and evaluated in order to reduce such environmental impacts (Whitmore et al., 2005). On the other hand, in other estuaries that have a more recent history of shrimp aquaculture development, the vegetation is in apparent good condition. However, since mangrove species have proved to be very tolerant to disturbance (Alongi, 2008), it is in these estuaries that water quality assessments are crucial to adequately verify that the appropriate concentrations of the discharges and the input of water do not harm the estuarine environmental conditions (Paez-Osuna et al., 2003).

The northern region of Sonora constitutes a different scenario because the area is scarcely populated and human activities have been practiced for a short period of time. Estuaries in Seri territory are in excellent conditions because development is very scarce and the Seri survey their lands to avoid unauthorized fishermen. The mangroves along Canal del Infiernillo are particularly very well protected, not just by the Seri, but by the environmental authorities as well. Efforts and resources should be directed to create this as a coastal protected area that ensures the conservation not only of mangroves, but also of other coastal ecosystems in order to keep sustaining the provision of environmental services that benefit many local communities.

In Bahía de Kino, recently developed unplanned activities have caused serious environmental damages like pollution, sedimentation, eutrophication, overharvesting, waste deposition, etc. Urgent restoration measures are needed to protect the resources left, to eventually restore natural conditions, and perhaps to recover ecosystem services that have been lost, such as the maintenance of fisheries.

Human development in BCS has a more recent origin than in Sonora, and the environment has not been as damaged. Nonetheless, the recent accelerated population growth and the increasing human activities are exerting pressures that are endangering the peninsular environment. The coastal region of the Sea of Cortés has been experiencing drastic modifications for the last 50 years as a result of the construction of tourism and industrial facilities (Enríquez-Andrade et al., 2005). Several mangrove populations along this coast are still in good condition, like those in Bahía Concepción or those near La Paz; however, there are many tourism developments planned or already underway which will seriously threaten these ecosystems in the future, as has already happened in Sonora and in other regions of BCS.

Along the Pacific coast of BCS, development has not yet been very intense, perhaps because the area is not as attractive for tourism and the roads are scarce and in poor conditions. The mangroves here are the largest in the state, and though the northern limits of its distribution are protected by UNESCO at Bahía de San Ignacio, the largest surface in the state represented by those of the Bahía Magdalena-Bahía de Almejas complex, is still without protection. This area should be a priority for the authorities, because this system provides with many goods and services from which both society and nature benefit. There are presently few aquaculture developments in the area and their activities can still be regulated before the environment quality is compromised, however our main concern is the large investments already underway to develop tourism facilities, which will impose pressure on water demands and the biodiversity, as has already happened in other places. If such accelerated and unplanned growth is to continue, the scenario will be similar to that of Sonora, where pollution and scarcity of resources are the prevailing conditions of this once rich coast.

The landscape we see today can only be understood if we are acquainted with its history (Swetnam et al., 1999), therefore our main interest is to provide lessons of how hastened and unplanned decisions have caused the uncontrolled development of economic activities in order to generate short term profits. The intensity of these activities may reduce the possibilities to practice others by the pollution of the soil, the depletion of water and reduction of biodiversity; and in the long term, these may have consequences that will even impede the development of the original activity itself.

The analysis of historical aerial photography used in this study illustrated the accelerated claiming of natural environments by humans, because they are often the only available source of information from times when ecosystems were less affected. The review of historical and socio economic information complements this analysis by informing about the relationship between population and the natural environments, since ecological changes are closely connected with socio economic factors like management regimes and the intensity of practices that have affected and changed the landscape throughout history.

It is hard to say if the increasing rate of conservation efforts will be able to stop the accelerated environmental degradation in northwestern Mexico, however there is a growing awareness of the importance to protect the natural environments around the Sea of Cortés, particularly mangrove ecosystems, which are vital for many biological processes and for the survival and well being of biodiversity and mankind.

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FIG. 1. Division of northwestern Mexico according to the historical development of human population and economic activities.

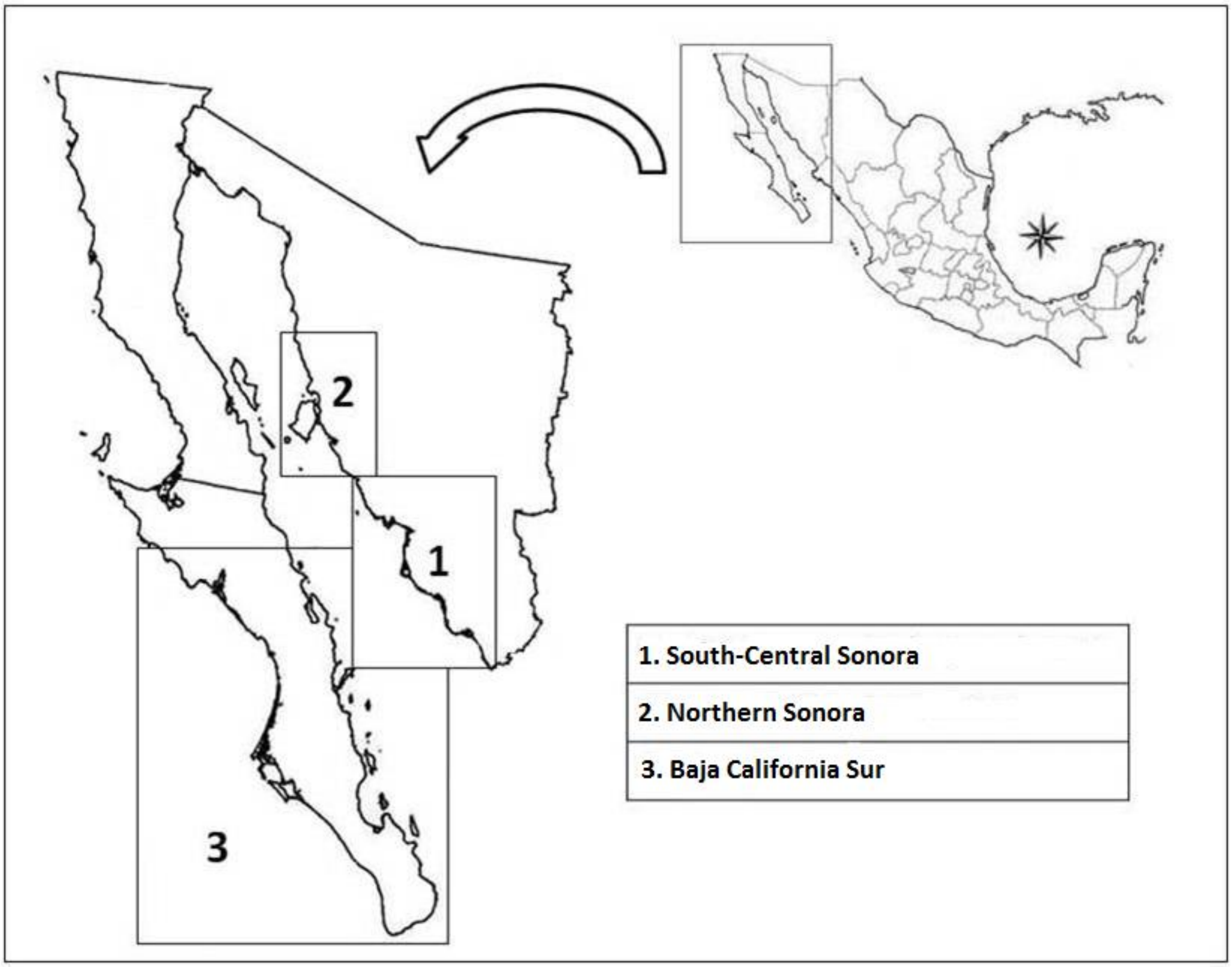


FIG. 2. South-central Sonora. 1. Yavaros-Moroncarit system. 2. Estero Tobari. 3. Las Guasimas-Estero Lobos system. 4. Guaymas.

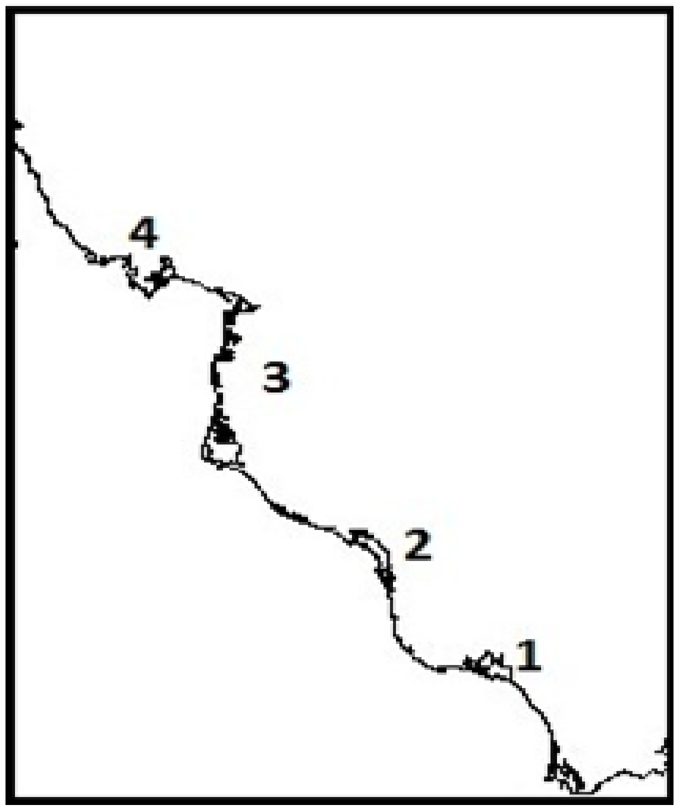


FIG. 3. Northern Sonora. 1. Estero Tastiota. 2. Estero Santa Cruz. 3. Seri estuaries. 4. Estero Sargento.

FIG. 4. Baja California Sur. 1. Bahía Balandra-Estero Enfermería. 2. La Paz-El Mogote. 3. Isla Espíritu Santo. 4. Puerto Escondido. 5. Loreto-Nopoló. 6. Bahía Concepción. 7. Mulegé. 8. San Lucas. 9. Estero La Bocana. 10. Estero El Coyote. 11. Laguna San Ignacio. 12. Bahía Magdalena-Bahía Almejas. 13. Estero Rancho Bueno.

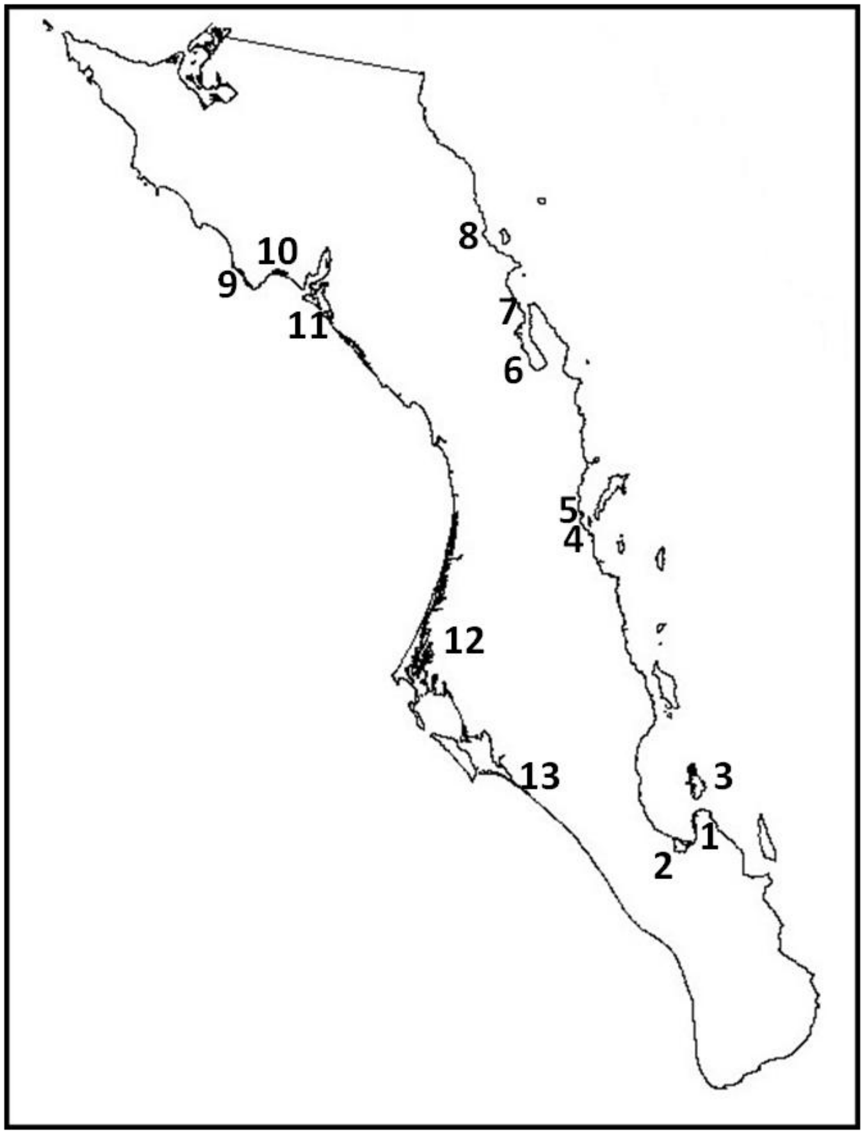


FIG. 5A. Yavaros-Moroncarit System. FIG. 5B. Left INEGI, 1973 1:70,000. Right Google Earth.

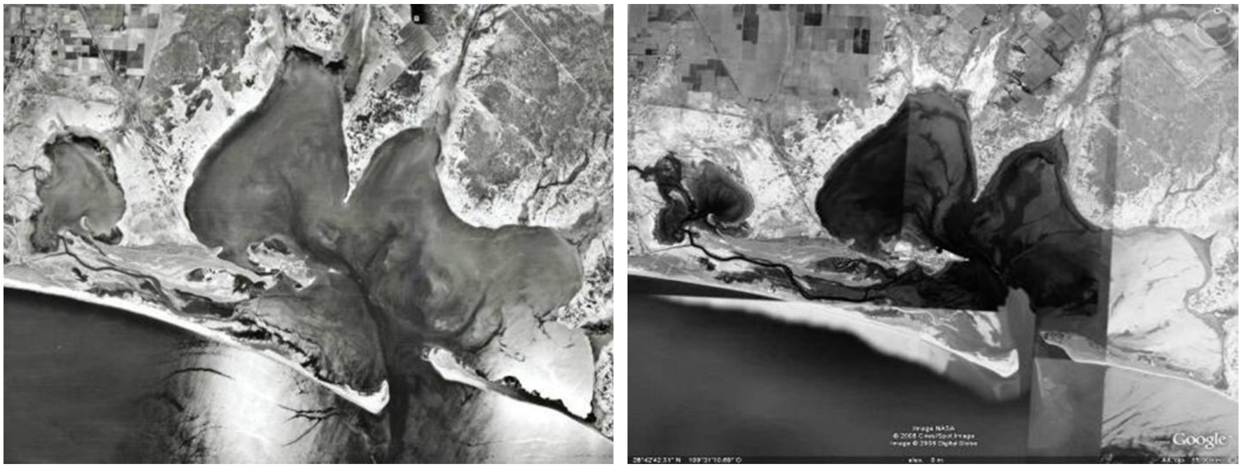
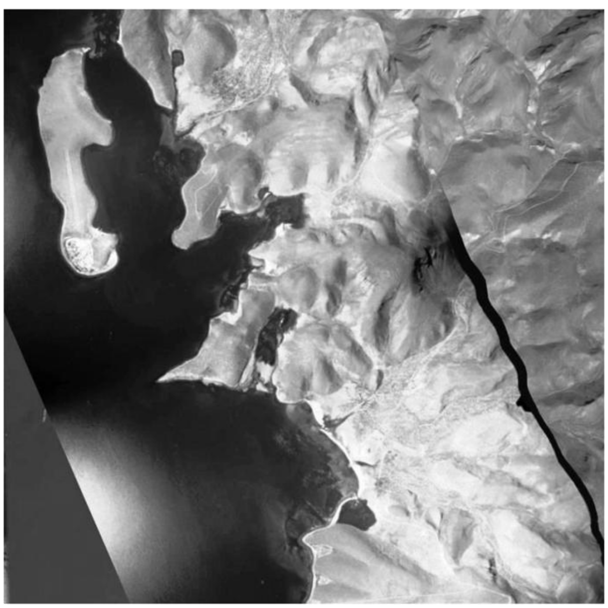


FIG. 6A. Estero Tóbari. Left INEGI, 1973 1:70,000. FIG. 6B. Right Google Earth.

FIG. 7A. Left City of Guaymas, ICA 1956 1:16000. FIG. 7B., Google Earth.

FIG. 8A. Left Bahía de Kino INEGI, 1973 1:70,000. FIG. 8B. Right Google Earth.

FIG. 9A. Pichilingue. Left. ICA, 1956 1:20,000. FIG. 9B. Right. Google Earth.



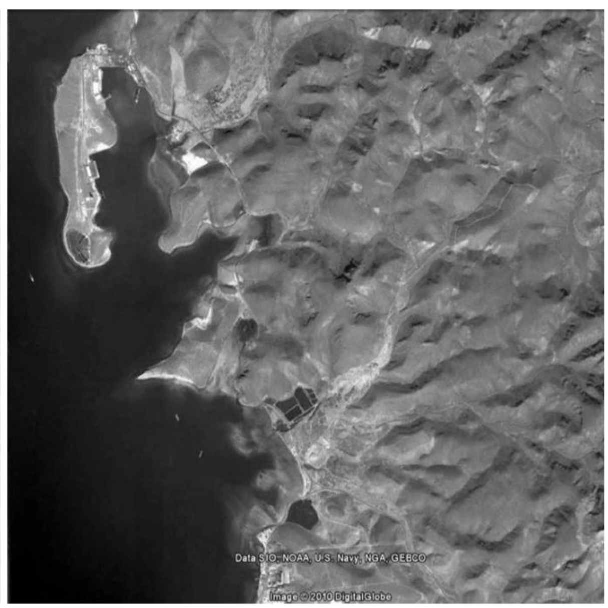


FIG. 10A. La Paz. Left. ICA, 1956 1:20,000. FIG. 10B. Right. Google Earth.

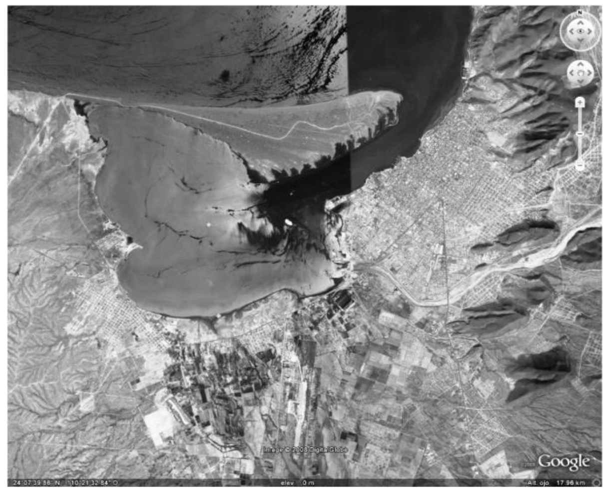


FIG. 11A. Puerto Escondido. Left INEGI 1973 1:50 000. FIG. 11B. Right Google Earth.

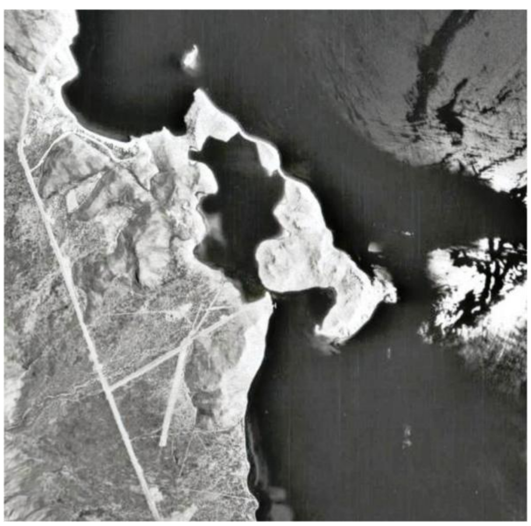


FIG. 12A. Mulegé. Left. ICA 1956 no scale. FIG. 12B. Right. Google Earth.

FIG. 13A. El Coyote estuary, Left. INEGI 1972 1:70,000. FIG. 13B. Right. Google Earth.

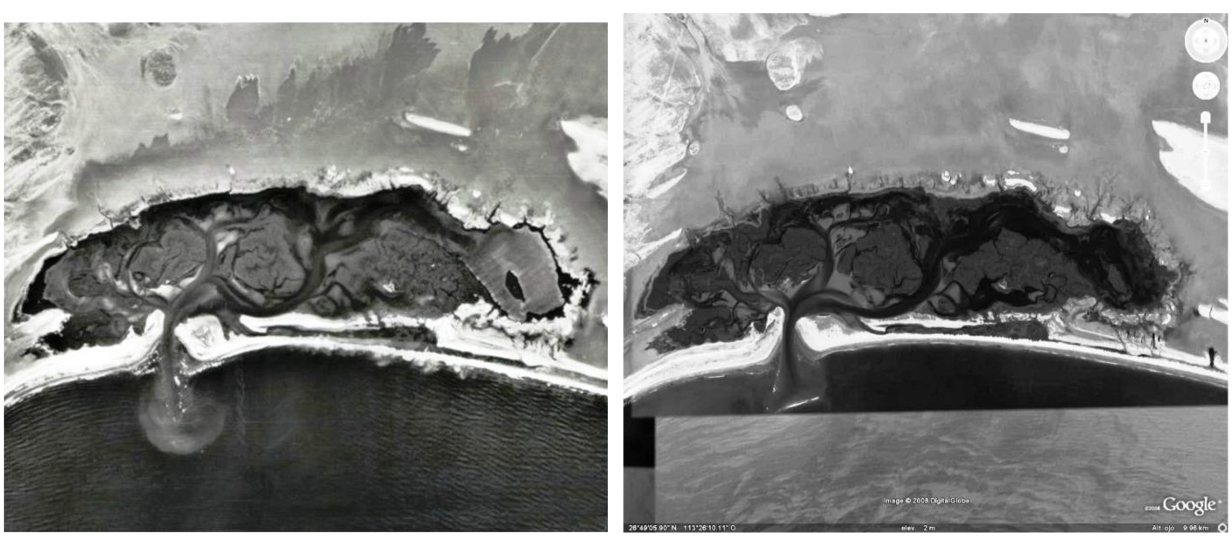
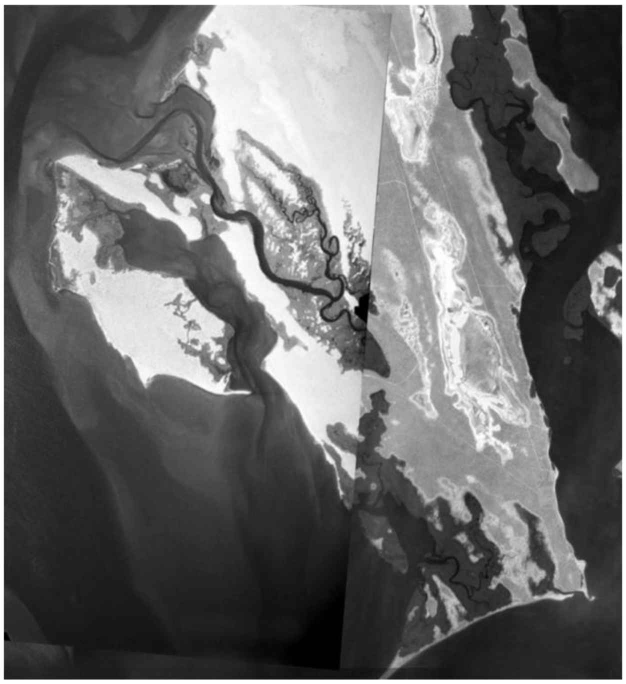
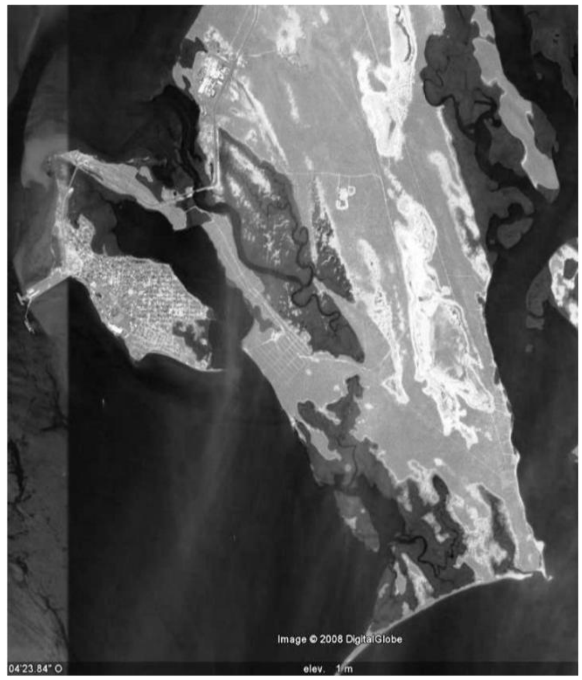


FIG. 14A. Puerto San Carlos. Left. ICA, 1962 no scale available. FIG. 14B. Right. Google Earth.





CAPÍTULO IV

Perspectivas contrastantes respecto a los manglares del Noroeste de México: Implicaciones para un manejo costero integral.

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Contrasting perspectives on mangroves in arid Northwestern Mexico: Implications for integrated coastal management

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ABSTRACT

Mangroves in Northwestern Mexico are vital to maintain coastal environments healthy, to provide nutrients for several food chains, and to supply valuable goods and services that sustain and improve human livelihoods. Many of these values offer a range of opportunities for economic development that attract workers, investors and developers. Recently, federal privatization policies have promoted an accelerated coastal development of this region to obtain large profits in short times, creating competing and overlapping interests to use coastal environments and control key resources. Such intense developments are modifying the ecological conditions of many coastal areas, threatening the provision of important ecosystem services to society. After years of centralized decisions, new paradigms are needed to achieve a coastal management that ensures long-term ecosystem maintenance, fair resource use and social equity. Recognizing the multiplicity of actors involved in coastal management and using a qualitative research methodology, we identified and explored the perspectives of different key stakeholders in the states of Baja California Sur and Sonora, Mexico, to better understand their views on mangroves use and management as well as the interaction among them. We discuss similarities and/or discrepancies found among stakeholders' perceptions by describing their central ideas and identifying overlapping interests that may create conflicts when defining development and conservation programs or formulating policies. This information also intends to encourage further research on the social-ecological system of the coasts in Northwestern Mexico and to contribute to address coastal management issues in integrated ways that consider the social dimension through documenting stakeholders' narratives in the future.

1. Introduction

Mangroves on the Pacific coast of the Americas reach their northernmost distribution in the arid regions of Mexico around the Sea of Cortés (SC), in the states of Sonora and Baja California Sur (BCS). This is a highly biodiverse and productive region where mangroves are vital to supply goods and services that sustain and improve human livelihood (Páez-Osuna et al., 2003; Glenn et al., 2006; Aburto-Oropeza et al., 2008).

The combination of biodiversity, aesthetic features and recreational possibilities found in the mangroves in Northwestern Mexico offers a range of opportunities that attract workers, investors and developers in search of economic profit. Furthermore, for decades the Mexican government has favored private investments around the SC to obtain short-term profits by privatizing the control of resources and centralizing decision making, creating scenarios of competing and overlapping interests to control the access to key natural resources (Young, 2001). Economic activities performed in this region contribute 10% to the national gross domestic product; 40% of the agricultural production and 65% of the aquaculture in the country (Páez-Osuna et al., 2003; Enríquez-Andrade et al., 2005). Fishing in the Sea of Cortés also generates revenues worth up to USD $300 million a year (WWF, 2005).

As a consequence of such accelerated and unplanned development these coasts have the fastest population growth rate in Mexico (INEGI, 2005; Glenn et al., 2006), and are currently experiencing intense environmental pressures that are transforming mangrove ecosystems at varying degrees and intensities while threatening also the continued provision of many valuable goods and services to society (Páez-Osuna et al., 1998; Whitmore et al., 2005; Holguín et al., 2006).

Since marginalized communities are more vulnerable to environmental degradation and are sometimes restricted or excluded

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from accessing resources, social inequity, poverty and illegal resource over-extraction are found in many local communities (Agrawal and Gibson, 1999; Young, 2001). For this reason, a growing number of environmental non-governmental organizations (ENGOs) are working in the region directing money and efforts towards community-based management to promote social justice, education, environmental conservation and sustainable development (Cariño et al., 2004). The presence of these organizations reflects the role that society is taking in social and environmental issues, and also the declining capacity of government at its different institutions to deal with these. Thus ENGOs are becoming strong actors that exert a powerful political influence (Clarke, 1998; Bryant and Bailey, 2005).

After years of experiencing governmental centralized decisions, defective planning, and inefficient implementation, new paradigms are needed to achieve an integrated coastal management that may increase the quality of life of local communities while maintaining ecosystems and natural resources at the same time (Young, 2001; Cariño et al., 2004; Basurto, 2005). This endeavor requires the analyses of human and natural systems interaction as well as understanding the complex relationships between natural and socio-economic variables (Fabbri, 1998). Formulation of actions and policies to achieve such management should focus on the complex web of actors involved in decision-making, particularly in how their multiple interests influence decisions and political processes (Adams et al., 2003; Ghimire and Pimbert, 1997; Bowen and Riley, 2003). This could help balancing tradeoffs between social gains, economic profit, and the delivery of ecosystem delivery, allowing fair resources among coastal resource users and the equitable distribution of the costs of conservation. This aimed at providing a "socially desirable" mix of coastal zone goods and services (Bower and Turner, 1997; Agrawal and Gibson, 1999; Brown, 2003).

Based on this scenario of a multiplicity of actors with diverse interests involved in decision-making processes regarding the management of coastal natural resources in Northwestern Mexico, this paper aims to analyze the views of local fishermen, governmental authorities, ENGOs, and scientists in BCS and Sonora about the presence, use, conservation, and drivers of change in mangrove ecosystems. By examining the central ideas, knowledge, opinions and management priorities of these actors respecting mangroves, we intend to identify also possible conflicts of interest about management practices and conservation in the arid regions of Northwestern Mexico. The final aim of the study is to contribute to policy formulation and the construction of alternative management strategies that consider the perspectives of the different actors involved in such a way that mangrove long-term maintenance is feasible. We hope the study will encourage further research on the social-ecological system of the coasts in Northwestern Mexico and provide a useful framework to address coastal management issues.

2. Material and methods

In order to gain insight into the diverse actors' perspectives on mangrove ecosystems, we used a qualitative research method. The selection of this approach from the social sciences is based on our research questions which look to understand ecosystem management and conservation issues form an actors' perspective (Long, 1992). Qualitative research is a field of inquiry that crosscuts disciplines and that has a long history. Not without difficulty, it has gained relevance in the last two decades. At its core is the notion of reality as socially constructed system (Berger and Luckman, 1966) emphasizing that people "create reality" based on their perceptions of the real world in which they are immersed by giving meaning to social and natural phenomena (Denzin and Lincoln, 2008). Peoples' decisions are therefore based on their constructions of reality; and these constructions can have different historical and cultural explanations (O'brien and Kollock, 2001). Within environmental studies this recognition has been acquiring acknowledgement as environmental problems result from social conflicts and dilemmas which apart from having historical, economical or political roots also rise from cognitive conflicts. That is, different stakeholders may have different knowledge, preconceptions and priorities regarding management issues which create conflicting arenas presenting challenges to alternative practices and policy formulation (Adams et al., 2003). Documentation of "the voices" and analysis of actors' views are becoming essential aspects of new ecosystem management approaches which part from the inclusion of humans in ecosystems (O'Neill, 2001) and recognize the use of collective narratives as part of systematic understandings of particular situations (Waltner-Toews et al., 2003).

The main research techniques used in the study were participant observation and semi-structured interviews (DeWalt et al., 1998). The first field visits to BCS and Sonora were performed in 2007 and 2008. Through participant observation and informal talks with people, we identified key actors and organizations relevant to mangrove use and conservation within 19 localities in both states (Babbie, 1995; Denzin and Lincoln, 1998) (Fig. 1). Based on these initial encounters, guides were constructed to develop semi-structured interviews that were later conducted to four of the main identified actors (Vela-Peón, 2001): fishermen, federal government officials, ENGO representatives, and scientists. It is important to mention that although we also identified actors from the private sector, most of our attempts to contact and obtain interviews from this sector failed.

The main interest of this study was to collect data about the social perceptions of the groups of stakeholders mentioned. Therefore, our interviews were structured around three basic themes: (1) changes in mangrove surface and causes of these changes; (2) importance, uses, and threats to mangroves and (3) government and private institutions working with mangrove-related themes. The application of semi-structured interviews allowed us to address the different stakeholders groups adapting the interviews according to respondent, locality and surrounding environment (Robson, 1994).

Using a snowball sampling method, 63 interviews were conducted in the Pacific and SC coasts in BCS and Sonora between 2008 and 2009 (Table 1). This method consisted in meeting someone (e.g. a fisherman) that was previously identified to have relevant information for the study and after interviewing this person, he/she was requested to recommend whom to interview next. Interviews were terminated based on information saturation, which consists to stop interviewing when no new data is identified (Taylor and Bogdan, 1996; Vela-Peón, 2001).

Digital audio recordings of interviews were transcribed and imported into *Atlas.ti* v.5.0 (SSD, 2003) to perform qualitative analyses of texts. Each group was analyzed separately. Transcripts were coded using a line-by-line review of texts and categories were created as they arouse from interviews in order to obtain perceptions, ideas, and interests of the different actors and reduce data into manageable formats. The categories were then linked into diagrams that resulted of the analysis, and which then structured the narratives presented in Results section. These diagrams are included since they serve as a graphical summary of the different perspectives and constitute support evidence of our analysis (Figs. 2–5). The number of respondents who expressed the same perception is included in parentheses and narratives are complemented with verbatim quotations, field notes and socio-economic and environmental information to validate and strengthen our findings.

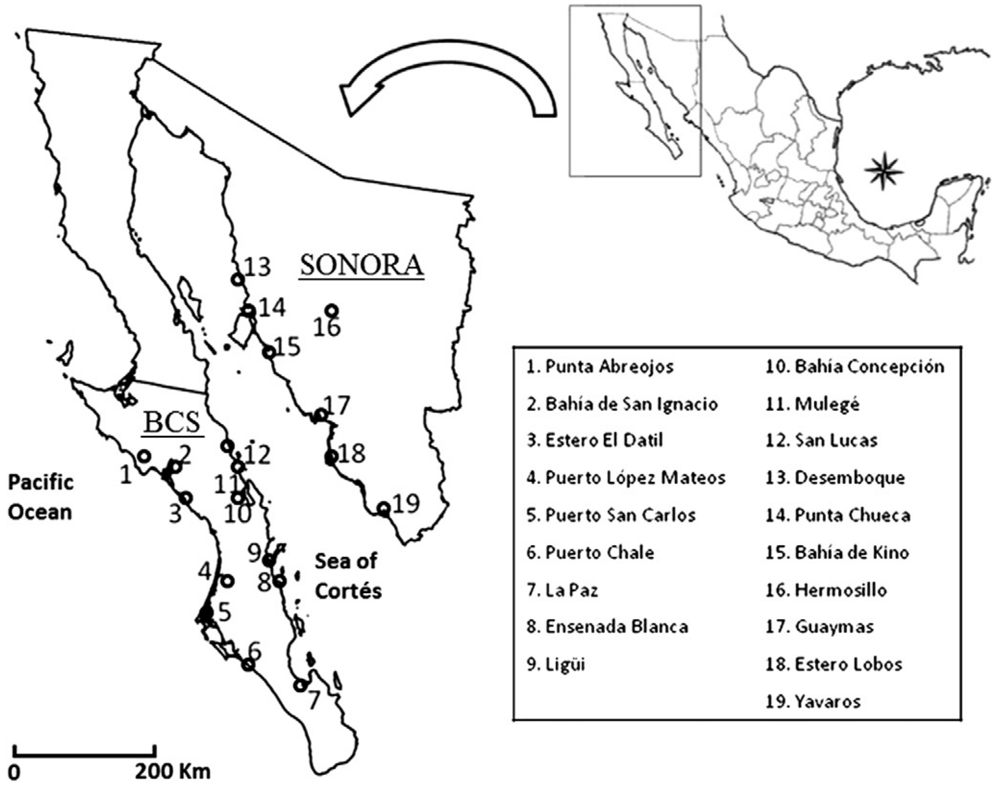

Fig. 1. Localities from BCS and SON where interviews were conducted between 2008 and 2009.

3. Results (Table 2)

The following narratives were constructed based on the diagrams presented in Figs. 2–5 (2: Fishermen, 3: Government, 4: ENGOs and 5: Scientists).

3.1. The perspective of fishermen

Some fishermen in the Pacific perceived that mangrove surface has increased (6) and others that it remains the same (5). In Puerto Chale one person said: *"It* [the mangrove] *keeps getting larger. When aquaculture ponds were constructed some mangroves were removed, but the responsible party got fined and has not cut more"*. In the SC, some fishermen mentioned that mangrove surface was decreasing (5) and a lower number thought that it had remained the same (3). One fisherman in La Paz expressed: *"…there are less* (mangroves)*, because they* [developers] *want more lands for construction, they come and cut trees."* In Sonora, the fishermen had different perceptions: in Bahía de Kino, Guaymas, Estero Lobos, and Yavaros some mentioned that surface was decreasing (6), while others from Bahía de Kino and Guaymas mentioned that it had remained the same (3). Fishermen from the ComCaac (Seri) tribe mentioned that it was increasing by growing landward (3).

In relation to the importance of mangroves, fishermen in the Pacific acknowledged that mangrove sustain fisheries and biodiversity (11), provide aesthetic values that attract tourism (7), and provide shade/shelter (3). Fishermen in the SC mentioned the importance for biodiversity (5) and shade/shelter (2), but one could not recall any importance (1). Fishermen in Sonora accredited their importance in sustaining fisheries and biodiversity (12), aesthetic values (8) and shade/shelter (1) ComCaac fishermen added traditional importance (3); one person in Bahía de Kino did not think they were important at all (1).

Regarding the uses of mangroves, fishermen in the Pacific use them for wood (6), medicine (5), and construction (3); two people did not know any use (2). Fishermen in the SC mentioned medicine (3), wood (2) and tannins (1); three did not recognize any use (3). Interviewees in Sonora acknowledged uses for medicine (6), construction (3), wood (2), food (1), tannins (1) and harpoons (1); two mentioned mangroves had no use (2).

When asked about threats to mangroves, one fisherman in the Pacific mentioned that mangroves are removed for aquaculture, but that they grow back afterwards (1). Two people mentioned that guano produced by birds killed mangroves in nesting areas (2). One mentioned destruction by locals (1), while two recalled industrial pollution in Puerto San Carlos (2): "[the area] *near that facility was full of mangroves, but it dumps grease and caustic soda to the water killing many trees"*. However, most interviewees in this coast mentioned that mangroves were in good condition and had no current threats (6). Fishermen in the SC said that threats come from construction (6) and hurricanes (3). In Sonora fishermen mentioned threats like trash (5), industrial developments (4), draining channels (3), aquaculture ponds (3), tourism and urban complexes (3); and floods (1). Another person mentioned an insect plague in Yavaros (1).

The presence of institutions working with mangroves was recognized by seven fishermen in the Pacific: two in Puerto San Carlos said that a foreign institution (The School for Field Studies, http://www.fieldstudies.org/index.cfm March 2010) was doing environmental education (2); two from Puerto López Mateos and three in Bahía San Ignacio mentioned that one ENGO (*PRONATURA*) and one ecotourism enterprise (*KUYIMA*) were promoting conservation (5). In the SC one fisherman in Mulegé mentioned that an organization from Sonora was working with environmental education promoting sustainable fisheries (1). Some fishermen in Sonora mentioned that universities visited their areas to make

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Table 1
Number of interviews within brackets conducted in BCS and Sonora by stakeholder group and locality.

BCS	SON
Fishermen (19)	**Fishermen (12)**
8 from the SC coast	Desemboque (N29 37.928 W112 21.810)
San Lucas (N27 13.094 W112 12.819)	Punta Chueca (N29 00.826 W112 09.637)
Mulegé (N26 53.895 W111 58.039)	Bahía de Kino (N28 48.466 W111 55.601)
Bahía Concepción (N26 32.986 W111 45.852)	Guaymas (N27 57.640 W110 58.673)
Ligüi (N25 44.662 W111 15.698)	Estero Lobos (N27 21.183 W110 27.292)
Ensenada Blanca (N25 43.523 W111 14.807)	Yavaros (N26 42.491 W109 32.656)
La Paz (N24 09.382 W110 19.572)	
11 from the Pacific coast	
Punta Abreojos (N26 43.939 W113 36.697)	
Bahía de San Ignacio (N26 49.256 W113 10.872)	
El Dátil (N24.24224 W111 31.129)	
Puerto López Mateos (N25 11.389 W112 07.211)	
Puerto San Carlos (N24 47.751 W112 06.887)	
Puerto Chale (N24 25.346 W111 33.236)	
Government officials (4)	**Government officials (6)**
Secretaria de Medio Ambiente y Recursos Naturales	Secretaria de Medio Ambiente y Recursos Naturales
Comisión Nacional Forestal	Comisión Nacional Forestal
Comisión Nacional de Áreas Naturales Protegidas	Procuraduría Federal de Protección al Ambiente
Scientists (7)	**Scientists (8)**
Centro Interdisciplinario de Ciencias Marinas	Universidad de Sonora
Centro de Investigaciones Biológicas del Noroeste	Centro de Investigaciones Biológicas del Noroeste
Universidad Autónoma de Baja California Sur	Prescott College Center
The School for Field Studies	
Environmental NGOs (4)	**Environmental NGOs (3)**
Centro Mexicano de Derecho Ambiental	Conservation International
PRONATURA Noroeste	Asociación Mangle Negro
The Nature Conservancy	
Natureserve	

studies around mangroves (7), but never interacted with them. Two fishermen in Guaymas acknowledged the presence of ENGOs protecting mangroves, but could not recall their names (2). Finally, two ComCaac fishermen acknowledged interaction with scientific institutions like Prescott College of the US and the University of Sonora in Mexico, which hired their services as guides when performing local research (2).

In relation to the government presence, fishermen in the Pacific mentioned that fishing authorities were issuing permits and monitoring illegal activities (7); some recalled the presence of environmental authorities to prevent poaching (6). As one fisherman in Puerto López Mateos mentioned: *"It is forbidden to use mangroves, because soldiers are constantly patrolling"*. One fisherman in Puerto San Carlos mentioned that government was performing water studies (1). In contrast, some fishermen in the SC said that government was absent between Santa Rosalia and Bahía Concepción (3), others near Loreto expressed that government was only issuing permits around the Protected Area and pursuing free fishermen instead of the large fleets from Sonora that overharvest local resources (2). Finally, fishermen in La Paz mentioned that government was issuing fishing permits and supporting them with incentives to substitute their reduced catches (2). In Sonora, ComCaac fishermen said they receive support from governmental programs, but since such programs had no continuity the money was wasted or not useful (2). Fishermen in Bahía de Kino expressed resentment towards government, mentioning that they were not taken into account at all (2), and that the government made arrangements with aquaculture developers to overlook environmental problems (2). Near Guaymas, some argued that government was present to prevent mangrove damage (2); in Estero Lobos, interviewees mentioned that government only issued fishing permits and regulated environmental problems from their offices (2). Finally, some fishermen in Huatabampo acknowledged that government was regulating fishing activities (3) and developing tourism (2).

3.2. The perspective of government

Interviewed officers in BCS considered that the surface of mangroves remained the same (4); however some acknowledged that tourism developments have removed or damaged some mangroves in the SC (2). Some respondents in Sonora said the construction of dams in 1950 impacted mangroves, but that at present they were growing back and expanding in some areas, and that recently created conservation laws and current projects were not damaging them (3). Others mentioned that mangroves were removed occasionally to construct aquaculture channels, but they grew back afterwards (2). However, another officer mentioned that mangroves were being depleted by poorly applied economic programs that promote aquaculture without considering environmental impacts (1).

The perceived importance of mangroves was similar in both states: all acknowledging their role in sustaining biodiversity, providing ecosystem services and aesthetic values that attract tourism (10).

When asked about the use of mangroves in BCS, one respondent said they were used for handcrafts (1), while others said that they were not used (3). Officers in Sonora mentioned uses for construction (4), wood (3), and tannins (2); or none (1).

The perceived threats to mangroves varied between states. BCS interviewees mentioned that pressures came from urban development (4), or environmental degradation (2) and removal by population (1). Officers in Sonora mentioned more threats like destruction and pollution by aquaculture (4) and drainage channels (4), urban and industrial construction (3), environmental degradation (2), and destruction by locals and tourism (3). Another person mentioned damages from tourism and aquaculture developments. However he did not know which mangrove species were protected by law and he said that mangroves were present in areas far away from their distribution (1).

Interviewees in BCS thought that government is working with scientists by requesting their technical advice (4). They expressed also that governmental institutions do communicate and work together on environmental issues (4). Officers in Sonora mentioned they work closely with scientists to develop monitoring and restoration projects (6). Some acknowledged the work of international ENGOs, like Conservation International and the World Wildlife Fund, and local organizations like *PRONATURA* and *Mangle Negro*, to promote conservation with local communities (3). Regarding the coordination with other governmental institutions, some expressed the existence of communication conflicts, and different, often contradictory agendas (3), adding a lack of capacity to work together and accomplishing goals (2). Another mentioned that the functions and jurisdictions of each institution were clear and without conflicts (1).

3.3. The perspective of ENGOs

According to some ENGOs representatives in BCS, the surface of mangroves is naturally increasing in some areas and decreasing in some others in the Pacific (2), while decrease in the SC is explained

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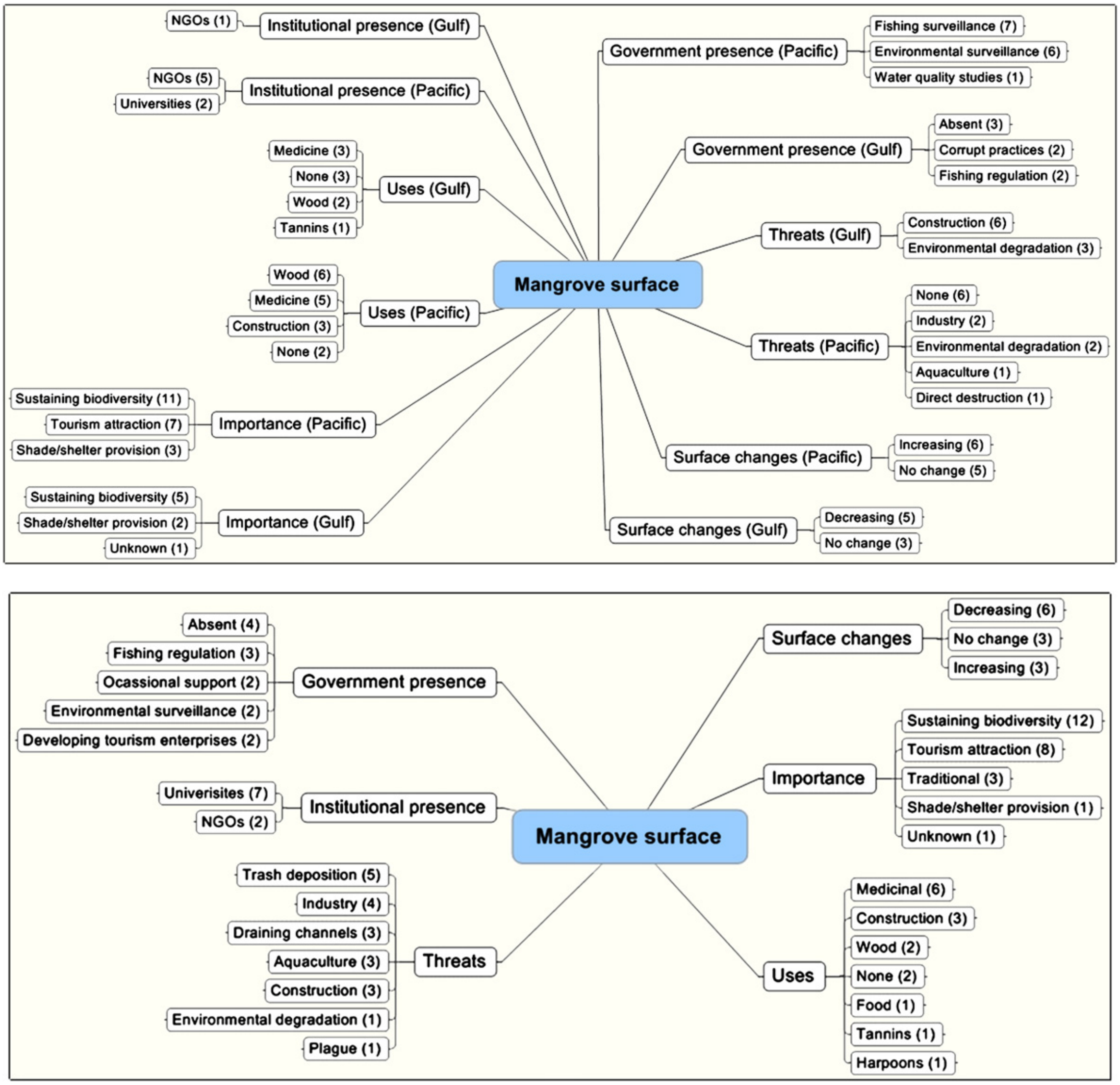

Fig. 2. Diagrams constructed based on the topics of the interviews conducted with the Fishermen. Upper: BCS. Lower: Sonora. In parenthesis the number of interviewees that expressed the same perception.

because of an accelerated coastal encroachment (4). Members of the same organizations in Sonora expressed that mangrove areas were decreasing (3).

All interviewees acknowledged the importance of mangroves to sustain biodiversity, provide ecosystem services, shade/shelter, and to have recreational values (7). The only difference was the traditional values for ceremonies given by indigenous groups in Sonora (1). In terms of uses, interviewees from BCS mentioned construction (3) and wood (2); while those in Sonora mentioned construction (2), wood (2) and medicine (1).

Perceived threats to mangroves by ENGOs in BCS derive from the construction of tourism developments (4), roads (3), direct destruction (1), lack of legislation knowledge (1) and land use change (1). In Sonora threats were aquaculture (3), drainage channels (2), unawareness from local people (1), developments (1) and land use change (1).

Interviewees in BCS considered that their work with scientists have contributed to the creation of new protected areas (3). However, some acknowledged that scientists frequently work separately and do not share information, weakening their strength as ENGO sector (2). The relation between ENGOs and scientists in Sonora was perceived as adequate, since scientific knowledge is considered when planning agendas and activities (3). Some mentioned that no links existed between scientists and government, and/or private agencies to stimulate exchange of ideas and facilitate actions (1).

When asked about the coordination of government institutions, ENGO representatives in BCS said there was none, and that each has its own agenda (4). One interviewee expressed: *"What coordination?. This lack of coordination is one of the principal threats to mangroves!."* Another person considered that problems derive from erroneous interpretation and application of laws, since mangroves are located in a coastal zone and disputes arise regarding jurisdiction (1). ENGO representatives in Sonora perceived government as fragmented, having different agendas and interests, which complicate their work to reach the necessary consensus to promote conservation, education and sustainability (3).

3.4. The perspective of scientists

Scientists in BCS said that mangrove surface in the Pacific was expanding landward in some areas, while reducing in others due to natural changes; overall it remained the same (3). Some considered

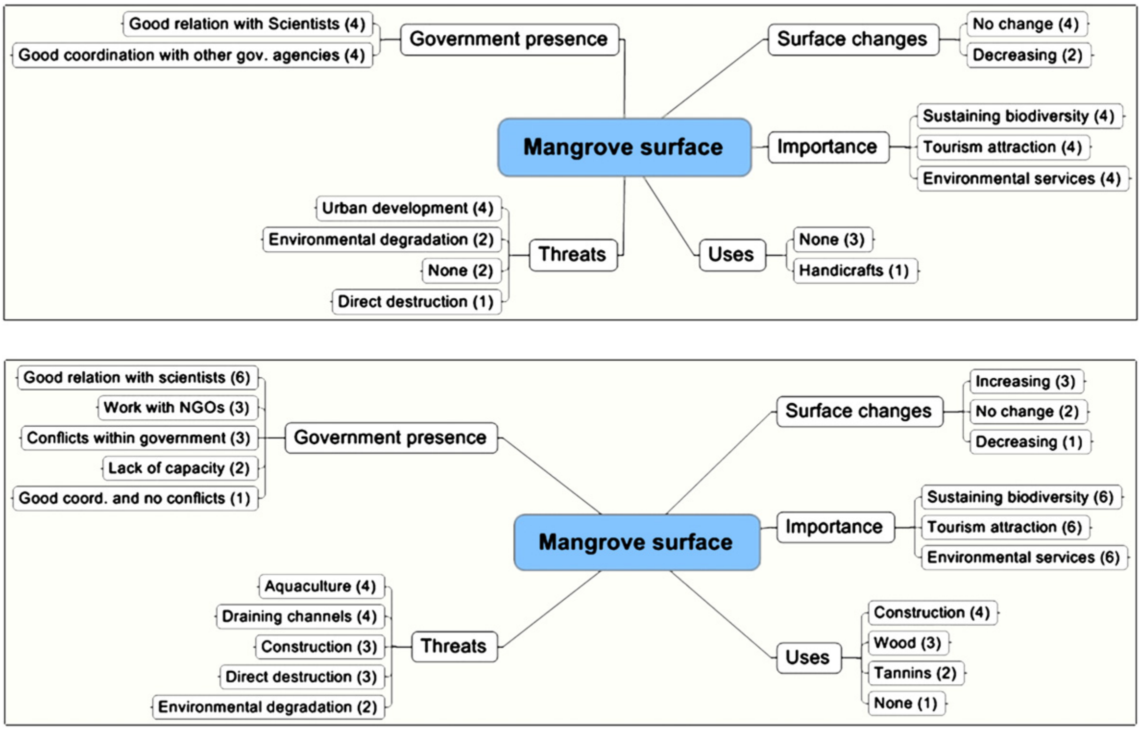

Fig. 3. Diagrams constructed based on the topics of the interviews conducted with the Government. Upper: BCS. Lower: Sonora. In parenthesis the number of interviewees that expressed the same perception.

a reduction close to cities and developments in the SC (5). In Sonora most interviewees said their surface was shrinking (6), while others thought it had remained the same (2). They mentioned, however, that since mangroves were constantly receiving drainage and wastes, they might experience future reductions (2).

For scientists in BCS, the main roles of mangroves were to sustain biodiversity (8), provide ecosystem services (8), increase productivity (4), provide shade/shelter (4) and aesthetic values (3). In Sonora perceptions were similar, acknowledging their importance for biodiversity (7), ecosystem services (4), tourism (3),

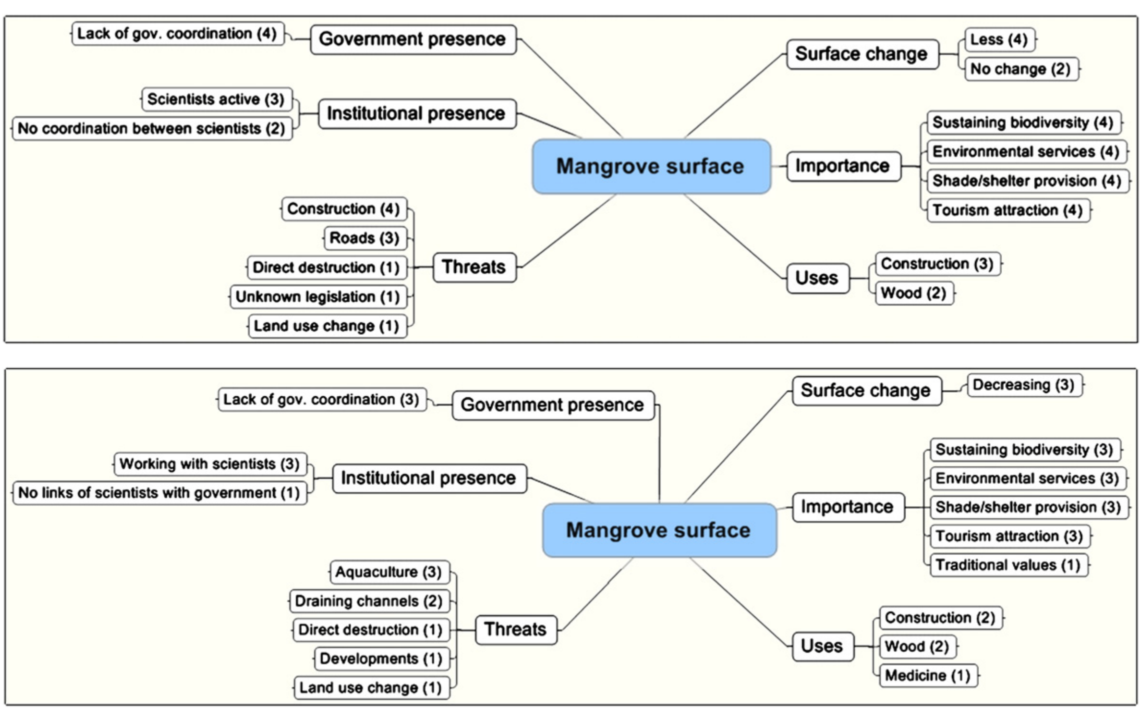

Fig. 4. Diagrams constructed based on the topics of the interviews conducted with the ENGOs. Upper: BCS. Lower: Sonora. In parenthesis the number of interviewees that expressed the same perception.

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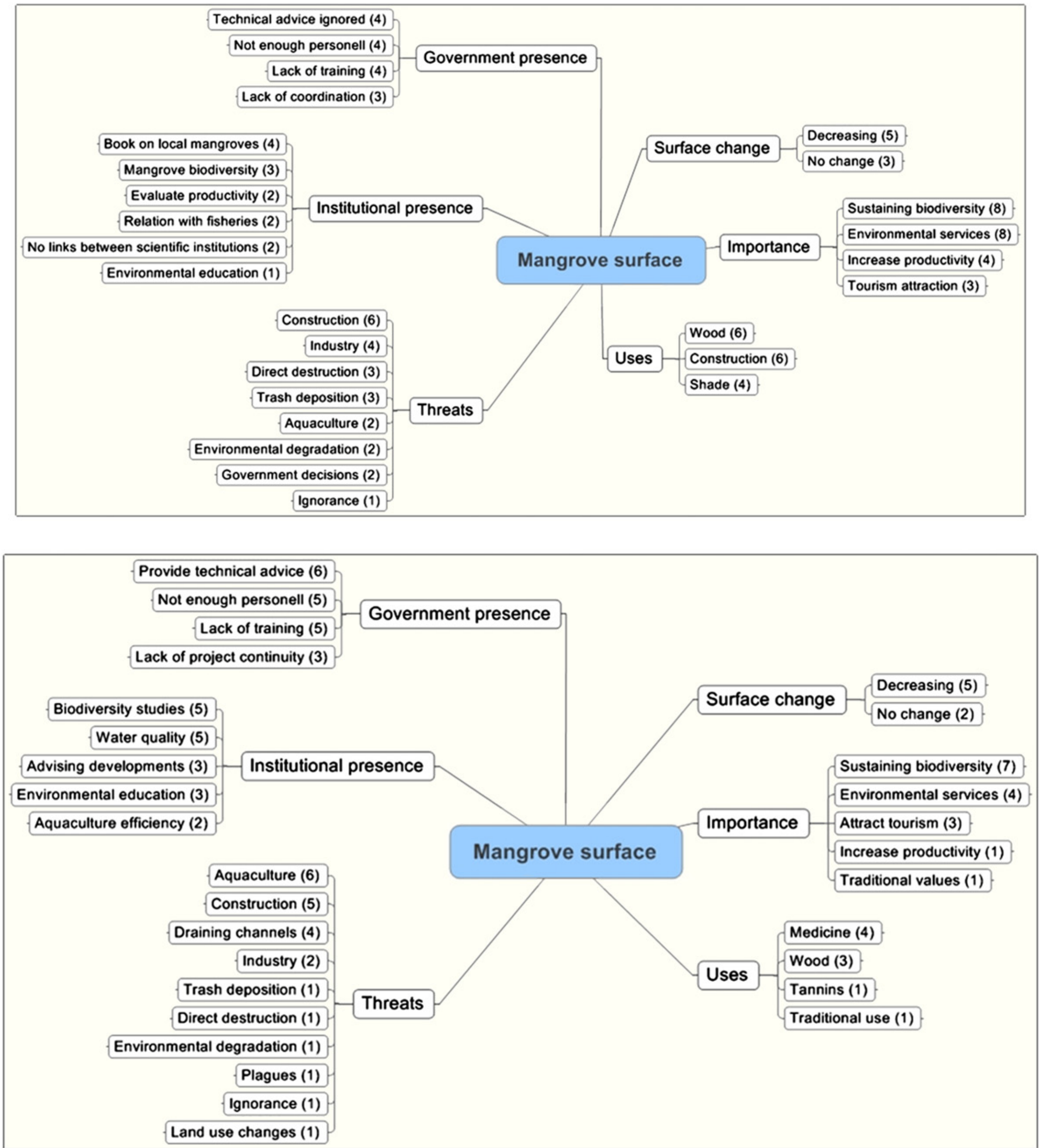

Fig. 5. Diagrams constructed based on the topics of the interviews conducted with the Scientists. Upper: BCS. Lower: Sonora. In parenthesis the number of interviewees that expressed the same perception.

increasing productivity (1), and also in providing traditional values for indigenous groups (1).

Among the uses of mangroves, BCS scientists mentioned wood and construction (6). In Sonora respondents acknowledged medicine (4), wood (3), tannins (1) and ceremonial uses (1).

The perceived threats to mangroves differed between areas. Respondents in BCS mentioned urban development (6), industrial complexes (4), aquaculture (2), direct destruction (3), waste and trash (3), environmental degradation (2), bad government decisions (2), and lack of environmental awareness (1). Interviewees in Sonora mentioned aquaculture (6), urban and tourism developments (5), drainage channels (4), industrial discharges (2), trash (1), destruction by tourism (1), environmental degradation (1), lack of environmental education (1) and land use change (1).

Scientists in BCS said they are working with mangroves around La Paz, conducting research on biodiversity, ecosystem productivity and fisheries (4). One person from The School of Field Studies mentioned they were doing environmental education campaigns (1). However, some scientists mentioned that no links existed between scientific institutions: each working in isolation and competing for funds, thus duplicating efforts (2). In Sonora scientists mentioned they worked in monitoring biodiversity and water around mangroves (5), evaluating development projects (3), developing technologies for water efficiency and waste treatment (2), and on environmental education (3).

Regarding their relation with government, interviewees in BCS said this sector continuously requested their technical opinion but it was hardly taken into account (4), as one interviewee mentioned: *"I have been asked to give my opinion, but it has never served any purpose, it is simply a procedure."* They mentioned that government lacked training and personnel to cover the necessities of the entire state (4), and some said there was no coordination among

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Table 2
Summary of categories that rouse from interviews with the four groups of stakeholders from BCS and Sonora. In brackets the number of persons of each category.

Area		Importance		Uses		Threats	
BCS	SON	BCS	SON	BCS	SON	BCS	SON
Fishermen							
No change (8) Increasing (6) Decreasing (5)	Decreasing (6) No change (3) Increasing (3)	Biodiversity (16) Tourism (7) Shade/Shelter (5) None (1)	Biodiversity (12) Tourism (8) Traditional (3) Shade/Shelter (1) Unknown (1)	Medicine (8) Wood (8) None (5) Construction (3) Tannins (1)	Medicine (6) Construction (3) Wood (2) None (2) Food (1) Tannins (1) Harpoons (1)	Construction (6) None (6) Environmental degradation (5) Industries (4) Direct destruction (1) Development (1) Aquaculture (1)	Trash (5) Industries (4) Waste drainage (3) Aquaculture (3) Construction (3) Environmental degradation (2)
Government							
No change (4) Decreasing (2)	No change (5) Decreasing (1)	Biodiversity (4) Tourism (4) Environmental services (4)	Biodiversity (6) Tourism (6) Environmental services (6)	None (3) Handicrafts (1)	Construction (4) Wood (3) Tannins (2) None (1)	Urban development (4) Environmental degradation (2) Direct destruction (1)	Aquaculture (5) Drainage (4) Construction (4) Direct destruction (3) Environmental degradation (2)
Environmental Non-governmental Organizations							
Decreasing (4) No change (2)	Decreasing (3)	Biodiversity (4) Environmental services (4) Shade/shelter (4) Tourism (4)	Biodiversity (3) Environmental services (3) Shade/shelter (3) Tourism (3) Traditional (1)	Construction (3) Wood (2)	Construction (2) Wood (3) Medicine (1)	Construction (4) Roads (3) Direct destruction (1) Unknown legislation (1) Land use change (1)	Aquaculture (3) Draining channels (3) Direct destruction (1) Developments (1) Land use change (1)
Scientists							
Decreasing (5) No change (3)	Decreasing (6) No change (2)	Biodiversity (8) Environmental services (8) Productivity (4) Shade/Shelter (4) Tourism (3)	Biodiversity (7) Environmental services (4) Tourism (3) Productivity (1) Traditional (1)	Wood (6) Construction (6)	Medicine (4) Wood (3) Tannins (1) Traditional (1)	Construction (6) Industry (4) Aquaculture (2) Direct destruction (3) Trash (3) Environmental degradation (2) Bad government (2) Ignorance (1)	Aquaculture (6) Urban/Tourism construction (5) Waste drainage (4) Industry (2) Trash (1) Direct destruction (1) Environmental damage (1) Ignorance (1) Land use change (1)

governmental institutions (3). Scientists in Sonora also mentioned that their technical opinion was often requested (6), and they shared opinions about the lack of training and scarcity of personnel (5). They also mentioned that government invited them to different projects, but none of these was ever concluded (3).

4. Discussion

4.1. Methodological aspects

The first issue that should be emphasized is the use of a qualitative research approach in this study. The analysis presented here is part of a research project on the situation of mangroves in this part of Mexico and first results on biophysical aspects are published elsewhere (López-Medellín et al., 2011). From the recognition that conservation issues are related to human interaction with ecosystems, our interest was to analyze the importance stakeholders confer to mangroves. The use of semi-structured interviews using mainly open-ended questions and the fact that it was possible to audio-record the interviews, allowed us to document the perspectives of each interview. When there is no previous research conducted on a particular subject as this was case, this research approach allows finding ideas of interviewees that would not be possible to obtain with techniques such as surveys with closed questions. In this way, our study contributes with information that could be useful when designing integrated coastal management plans or when formulating policies (Bowen and Riley, 2003; Garmendia et al., 2010).

Mangroves in Northwestern Mexico differ in their degree of degradation or maintenance according to factors such as the history of human population colonization, and the intensity of its expansion. Taking these into account, Sonora can be divided in two regions: the southern-central region, with the highest population density and human activities practiced since the 1700s by first European settlers; and the northern region, with lower population density and a history of settlement mainly occurring during the 20th century (Almada, 2000). BCS can also be divided in two regions: the SC coast with a low population density and settlements established in the 20th century, and the Pacific coast with even less population and scarce development (Del Río and Altable-Fernández, 2000).

We have divided the rest of our discussion into three other sections: Section 4.2 examines mangrove surface since different perspectives arose in our results regarding such a basic and important topic; Section 4.3 covers ecosystem services provided by mangroves as this reflects the importance given to them by the different stakeholders and Section 4.4 discusses coastal integrated management issues as aroused from our aims and findings regarding stakeholders perspectives for the long-term use and conservation of mangroves in Northwestern Mexico.

4.2. Mangrove surface: in expansion or at risk?

Most fishermen, ENGOs and scientists interviewed in the southern-central region of Sonora claimed that the surface of mangroves was shrinking due to the combined effects of accelerated urban and coastal settlement expansion, intense agriculture

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and ranching activities, resource overharvesting, as well as the construction and operation of aquaculture and other industrial complexes. However, other fishermen, scientists and government officers stated that mangrove surfaces remained basically the same in this region, even in those areas with severe contamination. Some scientists mentioned that this was due to a high resilience of mangroves and their capacity to cope with pollution.

In the north of Sonora, mangroves reach their northern distribution border within the ComCaac territory. According to local fishermen, the area still maintains good environmental conditions that allow the presence of healthy mangroves because there are no major developments and settlements. All fishermen interviewed in this region mentioned that mangroves were even expanding in surface by growing landward. Other fishermen and scientists from northern Sonora claimed that the surface of mangroves was definitely reducing in the vicinity of the city of Bahía de Kino, just south of the ComCaac territory, this mainly due to aquaculture activities and the construction of tourism developments.

During the 1980s, aquaculture activities began incipiently in this city; by 1997 changes in policies allowed private enterprises to freely enter and develop the coast, massively expanding this industry (Moreno et al., 2005). Páez-Osuna et al. (1998) found that this industry has altered local estuarine conditions by releasing chemicals and sediments, which further affect local fishermen through a consequent reduction in biodiversity and sediment deposition. Tourism was the other activity recognized to be posing strong impacts on mangroves in Northern Sonora; mainly as consequence of construction of facilities or by pollution and trash deposition. Tourism started in the area in the 1930s when sport fishermen from the US started to visit, and at present it is one of the main economic activities promoted in Bahía de Kino (Gobierno de Sonora, 2005).

Interviewing government officers in Sonora, we obtained contrasting responses regarding mangrove surface, which may reflect a lack of communication and/or coordination among government institutions. A possible explanation could be that as the state of Sonora grew and developed, more offices were formed to work and find solutions to the multiplying environmental problems. Because each office tends to maintain structures that protect their interests and follow objectives without consultation with others, conflicts arise. Often this results in having agencies working at cross-purposes which may also produce contradictory tasks (Huggett, 1998; Brechin et al., 2003).

In order to work towards sustainable development and specifically to achieve an integrated coastal management, it is fundamental that governmental institutions related to environmental issues become more organized, carry out coordinated activities, and most importantly, make use of good quality information (Hewawasam, 2000). However, it is important to mention that no scientific studies that analyze the changes in the surface of mangroves in the state of Sonora have been published to date. Such studies are urgently needed to provide baselines that will strengthen decision and policy making, and also help identifying areas were environmental conflicts are likely to be severe in the light of the accelerated development rates in this coastal region (Ruiz-Luna et al., 2008).

In BCS most interviewees agreed that the surface of mangroves in the SC coast was shrinking mainly because of the development of tourism facilities. Some fishermen also added that coastal encroachment is restricting shore access, a fact that is challenging social structures and the local economy in other coastal regions of the state as well. This situation was also noted by Presenti and Dean (2003), who mentioned that tourism facilities were being developed in rural areas, and the local population was either turned into labor force for tourists or displaced in order to construct more developments.

A contrasting scenario occurs in the Pacific coast of BCS, which has the largest mangrove surface and is the less inhabited and developed area in Northwestern Mexico (Whitmore et al., 2005; CONABIO, 2008). The few settlements here are located in sites where waters are very productive and biodiversity rich, and the small population lives from fishing highly priced species such as abalone and lobster (Young, 2001). Fishermen and scientists asserted that mangroves in this coast are in good condition and that their surface was the same or even expanding inland. Such mangrove landward expansion was confirmed by our own analysis of satellite imagery and aerial photographs from the region, in which we relate mangrove expansion in the Bahía Magdalena region with oceanographic anomalies and sea level rise (López-Medellín et al., 2011).

Governmental officers in BCS mentioned that mangrove surface remained basically the same throughout the state, but acknowledged that in some areas few mangroves were damaged by construction. However, they also recognized that the lack of personnel and budget make it difficult to perform the monitoring of the entire state and therefore they cannot be aware of environmental problems in all areas. The government of BCS is based in La Paz, a large city where growing tourism and industrial facilities have deteriorated or even removed entire mangrove stands within or near the city, as mentioned by some fishermen, scientists and ENGOs personnel. Government however, does not acknowledge such reductions, which have been previously identified in scientific publications (Holguín et al., 2006; Acosta-Velázquez and Ruíz-Luna, 2007). This indicating a lack of communication between government and the scientific sector, showing perhaps the incapacity of scientists to make visible and useful their findings or reflecting as well that governmental authorities promote a discourse directed to protect their interests and directives (Brechin et al., 2003).

ENGOs from both states shared the perception that in general the surface of mangroves was reducing. All interviewees from these organizations mentioned that they work closely with scientists to obtain accurate information on the present state of natural ecosystems, which might be the reason why similar perceptions in terms of mangrove threats and present surface were obtained from both sectors. Since ENGOs actions aim to influence policies and practices to promote conservation, sustainability, environmental awareness and social equity, they try to include all stakeholders in their conservation processes through broadening communications, reaching consensus and improving the management of the coastal regions in Northwestern Mexico. For these reasons, ENGOs seem to have broader perspectives on how power relations are established among actors in the management of coastal areas (Sanyal, 1994) and consider these aspects when conducting projects.

These contrasting perceptions about a relevant and basic issue such as changes in mangrove's cover may reflect the lack of communication channels and spaces for information exchange among the different stakeholders, which is fundamental in order to construct consensus and reach an integrated coastal zone management that contribute to sustainable development (Fabbri, 1998; Hewawasam, 2000).

4.3. Mangroves and ecosystem services

Mangroves were extensively recognized by most interviewees as providing a variety of services that benefit human livelihoods and that are related to ecosystem integrity and biodiversity. Although our study provides a qualitative valuation of such services and an economic valuation is still needed, these findings show the relevance of documenting how direct users of ecosystems (such as fishermen) as well as those responsible for regulating their use and promoting their conservation (Government and ENGOs) understand the society–ecosystems interaction (Garmendia et al., 2010). Scientists as generators of information emerge here again as an important sector that needs to get involved in management decisions (at different scales) providing the knowledge needed to support the conservation of mangroves in the long term because of their relevance to provide services (tangible such as fish, but also due to their role in climate regulation or natural processes such as natural waste decomposition in wetlands). Ecosystem services cannot only be prized when society has to compensate their loss (Ewel et al., 1998; Gilbert and Janssen, 1998). Undervaluation of these services has been one of the major factors driving the conversion of mangrove ecosystems to human-dominated systems (Costanza et al., 1997; Daily et al., 2000), because these are difficult to translate into economic currency. Studies are needed to better understand the linkages between coastal ecosystems such as mangroves and the social benefits associated with them. It is also necessary to determine which are the most important goods and services provided by mangroves within an area, in order to better allocate their local economic, ecological and cultural values. Determining the impacts that particular activities are imposing on mangroves will help to identify priority areas that ought to be preserved and/or restored.

Fishermen in the SC of BCS gave less importance to mangroves than fishermen in the Pacific and Sonora regions. Such contrasts might relate to the uneven distribution of mangrove surface between the two coasts which make some fishermen live in closer contact with these ecosystems than other groups (CONABIO, 2008). However, this may also indicate a lack of environmental awareness and regulations in these coasts, because while the fishermen in the SC of BCS did not acknowledged institutions working with mangroves, those in the Pacific coast recognized the presence of some institutions working in the area with environmental issues.

Nevertheless, even though the perception of fishermen in the Pacific coast of BCS and Sonora was that mangroves were important to sustain fisheries and biodiversity, as well as providing aesthetic values, their perception seemed not to be shared by other inhabitants in cities like Puerto San Carlos or Guaymas, were pollution, waste disposal and destruction of mangroves reflected the lack of interest that local inhabitants pay to this ecosystem evidencing also the absence of local environmental conservation actions and regulations.

In the central-southern region of Sonora, on the other hand, intensive activities such as aquaculture, agriculture and industrial complexes have had consequences on mangrove ecosystem services that were previously provided to society, in exchange for economic profits that benefit a few individuals or corporations. Some fishermen and scientists interviewed mentioned that mangrove surface in this area remains the same. However, it is important to mention that the mere presence of mangroves is not indicative of healthy coastal conditions and there is no guarantee that provision of ecosystem goods and services provided by healthy mangrove ecosystems continues (Alongi, 2008). For these reasons, there is a severe reduction of fisheries that were once plenty and supported many families, and presently fishermen are forced to switch between jobs or have to migrate to other regions in search of economic alternatives (Aburto-Oropeza et al., 2008). A similar scenario is occurring on the SC coast of BCS, where tourism developments are deteriorating or removing natural environments.

In contrast, the coast of the Pacific of BCS has not been subject to major developments, and fishermen earn good incomes and enjoy better livelihoods. Nevertheless, this coast is gradually being developed through tourism and aquaculture, which threaten coastal environmental conditions and may create the same scenarios of natural depletion and social inequity and poverty as in Sonora and the SC coast.

4.4. Managing perspectives for the long-term maintenance of mangroves in NW Mexico

In order to achieve an integrated management of the coastal area (Fabbri, 1998) in Northwestern Mexico, the development and implementation of a coordinated strategy to allocate environmental, socio-cultural and institutional resources is urgently needed. Such a process can take considerable time, since it requires continual information updating and adaptive management strategies. It also requires effective governmental policies and the establishment of active arrangements among stakeholders in order to make decisions, as well as management strategies which are based on the interconnections between coastal natural and social systems (Sorensen, 1993). Our study provides a first baseline of information regarding the perceptions of the key social actors whose decisions are directly related to their views and opinions. These views act as windows to understand the interplay of economic, political, cultural and ecological issues. As it has been emphasized in the ecosystem management literature, understanding these actors' perspectives and constructing narratives is seen as an essential part of the social system diagnosis (Grimble and Chan, 1995; Christensen et al., 1996; Waltner-Toews et al., 2003; Fletcher, 2007; Garmendia et al., 2010).

Managing ecosystems involves capacities of governance; that is reaching arrangements (prescriptions, rules, regulations) to organize sets of repetitive activities in order to obtain desired outcomes (Ostrom, 1990, 2005). Establishments of such arrangements and creation of rule systems need the participation of those stakeholders involved in the specific situation. For the case of mangrove sustainable management, it is necessary to revise the role of Government. Our findings agree with the idea that failure to promote environmental stewardship in many countries has been related to some high ranking officers that base political decisions on personal economic gain and prioritize activities that produce large profits in the short term by allocating vital resources to private parties and without considering environmental consequences (Bryant and Bailey, 2005).

A dissimilar presence of governmental authorities in BCS is of great concern to improve management practices of coastal areas. Fishermen of the Pacific coast recognized an active presence of government which works as a constant reminder that mangroves are protected. In contrast, fishermen in the SC stated that environmental authorities were totally absent, this representing a lack of interest on environmental issues. Government was seen also as concentrating its efforts in areas with better social organizations and where economic activities such as fishing or tourism provide good profits, neglecting highly marginalized and less organized communities where environmental impacts due to resource over-extraction are higher.

Furthermore, in regions where the operation of large aquaculture or tourism developments are producing large economic profits, such as central-southern Sonora or the SC coast in BCS (SAGARPA, 2006, www.sectur.gob.mx March 2010), the government is inclined to benefit a few private parties by granting them access and control of vital resources. Since such enterprises can only be sustained by wealthy and powerful individuals or corporations, local communities cannot compete with them and are excluded from resource use, increasing local social inequity, conflicts over appropriation of resources and resource poaching (McGoodwin, 1980; Luers et al., 2006). Poverty and environmental degradation derive from unplanned decision-making processes where impact of growing populations upon coastal ecosystems have negative effects on mangroves' health and productivity, as was evidenced from our interviewees.

Filling the gaps left in many cases by governmental inefficiency, ENGOs have proved effective in promoting sustainable practices by bringing together local inhabitants with other stakeholders, strengthening decision making and improving their quality of life (Castillo, 1999). By questioning the government as promoter of social and environmental interests and by working with different actors to seek common objectives and empower local communities, ENGOs build institutions that can challenge local, regional or national elites and exert pressure on governments and businesses to change degrading practices by including scientific information (Clarke, 1998; Bryant and Bailey, 2005). For this reason, the presence of such organizations is critical to achieve a successful coastal management in Northwestern Mexico (Brechin et al., 2003).

In the case examined here, ENGOs emphasized problems of coordination with different governmental institutions because of their different agendas and interests, but acknowledged that cooperation was possible when creating new protected areas. When interviewing other social sectors, however, they stated that ENGOs sometimes work in isolation, compete for funding with other organizations rather than pooling resources in common efforts, a situation that fails to hasten political change. A similar situation aroused when interviewing ENGOs representatives regarding their relationship with scientists; recognizing no communication interactions between scientific institutions or even between scientists within a same institution.

Technical capabilities are extremely needed to accomplish conservation and local peoples' sustainable livelihoods. Having accurate knowledge of natural resources and the systems that produce them is considered relevant for construction of strong governance systems (Ostrom et al., 1999). Assistance and commitment of international and national organizations is crucial to support information exchange, feasibility studies, pilot projects, and funding (Sorensen, 1993; Brechin et al., 2003). Consequently the participation of scientists is essential to formulate management and conservation policies (Miller and Hobbs, 2002) and this has been a constant demand from different social sectors (Castillo et al., 2005). Scientific information regarding ecosystems functioning could be crucial to determine thresholds when using natural resources and to respond to environmental contingencies. Scientific institutions should work closely with the different stakeholders not only to facilitate the application of research results but also to identify information needs and to establish research agendas (Castillo, 2000). Our results show that sectors such as fishermen who are direct users of mangroves services shared an alien perception towards research institutions; and their interactions with these were at best scarce (Kriebel et al., 2001).

Despite the importance of scientific studies, most information is almost exclusively published in scientific journals and rarely reaches local communities and other stakeholders (Castillo and Toledo, 2000). This situation was evidenced here through the perception of government regarding mangrove surface in BCS, which has been reported to be diminishing by scientists but this view has not moved outside academic circles. It is crucial that scientific knowledge is communicated to the diversity of social actors and decision makers to raise awareness on environmental problems in order to define research projects and agendas in a two-way process according to local and regional priorities (Castillo et al., 2005; Perdomo-López, 2007). This could foster social participation and encourage local population to manage and conserve natural ecosystems in such ways that these can be maintained in the long term and provide society with benefits (Castillo, 2000; Miller and Hobbs, 2002).

5. Conclusions

Different actors with varying interests and sometimes strong power differences are involved in the management of mangrove ecosystems in northwestern Mexico. Achieving an integrated coastal management in this region is a difficult task. However, an initial step is the identification of stakeholders' perspectives. The use of a qualitative research approach in this study has proved useful since it allowed documenting actors' views from an open and inductive approach.

The governmental sector is crucial in order to design integrated coastal management plans and strategies. In this study it was found that the different environmental institutions and officers have different agendas and objectives and cannot act therefore in a coordinated way. Furthermore, the lack of budget and personnel complicates the scenario because it is impossible for this sector to cover large areas such as those of the coastal states in northwestern Mexico. On the other hand it was recognized that although the scientific sector plays a relevant role as provider of accurate information regarding ecosystems and their long-term conservation; this sector is poorly communicated with the rest of stakeholders. Scientific information should strengthen decision and policy making processes from the local to the national and international levels. Consequently, it is of the outmost importance to broaden the channels of communication among stakeholders to achieve an integrated coastal zone management. An important actor that can promote such communication is the environmental NGOs sector. Their actions often aim at promoting communication among stakeholders and influencing policies and practices. However, these organizations frequently work in isolation, competing with each other for funding and doubling their efforts, failing in cases to contribute to the needed changes.

Fortunately, a growing awareness in taking urgent action to protect ecosystems in Northwestern Mexico has been detected, as well as an increase in national and international efforts. Nevertheless, there is still much to be done to bring local and regional actors together in order to construct an endogenous development model that can transit to sustainability, allowing future generations to enjoy the benefits of mangrove ecosystems.

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DISCUSIÓN GENERAL

Son pocos los estudios que se han realizado en los manglares de las zonas áridas del noroeste mexicano y éstos en su mayoría se enfocan ya sea a una localidad en particular o a un estudio en específico. Por ello, en la presente tesis decidimos analizar conjuntamente los manglares de Sonora y Baja California Sur, analizando estos ecosistemas desde varias perspectivas, para así proveer información sobre la importancia ecológica, histórica y social en una región que está entre las más diversas y productivas del mundo, pero que a la vez está siendo severamente amenazada por un crecimiento y desarrollo voraz.

En términos ecológicos, en este trabajo identificamos varios patrones generales que inciden negativamente sobre los ecosistemas de manglar en la región y que se ven reflejados en su salud y en la disminución en la provisión de funciones y servicios ecológicos. Entre éstos, podemos mencionar patrones globales como el aumento del nivel del mar que está modificando la superficie de manglares empujándolos tierra adentro; políticas de desarrollo mal planeadas o aplicadas que buscan el beneficio económico en el corto plazo sin considerar el medio ambiente; así como el desconocimiento de la población local sobre su importancia y los beneficios que proporciona.

En la primera parte de este trabajo realizamos una síntesis estadística de las investigaciones que evalúan la productividad de los manglares del noroeste mexicano, ya que su elevada producción orgánica representa una fuente importante de nutrientes y energía para muchos procesos tróficos. Los resultados de este análisis indican que a pesar de encontrarse en una región árida donde los recursos escasean, por lo general, la producción de materia orgánica es muy elevada e incluso comparable con los manglares localizados en los trópicos. Estos manglares son capaces de convertir eficientemente los nutrientes disponibles en biomasa, gracias a comunidades de hongos, bacterias, protozoarios y algas que viven asociados a su rizósfera que les permiten retener nutrientes vitales como Fósforo y Nitrógeno (Twilley y Day 1999; Holguín et al. 2001; Alongi et al. 2005). Este mantenimiento y ciclado de nutrientes es sin duda una de las principales funciones que tienen los manglares en la bioquímica de las regiones costeras del noroeste de México.

En la última década, los ecosistemas de manglar de todo el planeta han sido catalogados entre los más amenazados por las presiones de desarrollo económico (Primavera 2005; Duke et al. 2007). En México varios estudios de análisis espacial han reforzado esta situación evidenciando la reducción en la superficie de estos ecosistemas (Ramírez-García et al. 1998; López-Portillo y Ezcurra 2002; Alonso-Pérez et al. 2003; INE 2005; Berlanga-Robles y Ruíz-Luna 2007). Sin embargo, estudios realizados en las costas del Pacífico mexicano han registrado un aumento en la cobertura de manglar (De la Fuente y Carrera 2005; Hernández-Cornejo et al. 2005; Hak et al. 2008). Al observar detalladamente los resultados de estos estudios, identificamos un patrón aparente: el manglar parece aumentar en aquellas orillas localizadas tierra adentro, mientras que disminuye en las orillas que dan hacia el mar. A partir de estas observaciones, decidimos estudiar si estos cambios podrían ser atribuidos al aumento del nivel del mar y la ocurrencia de fenómenos oceanográficos, eligiendo la región de Bahía Magdalena en la costa del Pacífico de Baja California Sur como sitio de estudio. Esta zona está formada por un extenso complejo de canales y bahías donde la parte interna al este del complejo está formada por grandes planicies desérticas, donde una leve variación en el nivel del mar sería capaz de inundar grandes superficies de salitrales.

Mediante el análisis de fotografías históricas, imágenes de satélite y realizando muestreos en campo, evidenciamos que la superficie de manglar ha aumentado significativamente, ampliando su extensión tierra adentro a una tasa anual promedio de 1.16% entre 1986 y 2001. Identificamos también que el nivel medio del mar ha aumentado a una tasa de 2.2 mm por año y que en periodos extraordinarios como los fenómenos de El Niño puede crecer mucho más. Esto ha permitido la colonización por manglares de nuevos espacios que antes estaban ocupados por vegetación halófita y suelos híper salinos, donde el aumento del nivel del mar empuja las semillas cada vez más tierra adentro y a la vez reduce la concentración de sal, lo que permite el establecimiento de las plántulas. Sin embargo, este aumento no debe calmar la preocupación sobre la conservación de estos ecosistemas, pues aunque es claro que los manglares están respondiendo al aumento del nivel del mar, los beneficios del nuevo crecimiento no son comparables con la pérdida o destrucción del manglar de borde que es el que provee mayores servicios ambientales como la protección de costas e incremento en las pesquerías (Aburto-Oropeza et al. 2008; Barbier et al. 2008; Koch et al. 2009).

Las costas de Sonora y Baja California Sur han cambiado gradualmente al ritmo del crecimiento poblacional y el desarrollo de actividades económicas realizadas durante el último siglo. Los cambios experimentados han afectado las condiciones ambientales y la salud de los manglares, disminuyendo la biodiversidad y deteriorando la capacidad de éstos para proveer servicios vitales para la región, como lo es el servir de sitios de reproducción para muchas especies de importancia comercial (Enríquez-Andrade et al. 2005; Whitmore et al. 2005; Glenn et al. 2006; Aburto-Oropeza et al. 2008). La degradación ambiental varía según la cantidad de tiempo en que se han desarrollado determinadas actividades, así como por el tipo e intensidad de las mismas (Adeel et al. 2002; Duke et al. 2007). Por ello, el conocer la historia del desarrollo humano en una región es fundamental para comprender la forma en que éste ha impactado los ecosistemas de manglar, así como para identificar sitios donde los conflictos para la conservación pueden ser severos y así poder realizar acciones de planeación y mitigación adecuadas que eviten procesos que han probado ser perjudiciales en el pasado (Swetnam et al. 1999). Mediante un estudio de ecología histórica nos propusimos registrar y entender cómo los diferentes procesos de expansión humana han afectado los ecosistemas de manglar a través del tiempo, evaluando las consecuencias ambientales que ha tenido un desarrollo económico sin planeación en la región. De esta forma, en aquellas áreas donde se han practicado actividades humanas por más tiempo y con mayor intensidad evidenciamos un severo daño ambiental y un déficit en la provisión de los servicios ambientales que comúnmente se proveían. Por el contrario, en zonas donde el desarrollo es aún escaso, prevalecen condiciones ambientales adecuadas y los ecosistemas continúan proveyendo servicios de gran importancia para los ecosistemas y las poblaciones humanas de las regiones costeras.

Los valores naturales, estéticos y recreativos de los manglares de la región ofrecen oportunidades de desarrollo que han atraído y continúan atrayendo trabajadores, inversores y desarrolladores que han transformado estos ecosistemas de diversas maneras amenazando su conservación (Paez-Osuna et al. 1998; Enriquez-Andrade et al. 2005; Whitmore et al. 2005; Holguin et al. 2006). Esta multiplicidad de actores involucra a una diversidad de percepciones sobre los manglares y genera diversos intereses para acceder y/o controlar las regiones costeras de importancia económica. Reconociendo esta variedad de actores e intereses, decidimos incluir la dimensión humana representada por pescadores, personal de gobierno, ONGs ambientales y científicos en Sonora y Baja California Sur. El entender cómo la gente interactúa e influye sobre la conservación y/o destrucción de los manglares, nos permitió identificar opiniones e intereses divergentes u opuestos que están produciendo conflictos en la conservación y el manejo en las regiones áridas del noroeste de México, y que se reflejan en el estado ambiental actual de los ecosistemas de manglar.

El sistema gubernamental con sus diferentes niveles e instituciones juega un papel determinante en la forma en que los actores actúan entre ellos y con el medio ambiente, ya que es quien otorga o restringe el acceso y el uso exclusivo de los recursos naturales (Bryant y Bailey 2005). En este estudio identificamos conflictos de diversa índole que se originan en las instituciones de gobierno y que se manifiestan en el desarrollo desmedido de actividades económicas y el deterioro ambiental: el bajo presupuesto, la escases de personal y la falta de capacitación limitan las labores de inspección y vigilancia de los recursos naturales. Identificamos una comunicación deficiente entre los diversos actores de gobierno, lo que genera conflicto de intereses en la elaboración de agendas y programas; la comunicación gubernamental con el sector académico es meramente un trámite burocrático y la opinión de éste último es rara vez tomada en cuenta; finalmente, algunos funcionarios basan sus decisiones políticas en su economía personal, otorgando prioridad a actividades que producen grandes ganancias en el corto plazo sin considerar las consecuencias ambientales (Bryant y Bailey 2005).

Identificamos que las ONGs ambientales están jugando un papel crítico en la conservación y el desarrollo sustentable de la región, ya que su trabajo promueve prácticas sustentables e involucra habitantes locales con otros actores, buscando objetivos comunes y fortaleciendo las comunidades mediante la construcción de instituciones que puedan contrarrestar grupos más poderosos locales, regionales o nacionales (Clarke 1988). Estas ONGs suelen ejercer presión sobre el gobierno y las empresas privadas para cambiar prácticas que están deteriorando el medio ambiente mediante la inclusión de información científica (Bryant y

Bailey 2005). Su presencia está siendo fundamental en la región para fortalecer la toma de decisiones y promover la justicia social y la equidad para comunidades marginadas (Castillo 1999; Brooks et al. 2006).

Finalmente, evidenciamos la falta de comunicación que tienen los científicos con el público en general y con los tomadores de decisiones, ya que aunque se han realizado varios estudios sobre el valor y la importancia de los manglares, estos trabajos no se conocen afuera del sector académico. Es imperativo que el trabajo científico sea difundido no solo a través de revistas científicas, sino en reuniones con diversos actores para elaborar estrategias adecuadas en la resolución de problemas ambientales y el desarrollo sostenible de la región.

No obstante, a pesar del elevado deterioro ambiental, cada vez existe una mayor conciencia ambiental de tomar acciones para proteger los ecosistemas costeros del noroeste de México que se ve reflejada en mayores esfuerzos nacionales e internacionales. Diversos sectores de la sociedad están trabajando en la conservación de la región involucrando a científicos, educadores y ONGs. Como resultado se han creado varias áreas naturales protegidas en la región, se ha incrementado la educación ambiental y ya existen algunos ejemplos de conservación basada en las comunidades locales.

Sin embargo, hay aún mucho por hacer aún para acercar a los distintos actores locales y regionales para lograr un desarrollo integrado que sea compatible con la conservación de los recursos naturales y que considere las prioridades consensuadas de la región. Esto permitirá a las generaciones futuras seguir aprovechando los beneficios proveídos por los ecosistemas de manglar.

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