CONSERVATION SCIENCE IN MEXICO'S NORTHWEST

ECOSYSTEM STATUS AND TRENDS IN THE GULF OF CALIFORNIA

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This book is dedicated to the memory of
Laura Arriaga Cabrera, Salvador Contreras-Balderas,
and Daniel Lluch Belda, caring colleagues,
great scientists, and exceptional human beings
to whom Baja California and the Gulf of California
owe so much.

Dedicamos este libro a la memoria
Laura Arriaga Cabrera, Salvador Contreras-Balderas y
Daniel Lluch Belda, colegas comprometidos,
grandes científicos, y seres humanos excepcionales,
a quienes Baja California y el Golfo de California
tanto les deben.

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

Xavier López-Medellín[1] and Exequiel Ezcurra[2]

The northwestern region of Mexico is among the most productive and biodiversity-rich areas of the world, which has provided ecological services to humans since pre-Hispanic times and continues to provide them today. Mangrove ecosystems in this region are fundamental to maintain the coastal environmental quality. They also 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 in this region. To observe and understand how human patterns and processes have affected mangrove ecosystems through time and evaluate the consequences that unplanned development activities have had in Sonora and Baja California Sur, we integrated historical information, aerial photography and field surveys. We register how these landscapes have gradually changed over the last century as human development 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, like the once rich fisheries, have vanished. On the other hand, in areas where development is still scarce, like some in the Pacific coast of Baja California Sur, mangrove ecosystems present suitable environmental conditions and still provide vital services to human populations.

1. INTRODUCTION

The waters and coastal environments of the Sea of Cortés in the arid northwestern Mexico, constitute one of the most productive and biodiversity rich areas of the

world (Sala *et al.* 2004, Enriquez-Andrade *et al.* 2005). This region has provided environmental services to the human populations that have inhabited the coastal areas of the present states of Sonora, Baja California Norte and Baja California Sur for millennia (Almada 2000, Del Río and Altable-Fernández 2000).

Human societies have been part of these natural environments, and have exerted different pressures on its ecosystems with an ever-increasing trend for a long time. Currently, this coastal region is inhabited by almost ten million people and has one of the highest population growth rates in the country (INEGI www.inegi.org.mx). Such demographic growth results from the different opportunities that the waters and coastal environments of the Sea of Cortés provide to develop economic activities. Waves of immigration from regions with agriculture and/or livestock practices have and are currently settling in the area searching for alternative economic incomes. As this human expansion continues, economic activities are exerting development pressures that have transformed the natural environmental conditions compromising the integrity of several ecosystems and their capacity to provide environmental services (Enriquez-Andrade *et al.* 2005, Glenn *et al.* 2006).

The presence of mangrove ecosystems in these arid regions is essential to sustain the environmental quality of the coastal ecosystems and improve the quality of human life (Holguín *et al.* 2006, López-Medellín *et al.* 2011). The intricate structure of their roots and stems provide habitat to several marine and terrestrial species, many of which have economic importance and/or sustain fisheries (Aburto-Oropeza *et al.* 2008); their canopy provides stopover sites for migrating species and can sometimes be the only green vegetation available in the arid landscape (Palacios and Mellink 1995, Whitmore *et al.* 2005); the high production of organic matter intrinsic to these ecosystems contributes with large quantities of organic matter and nutrients to both land and sea (Flores-Verdugo *et al.* 1992, Holguín *et al.* 2001, Félix-Pico *et al.* 2006); they also remove contaminants by incorporating them in their tissues or immobilizing them in sediment (Feller *et al.* 1999, Rivera-Monroy *et al.* 1999); mangroves and their vicinity also provide appropriate environments for the development of aquaculture (Páez-Osuna *et al.* 2003) and constitute scenic landscapes that are suitable for recreational and tourism activities (Presenti and Dean 2003).

The waters and coastal environments of the Sea of Cortés constitute ideal places for the development of economic activities that are attracting a large population to settle on its coasts with ever increasing development pressures that are transforming the natural environments and their capacity to provide ecosystem services (Enriquez-Andrade *et al.* 2005, Glenn *et al.* 2006).

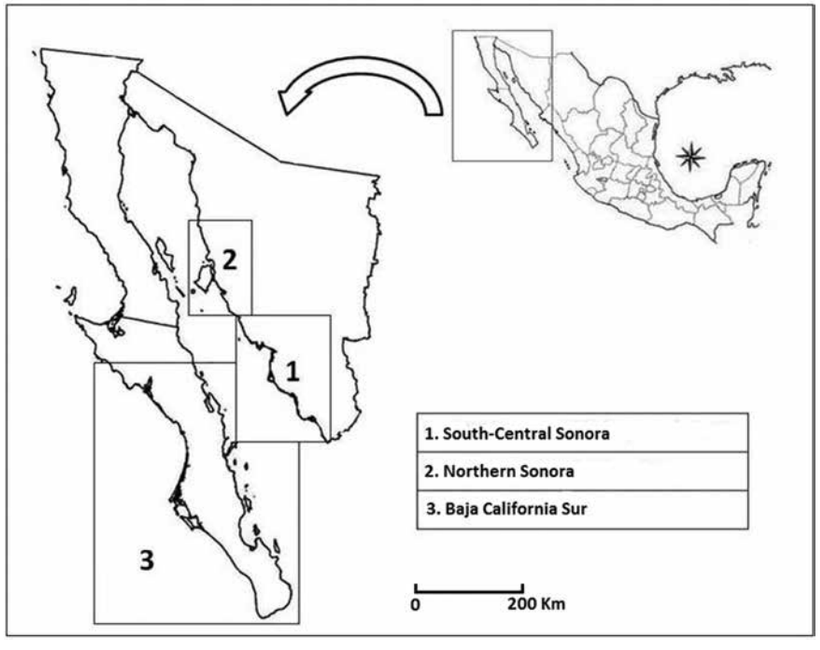
Furthermore, the urgency to generate rapid economic growth in Mexico has historically promoted policies that focus on economic gain by encouraging the development of hastened practices to maximize short-term yield, rather than harvest resources in a sustainably fashion (Young 2001, Basurto 2005). This situation has had negative impacts on both coastal ecosystems and human populations, because it threatens the different ecosystem functions, services and economic values from which the region and its population benefit (Enriquez-Andrade *et al.* 2006, López-Medellín *et al.* 2011). Therefore, it is of the outmost importance that the degradation of natural environments is reduced or 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 about activities that highly degrade natural environments, we combine historic data with current information and local environmental and socioeconomic data in this manuscript and provide a summary on the history of the human populations and the economic developments in the coasts of the arid territories in northwestern Mexico in order to illustrate the environmental consequences of unplanned development activities.

By visually comparing historic aerial photographs with modern imagery, we provide reference frames of times when natural ecosystems were less affected by humans and examine how the accelerated development has claimed coastal environments; finally, 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. We hope that this regional synthesis of material and political environmental history will serve as a starting line to further develop this kind of studies in this part of the world.

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

1. South-central Sonora. A region with many wetlands influenced by deltas of large rivers. Has higher population density that practiced agriculture, cattle, mining, fishing and trade since the 18th century (see Figure 2).
2. Northern Sonora. Has lower population density, its development largely related to a fishing expansion in the 20th century (see 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 (see Figure 4).



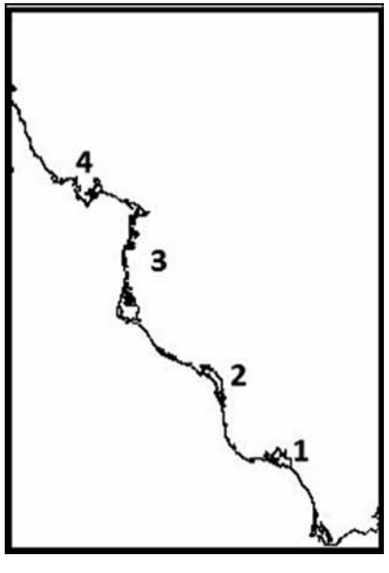


FIGURE 1 (ABOVE). Division of northwestern Mexico according to the historical development of human population and economic activities. FIGURE 2 (BELOW). South-central Sonora. 1. Yavaros-Moroncarit system, 2. Estero Tobari, 3. Las Guasimas-Estero Lobos system, 4. Guaymas.

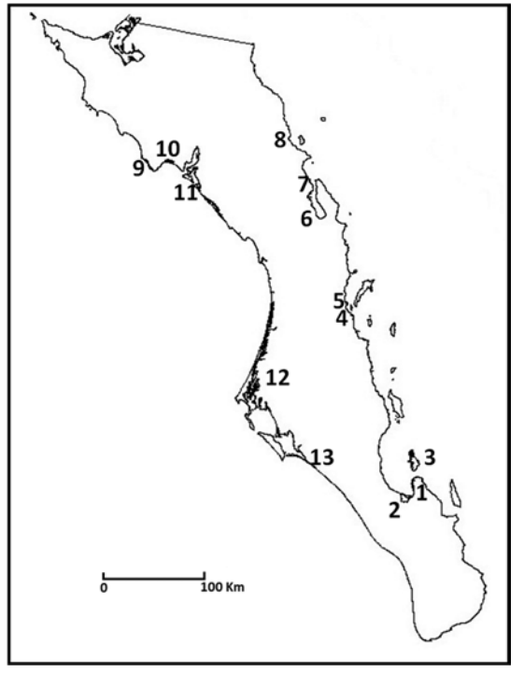


FIGURE 3 (ABOVE). Northern Sonora. 1. Estero Tastiota, 2. Estero Santa Cruz, 3. Seri estuaries, 4. Estero Sargento. FIGURE 4 (BELOW). Baja California Sur. 1. Bahía Balandra-Estero Enfermería, 2. La Paz-El Mogote, 3. Isla Espíritu Santo, 4. Puerto Escondido, 5. Loreto-Nopoló, 6. Bahía Concepción, 7. Mulegé, 8. San Lucas, 9. Estero La Bocana, 10. Estero El Coyote, 11. Laguna San Ignacio, 12. Bahía Magdalena-Bahía Almejas, 13. Estero Rancho Bueno.

2. MATERIALS AND METHODS

The historical development of human activities in the states of Sonora and BCS was summarized after an extensive literature review. This information was complemented with current data on the type and size of human population, as well as current development activities, taken from the Instituto Nacional de Estadística, Geografía e Informática (INEGI, www.inegi.gob.mx).

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). Historical photography was then compared with high resolution images from Google Earth and the human development around mangrove ecosystems in both states was visually registered.

Finally, we conducted a series of field visits in Sonora and BCS between 2007 and 2009 in order to assess the intensity of human activities and assess their effects on the mangrove ecosystems and their surrounding environments.

3. RESULTS

3.1. 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 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. In the early 18th century the missionaries started settlements and 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, local products were being incorporated into the national commerce. The period of President Porfirio Díaz (1883–1911) promoted foreign investments, designed to enhance communication systems and create better public works. This situation attracted migrants from all over the country, accelerating the population growth and the development of economic activities (Coerver 1977). However, during the crisis of 1908 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 to promote economic growth. Large investments were directed to construct dams, channels and roads to enhance irrigation-based agriculture and 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 (Almada 2000). The introduction of outboard motors, nylon nets and larger boats in the 1950s accelerated the exploitation of marine resources, which soon started to decimate. Furthermore, the pesticides and fertilizers used in agriculture in the upper valleys were conducted towards lagoons and estuaries by large draining channels, threatening the fishing cooperatives' income (McGoodwin 1980).

Consequently, by the beginning of 1970 soil productivity was severely reduced and fish captures diminished drastically, which resulted in lower revenues and greater debt (Almada 2000). As a strategy to expand the economic alternatives of the ejido sector, aquaculture was introduced in Sonora in 1983. However, limited access to credits and lack of material and technical resources detained 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 encouraging partnerships with the private sector to create credit opportunities (Luers *et al.* 2006). These reforms 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. 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 (Luers *et al.* 2006).

3.2. Present state of mangrove ecosystems in south-central Sonora

The first mangrove estuary in southern Sonora is the Yavaros-Moroncarit system, where the town of Yavaros (population 4,000) borders the estuary and the mangroves. Large depositions of trash and other wastes attest to the popularity of these areas as waste disposal sites. In the 1960s a road was constructed to connect Yavaros

FIGURE 5A. Yavaros-Moroncarit System, INEGI 1973, 1:70,000.

FIGURE 5B. Yavaros-Moroncarit System, Google Earth.

with Huatabampo, the largest city in southern Sonora (population 30,000), blocking the natural water flow and caused severe sediment deposition and mangrove mortality. In 1985, because sardine fishing was a profitable activity, industrial and fishing ports, as well as fish processing plants were established in Yavaros (Cisneros-Mata *et al.* 1995).

In recent times the area is undergoing severe environmental problems: sediments and contaminants flush down from the Mayo River valley through large drainage channels, polluting the waters and transforming the estuary by blocking the natural water flows. 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; the channels that direct waste into the estuary are evident.

Estero Tóbari, 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 blocked the natural water flows. It also receives pesticides and fertilizers from adjacent agricultural developments through a draining channel, which results in heavy pollution, eutrophication and sedimentation.

South of the city of Guaymas, there is a large system of coastal lagoons that begin in Las Guásimas and end in Estero Lobos. Mangroves are located in the coastal limit of the fertile Yaqui river valley, an area where the Yaqui indigenous nation has exclusive fishing rights. These mangroves are impacted by drainage channels that spill residues into the estuaries, blocking water flows and highly polluting the area causing biodiversity loss. Aquaculture ponds have also been constructed in the area, adding pressure to these coastal environments.

The next mangroves are located around Guaymas 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) started on fishing products and their processing (Almada 2000). The local fishing industry contributed 70% of the state's fishing productivity. However, in recent times the decline of fisheries by overharvesting and the increasing pollution switched economic activities over to assembly

FIGURE 6A. City of Guaymas, ICA 1956, 1:16000.

FIGURE 6B. City of Guaymas, Google Earth.

plants and tourism. Today, Guaymas keeps growing, urban settlements and industrial facilities are being developed all over the bay increasing human pressure on coastal environments, as illustrated on Figures 6a and 6b. There is, however, a growing initiative by environmental NGOs to protect natural ecosystems, and recently the state has declared a large mangrove protected (Estero El Soldado).

3.3. History of development in northern Sonora

For more than 2000 years, the northern part of Sonora was inhabited by seminomadic tribes like the Seri, who lived from hunting, fishing and gathering, moving according the availability of resources (González-Bonilla 1941, Almada 2000).

Early European explorations consisted on military reconnaissance missions in the mid 16th century. 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. 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 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, an area with large fishing resources because there are no developments that pollute the marine environment. The Seri created a traditional guard to survey their area for unauthorized fishermen (Wong 1999).

In the early 20th century, a small fishermen settlement existed in Bahia de Kino, 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 (Basurto 2006). Conflicts which continue to the present day, started within the community in a struggle for resources between fishermen (Moreno *et al.* 2005).

Aquaculture started 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 development, and in 2002 thirteen farms produced more than 2500 tons of shrimp exceeding the captures of the fishing industry (Moreno *et al.* 2005).

Fishing opportunities 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.

3.4. Present state of mangrove ecosystems in northern Sonora

The first mangroves, going from south to north, are located in Estero Tastiota, where large aquaculture developments have almost removed all mangrove vegetation. Sixty kilometers to the north is the next mangrove community surrounding the Estero Santa Cruz, in the vicinity of Bahía de Kino with a population of 5,000 inhabitants. The structures in the city are mainly constituted by fishermen and tourism houses, restaurants and aquaculture complexes.

Damage to the mangroves comes from trash, construction and liquid wastes disposed directly in the estuary. Aquaculture ponds 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 7a and 7b show the construction of roads, aquaculture ponds and draining channels connected to the estuary.

The best preserved mangroves in Sonora are located in the land of the Seri, the northernmost limit of their distribution. Human development is scarce, with two Seri settlements: Desemboque and Punta Chueca, with a population of 658 dedicated to fishing and/or crafts. The channel between mainland and Isla Tiburón is known as Canal del Infiernillo and has a series of small mangrove estuaries, the largest being Punta Arenas. Further north is Estero Sargento, with more than 5 kilometers of a large mangrove ecosystem, the last of these ecosystems in the state. Mangrove ecosystems in the land of the Seri are in very good conditions since they acknowledge their importance for the fisheries in their area and therefore protect them. See table 1 for a summarized review of the mangrove localities and the presence of human settlements and/or activities in the state of Sonora.

TABLE 1 (RIGHT). Mangrove localities in the coast of Sonora, Mexico.

Locality	Rhizophora mangle	Laguncularia racemosa	Avicennia germinans	Conocarpus erecta	Fishing intensity	Tourism intensity	% of dead mangroves	Human settlements	Population
Canal del Infiernillo	√	√	√	√	Low	Low	-25%	2 native populations with dirt roads and small houses, hospital and school	674
Estero La Cruz	√	√	√	√	High	High	25%	Large population with all services, paved roads and industries	5,000
Estero El Soldado	√	X	√	√	High	Medium - High	-25%	Port, industries, hotels, restaurants, houses.	97,593 of Guaymas
Manglar de Guaymas	X	√	√	√	High	High	75%	Port, industries, hotels, restaurants, houses.	97,593 of Guaymas
El Rancho	X	√	√	√	High	High	75%	Urban area of Empalme	38,533 of Empalme
Las Guásimas	√	√	√	√	High	Low	25%-50%	Fishermen camps and draining channels	16
Estero Lobos	√	√	√	√	High	Low	25%	Construction in progress	200
Tóbari	√	√	√	√	High	Medium - High	25%-50%	Road dividing the estuary in half, draining channels and aquaculture complex	—
Yávaros-Moroncarit	√	√	√		High	Medium - High	25%	Medium size population, aquaculture, industries	3,860

FIGURE 7A (ABOVE). Bahía de Kino, INEGI 1973, 1:70,000. FIGURE 7B (BELOW). Bahía de Kino, Google Earth.

3.5. History of development in BCS

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 resources (Del Río 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. It wasn't until the late 17th century that the missionaries established a series of missions starting in the coastal region of Loreto. Missionaries and soldiers gathered the natives and developed a few agriculture and cattle activities, as well as scarce mineral and pearl extraction. After the Jesuits were expelled from all the territories of Spain in 1767, 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 port of San José del Cabo (Del Río and Altable-Fernández 2000).

By the beginning of the 19th century, agriculture, cattle and mining activities became more important, and their production reached national and international markets. Trade became a profitable activity and the city of La Paz grew quickly (Del Río and Altable-Fernández 2000).

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

The Mexican revolution started in Mexico in the first decade of 1900, but its effects were hardly felt in the Peninsula. Resources from mainland became scarce, which greatly slowed the local economy, population growth slowed, and by 1929 there was a total population of 47,000 people working in the mining colonies and agriculture/cattle settlements. In response to this lack of expansion, the 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 (Del Río and Altable-Fernández 2000).

In the 1960s, the southern region of Baja California underwent a large process of industrialization, and credits were granted to farm large surfaces. The ferry to

communicate the Peninsula with mainland was introduced, and in the '70s the highway that connected the Peninsula from north to south was finished. This contributed to the development of commerce and tourism, increasing the population to 130,000 inhabitants (Del Río 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 (Del Río 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 income generated by tourism represented 27% of the total state incomes (Del Río and Altable-Fernández 2000). From 1995 on, the tourism industry has been a major socioeconomic factor in the Peninsula. The construction of large residential and tourism complexes around the Sea of Cortés are increasing water demands, restricting access to resources and polluting surrounding ecosystems with residual waters (Beltrán-Morales 2005, De Sicilia-Muñoz 2000).

Marine resources from the rich waters of Baja California have provided additional sources of profit. In the 1930s fisheries policies were created to support fisheries (Young 2001), and to date 650 species have been identified as exploitable (Cortés-Ortiz *et al.* 2006). On the Pacific coast, species with high commercial value like 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 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 this industry keeps growing, and in 2002 it contributed more than 12% of the national captures (Cortés-Ortiz *et al.* 2006).

3.6. The Pacific coast

The first mangrove from north to south is located in a 15 kilometers estuary named La Bocana, flanked by two fishing communities of 2,000 inhabitants: Punta Abreojos and La Bocana. The population relies upon lobster and abalone, which are highly valued species in the market and sustain their economy; some others capture clams, oyster and some fish for local consumption (Cortés-Ortiz *et al.* 2006). Southeast from Punta Abreojos is El Coyote estuary (see Figures 8a and 8b), a series of channels and islets covered by mangroves in excellent condition; there is a small lodging

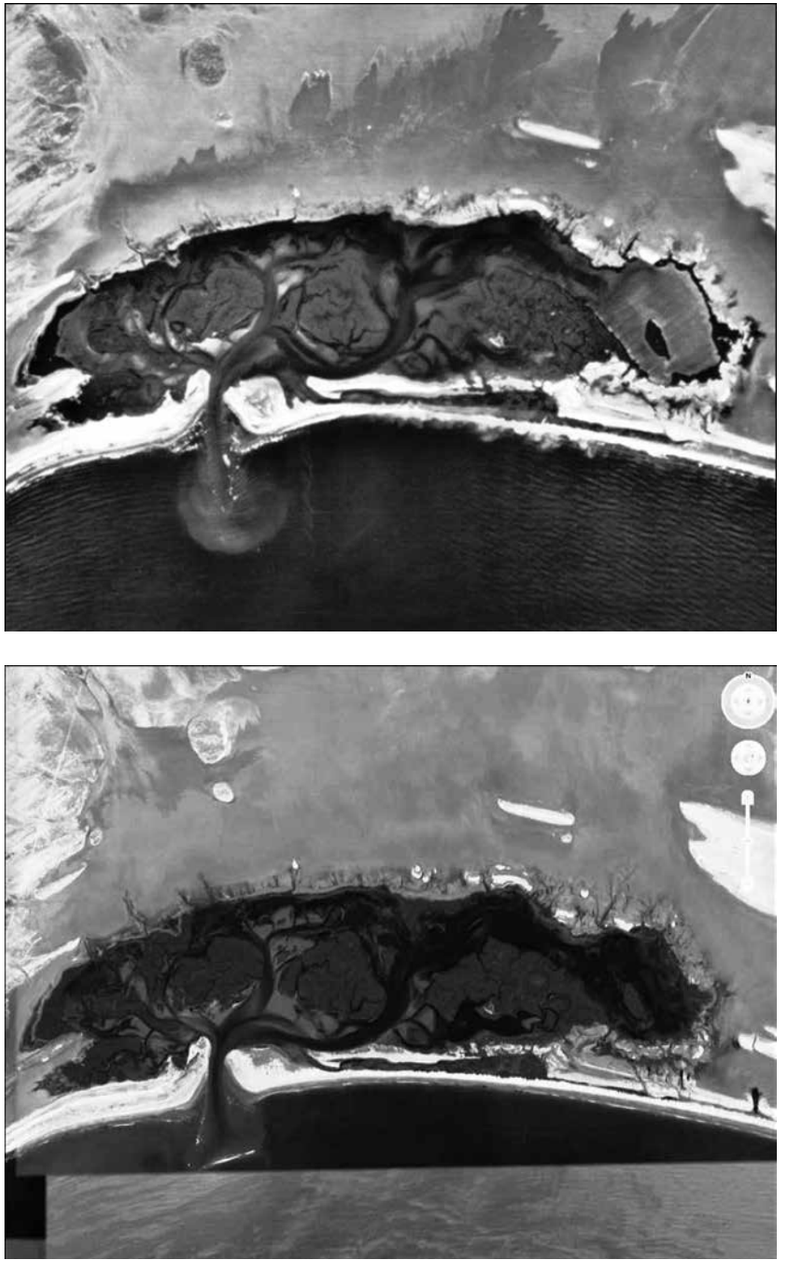


FIGURE 8A (ABOVE). El Coyote estuary, INEGI 1972, 1:70,000. FIGURE 8B (BELOW). El Coyote estuary, Google Earth.

facility with cabins and latrines that was constructed in 1980, as well as a couple of fishermen's houses and 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, which continues south to Estero El Dátil; the population is distributed in three settlements: Luis Echeverría and El Cardón with 1,000 inhabitants, and El Dátil, which is located adjacent to the estuary of the same name with less than 100 inhabitants. Fishing is the principal activity of the local population, however there is a growing number of people working in oyster farms.

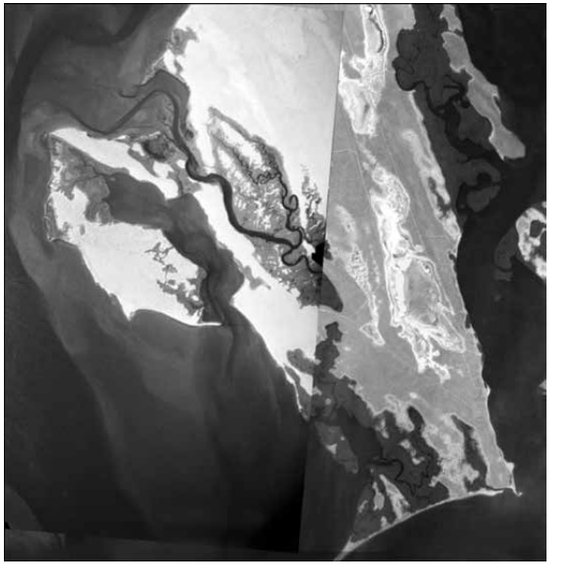
Further south, the area of Bahía Magdalena-Bahía Almejas, is the largest mangrove ecosystems of BCS distributed in a complex set of estuaries and channels covering more than 130 kilometers. This region is one of the most important coastal zones in northwest Mexico and contributes with 65% of the BCS fishery production (Lluch-Belda *et al.* 2000). Human population is distributed mainly in two port cities: Puerto Adolfo López Mateos and Puerto San Carlos, the rest lives in small fishermen camps scattered along the coast.

Puerto Adolfo López Mateos is a town of 2,200 inhabitants, who live mainly from fishing or working 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, 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.

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

Dead mangroves were observed close to these cannery industries probably due to the discharges; furthermore, in some areas where mangroves are adjacent to the city, the accumulation of construction debris and household trash block the natural water flux and killed mangroves. Figures 9a and 9b show how in Puerto San Carlos, the most evident changes were due to the growth of the city, the expansion of roads and bridges and the development of the port.

Mangroves continue south of Puerto San Carlos to the bays of Almejas and Santa María. The population in this area is distributed mainly in Puerto Chale with a



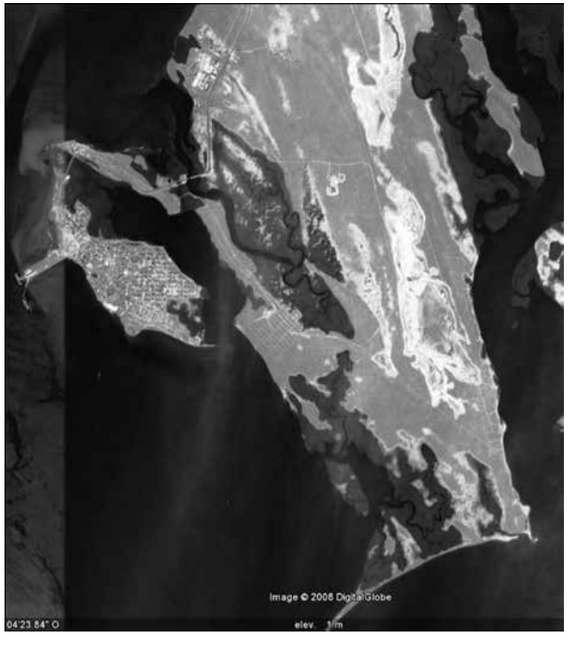


FIGURE 9A (ABOVE). Puerto San Carlos, ICA 1962, no scale available. FIGURE 9B (BELOW). Puerto San Carlos, Google Earth.

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 there existed a large sea farming complex owned by an ejido; however, it was recently sold to foreigners to develop tourism facilities; presently two private shrimp farms were also established. Rancho Bueno is the last estuary with mangroves in BCS, there is only one settlement running a small oyster farm that has been in operation for 10 years, and the mangroves there are in good condition.

3.7. 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 is the southernmost mangrove on this coast, where a coastal lagoon is surrounded by mangroves in good condition, since this bay, near the city of La Paz, has recently been declared a protected area. Further north is another estuary called El Merito that is still 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 is an area with high tourism and industrial developments, constructions include a shuttle port, fuel and cement factories, universities and tourism facilities. Embedded in the city of La Paz is a small coastal lagoon called Enfermería, which has been severely polluted and damaged by road construction and aquaculture development.

Other mangroves are embedded in La Paz, a city of 189,176 inhabitants who live mainly from tourism. The city has a large port and airport, as well as several industries and tourism facilities that contribute important profits to the city. Due to its arid location, water scarcity is a problem, and with more hotels under construction water supplies and environmental quality are being compromised. These mangroves show disturbance signs like oil, trash and construction debris deposition. In front of Bahía de La Paz is a large mudflat called El Mogote, with some mangrove populations facing the bay, the area is undergoing rapid tourism developments that represent a threat to the conservation of these ecosystems (Holguin *et al.* 2006). Figures 10a and 10b show 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.

North of La Paz is the Espíritu Santo Island, which was declared a protected area in 2001. The west side of the island has eight mangrove sites in excellent condition. In 1903, some facilities were built for the production of pearls and opening channels through the mangroves. However, the facility was abandoned in the '70s due to production failure. Presently there are no settlements in the island and the impact of tourism is very low.

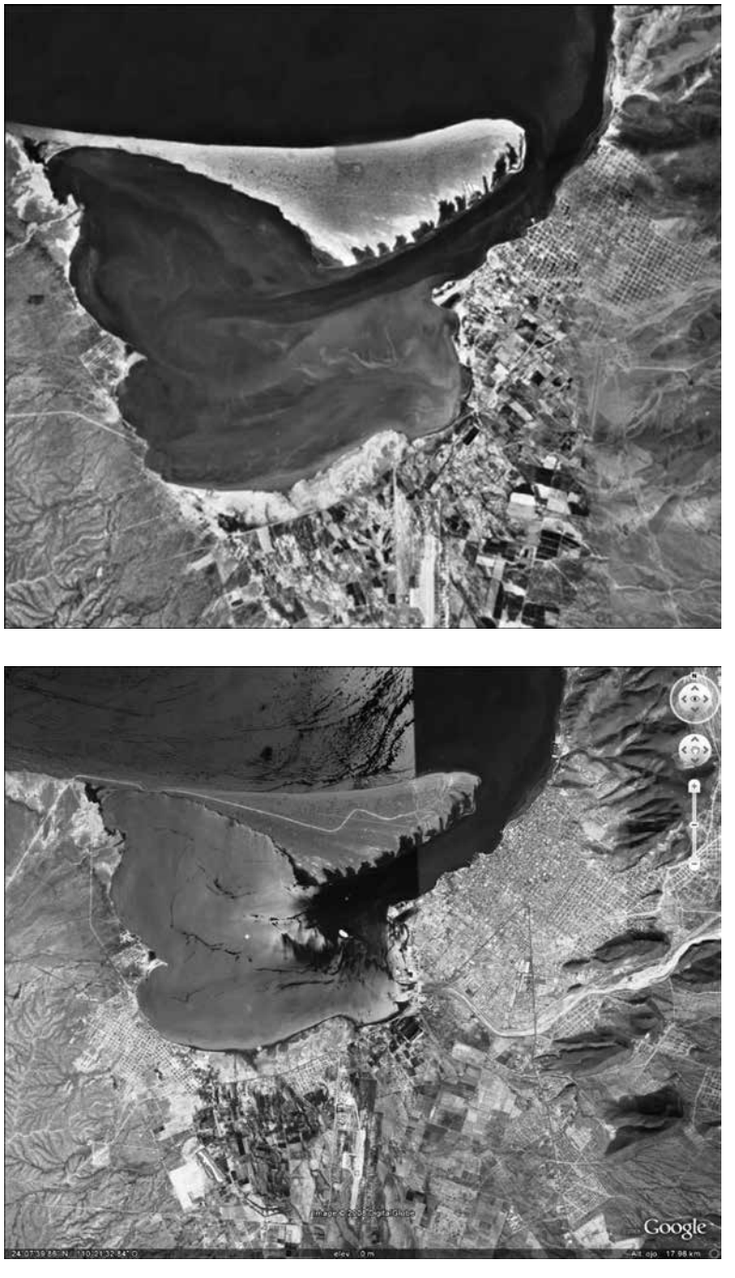


FIGURE 10A (ABOVE). La Paz, ICA 1956, 1:20,000. FIGURE 10B (BELOW). La Paz, Google Earth.

Some small mangrove patches are located along the coast to the north up to Loreto. The first 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.

A couple of kilometers north, in the Loreto-Nopoló area, another series of mangroves located in the vicinity of Ligüi were severely damaged during the 2003 hurricane season. Some other small mangrove stands are around the community of Ensenada Blanca, where a hotel is being developed and conflicts with fishermen are already occurring by restricting their access to the beach. A couple of miles north from Ensenada Blanca, a medium size mangrove estuary was completely covered with sand in 1976–1977 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, a large mangrove stand in good condition and with a small fishing community, followed by Playa Armenta, 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 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. El Burro, has a medium-sized mangrove patch bordering a lagoon, and small houses distributed along the shore, the lagoon is being filled in by 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, where little tourism development is still present.

Continuing to the north is the town of Mulegé, located next to a large estuary that flows into the Sea of Cortés with a population of 3,317 inhabitants. 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. Figures 11a and 11b show the construction of roads, urban and tourism developments in Mulegé. Another impact to mangroves in the area is the occurrence of hurricanes, which periodically damage this vegetation.

The last mangrove stand along this shore in BCS is located 50 kilometers north of Mulegé in a small settlement called San Lucas, which has tourist houses, RVs and

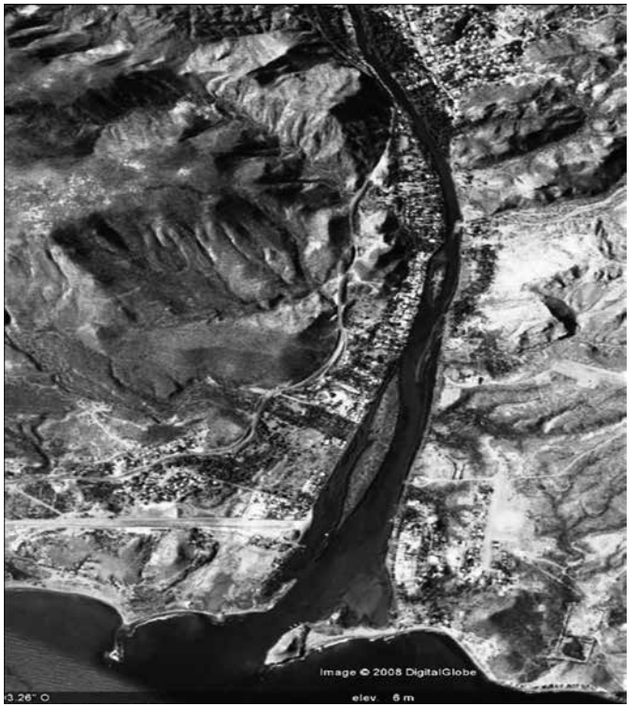


FIGURE 11A (ABOVE). Mulegé, ICA 1956, no scale available. FIGURE 11B (BELOW). Mulegé, Google Earth.

military barracks. A thin bar of sand forms a small inlet, where mangroves are in well conserved patches. Among the population of 203 inhabitants fishermen capture squid and fish from the sea, and clams, crabs, oyster and octopus in the mangroves. See tables 2 and 3 for a summarized review of the mangrove localities and the presence of human settlements and/or activities in the Peninsula of Baja California.

4. DISCUSSION

In the last century, the landscape of northwestern Mexico 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 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, damages can be identified following the historical development of human populations. The degree of human damage to mangrove ecosystems 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 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, which is causing poverty and resource over extraction.

Some mangrove populations have been almost completely removed for the construction of aquaculture complexes, as well as by the direct disposal of their solid and liquid wastes, and some are so severely damaged that their recovery seems very difficult if not impossible. For these reasons, it is imperative that the construction of these complexes is properly planned and evaluated in order to reduce environmental impacts (Whitmore *et al.* 2005).

Other estuaries that have a more recent history of development and in these places 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 discharges'

TABLE 2. Mangrove localities in the Pacific coast of BCS.

Locality	*Rhizophora mangle*	*Laguncularia racemosa*	*Avicennia germinans*	Fishing intensity	Tourism intensity	% of dead mangroves	Human settlements	Population
La Bocana	√	√	X	Medium-High	Low	-25%	Houses, industries, small ports, fishing camps	2,000
El Coyote	√	√	X	Medium	Medium	-25%	Houses, hotels and restaurants	15
Bahía San Ignacio	√	√	X	Medium	Medium-High	-25%	Tourism camps ejidos Luís Echeverría and El Cardón	1,000
El Dátil	√	√	X	Low	Low-Medium	25%	Ejido El Dátil	-100
Puerto López Mateos	√	√	√	Medium	Low-Medium	50%	City with port and industries	2,200
Puerto San Carlos	√	√	√	High	Medium-High	20%	City with port and industries	3,600
Puerto Chale	√	√	√	Medium	Low	-25%	Fishing camps	300
Loma Amarilla	√	√	√	Low-Medium	Low	25%-50%	Aquaculture ponds	0
Rancho Bueno	√	√	√	Medium	Low	-25%	Fishing camps and oyster farms	8

TABLE 3. Mangrove localities in the Sea of Cortés coast of BCS.

Locality	Rhizophora mangle	Laguncularia racemosa	Avicennia germinans	Fishing intensity	Tourism intensity	% of dead mangroves	Human settlements	Population
Bahía Balandra	√	√	√	Medium-High	Medium	-25%	—	—
Bahía El Merito	√	√	√	Medium-High	Medium	-25%	—	—
Bahía Pichilingue	√	X	√	Medium-High	Medium	50%-75%	Port, industries, hotels, restaurants, houses.	200,000 of La Paz
Puntas Prieta and Colorada	√	√	√	Medium-High	Medium	50%-75%	Aquaculture complex, houses, restaurants and industries	200,000 of La Paz
El Zacatal	X	X	√	Medium-High	Low	75%	Urban area of La Paz	200,000 of La Paz
El Comitán	X	√	√	Medium	Medium	25%-50%	20 houses	100
El Mogote	√	√	√	Medium-High	Medium	25%	Construction in progress	—
Isla Espíritu Santo	√	√	√	Low	Medium-High	-25%	—	—
San Evaristo	X	√	X	Medium	Low	75%	Fishermen population	60
Isla San José	√	√	√	Medium-High	Low	-25%	—	—

TABLE 3 (CONTINUED). Mangrove localities in the Sea of Cortés coast of BCS.

Locality	Rhizophora mangle	Laguncularia racemosa	Avicennia germinans	Fishing intensity	Tourism intensity	% of dead mangroves	Human settlements	Population
Timbabichi	√	√	√	Medium-High	Low	-25%	Fishermen population	60
Agua Verde	X	√	X	Medium-High	Low	-	Fishermen population	172
San Cosme	X	√	√	Medium-High	Low-Medium	25%	Fishermen population and luxury hotel	20
Ligüi	X	√	X	Low-Medium	Low-Medium	75%	Fishermen population	200
Puerto Escondido	√	X	X	Medium-High	Medium-High	-25%	Port facility	—
Ensenada El Manglito	√	√	√	Low-Medium	Low-Medium	-25%	Fishermen camps	—
Puerto Escondido	√	X	X	Medium-High	Medium-High	-25%	Port facility	—
Ensenada El Manglito	√	√	√	Low-Medium	Low-Medium	-25%	Fishermen camps	—
Playa Armenta	√	√	√	Low-Medium	Low-Medium	-25%	Dirt road	—
Playa El Requesón	√	√	√	Low-Medium	Low-Medium	-25%	Palapas and latrines	—

TABLE 3 (CONTINUED). Mangrove localities in the Sea of Cortés coast of BCS.

Locality	Rhizophora mangle	Laguncularia racemosa	Avicennia germinans	Fishing intensity	Tourism intensity	% of dead mangroves	Human settlements	Population
Playa San Buenaventura	X	√	√	Low-Medium	Medium	25%	Small houses, stores, hotel and restaurant	—
Santa Bárbara	√	√	√	Low-Medium	Low-Medium	-25%	Construction of tourism development	—
Playa El burro	X	√	√	Low-Medium	Medium	25%	Houses on the beach and road over mangrove	—
Playa Santispac	√	X	√	Low-Medium	Low-Medium	—	—	—
Mulegé	√	√	√	Medium-High	Medium-High	25%-50%	City	53,000
San Lucas	√	√	√	Medium	Low-Medium	-25%	Houses, tourism and fishermen village, military headquarters	203
El Rincón	X	√	√	Low-Medium	Medium-High	-25%	Dirt road	—
La Mona	X	√	X	Low-Medium	Medium-High	-25%	Small houses own by tourism	8

concentrations 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 shorter period of time. Estuaries in Seri territory are in excellent conditions because development is scarce and the Seri survey their lands for unauthorized resource poaching. The mangroves along Canal del Infiernillo are particularly well protected, by both the traditional and the environmental authorities. Efforts and resources are being directed to decree this area protected an endeavor that will not only ensure the conservation of mangroves, but of other coastal ecosystems and will allow the continued provision of environmental services that benefit local communities.

Finally in Bahía de Kino, recently developed unplanned activities have caused serious environmental damages. Urgent restoration measures are needed to protect the resources left, to eventually restore natural conditions, and perhaps recover ecosystem services that have been lost, such as the maintenance of fisheries.

Human development in BCS has a more recent origin and the environment has not been as damaged. Nonetheless, recent accelerated population growth and increasing human activities are exerting pressures that are endangering the peninsular environment. The Sea of Cortés coast in this state has experienced 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; 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 like Mulegé or Loreto.

Along the Pacific coast of BCS, development has not yet been very intense, perhaps because the area is not as attractive for tourism and/or because the roads are scarce. Mangrove ecosystems in this coast are the largest in the state, and even though the northern limit of their distribution (Bahía de San Ignacio) is protected by UNESCO, the largest surface in the state represented by those of the Bahía Magdalena-Bahía de Almejas complex, is still without protection. Therefore, we consider that this area should be a priority for authorities, because it provides many goods and services from which both society and nature benefit. There are 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 the opposite coast or in Sonora, where pollution and scarcity of resources are the prevailing conditions of this once fisheries 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 the area 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 was useful to illustrate 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 by humans. The review of historical and socio economic information complemented this visual 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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Exploring Mexico's northwest, the Baja California Peninsula, its surrounding oceans, its islands, its rugged mountains, and rich seamounds, one feels diminished by the vastness and the greatness of the landscape while consumed by a sense of curiosity and awe. In a great natural paradox, we see the region's harsh arid nature molded by water through deep time, and we feel that its unique lifeforms have been linked to this desert and sea for thousands of years, as they are now.

These landscapes of fantasy and adventure, this territory of surprising, often bizarre growth-forms and of immense natural beauty, has inspired a wide array of research for over two centuries and continues to inspire the search for a deeper knowledge on the functioning, trends, and conservation status of these ecosystems in both land and ocean.

This book offers a compilation of research efforts aimed at understanding this extraordinary region and preserving its complex richness. It is a synthesis of work done by some exceptional researchers, mostly from Mexico, who indefatigably explore, record, and analyze these deserts and these seas to understand their ecological processes and the role of humans in their ever-changing dynamics.

Elisabet V. Wehncke

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