Human Alteration of the North Yucatán Coast, Mexico

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The north coast of the Mexican state of Yucatán, centered on the port of Progreso, has been substantially altered by humans over the past century or so. The barrier-lagoon complex, naturally fronted by long straight beaches, has been significantly altered by port and harbor improvements and also summer-home construction along the beachfront. As the shoreline has retreated because of both natural and human causes, structures such as groins and seawalls were built to combat this transgression of the sea. Hurricanes and winter storms have accelerated and geographically extended the volume and range of human modification of the shoreline. Today, a 20-km-long coastal reach can no longer be considered “natural.” Key words: coastal development, shoreline modification, hurricanes, Yucatán

Human modification of shorelines has been a research theme of geographers for many years (Johnson 1919; Davis 1956). In the 1980s, H. Jesse Walker (1981, 1984) investigated global impacts of structural modification. In the late 1980s, a comprehensive volume on artificial structures provided an overview of structural modification of shorelines throughout the world (Walker 1988). The impact of artificial structures upon adjacent natural beaches was documented at various venues, including Mexico (Gutierrez-Estrada et al. 1988). The specific role of recreation and tourism in leading to shoreline modification was the focus of two edited books in the 1990s (Fabbri 1990; Wong 1993) and has been a research theme of this author for many years (Meyer-Arendt 1987a, 1987b, 1990, 1991b, 1993, 1999, and 2001).

This chapter examines the north coast of Yucatán, with particular emphasis upon humans as agents of landscape change. Port and harbor improvements, along with summer-home construction, have been the major catalysts of shoreline modification, although hurricanes and other severe storms have helped accelerate degradation of the once-pristine coastline. The natural sweeping shoreline that attracted entrepreneurs and tourists has now been altered into a human-modified shorefront.
The Physical Setting

The north coast of Yucatán is composed of a beach-ridge plain perched on the limestone platform of the Yucatán Peninsula where it dips northward into the Gulf of Mexico (Meyer-Arendt 1993). This beach-ridge “barrier” is separated from the exposed-limestone mainland by a lagoon/mangrove swamp complex known generically as la ciénaga (lagoon/wetlands), and as the Estero Yucalpetén (estero = estuary) in the vicinity of Progreso (Figure 1). The beach-ridge plain varies in width, and around Progreso it approaches one km in width. Active primary dunes occur in natural areas of the beachfront, and dune heights of up to 3 m are found west of Chuburná Puerto (Figure 2). At the shoreline, the depth to limestone bedrock averages 3-4 m (Sánchez and Vera 1963). The shoreline is generally long and straight, except where headlands have been formed by small Pleistocene limestone outliers (Figure 3). These function as natural breakwaters and locally reduce wave energy (Sapper 1945; Edwards 1954).

The north Yucatán beach-ridge complex probably originated in a Holocene sequence of accretion and erosion similar to that along other reaches of the Mexican Gulf Coast (Psuty 1967; Stapor 1971; Tanner and Stapor 1971; and Tanner 1975). The multiple-ridge plain is indicative of a regressive phase of sand

![Figure 1. Location of the north coast of Yucatán and recent hurricane tracks.](image-url)
abundance and accretion, although transgression has prevailed in the historic period (Gutierrez 1983). The beach sands contain no quartz but high proportions of shell fragments (Isphording 1975), indicative of a nearshore source of the beach material. There is east-to-west longshore sediment transport, set up by longshore currents coming into the Gulf through the Yucatán Channel. Net westward longshore sediment transport rates of 30,000 m³/yr have been estimated for the shore zone east of Progreso (Sánchez and Vera 1963; SCT 1986).
Wave energy is relatively low along the north coast of Yucatán, except during storm events. Because of its north-facing orientation, the north coast is more prone to winter storms associated with *nortes* (northers) than to tropical cyclones. On average, 20–25 nortes reach Yucatán during the winter season (Vivó 1964; Mosiño and García 1974), and the strongest of these cause erosion and lagoonal flooding. In Tabasco, Psuty (1967) observed a pattern of seasonal shoreline change in which wider summer beaches give way to narrower, nortedominated winter beaches. Hurricanes approach or cross the Yucatán Peninsula on an east-to-west track usually once a year (Wilson 1980), but only rarely are they of the magnitude (category 5) of Hurricane Gilbert of 1988 (Meyer-Arendt 1991a; 1991b) or even Hurricane Isidore of 2002 (category 3). Hurricanes have been known to stall for a prolonged period in the central or northern Gulf of Mexico and initiate a reversal of currents along the north Yucatán coast. This reversal, driven by an uncommon west wind called *chikin-ik* by the native Mayans, may cause erosion along localized reaches that normally lie in sheltered locations such as in the lee of natural headlands or artificial structures (Meyer-Arendt 1993).

The north coast of Yucatán has been in a transgressive phase since the late 1800s, although the sandy headlands associated with the limestone outliers appear to be relatively stable. Cliffling of dunes is visible in areas where dunes have not been altered, notably east of Uaymitún and west of Chuburná Puerto. Beachfront coconut palms are periodically uprooted because of wave action. Shoreline retreat of 200 m over a 110-year period has been reported in the literature (Gutierrez 1983), but this seemingly high rate may have been estimated from inaccurate historic charts (see, for example, Antochiw 1994).

Analysis of aerial photographs revealed much variability in shoreline change along the north coast of Yucatán since the 1940s. Shoreline retreat rates were found to be relatively low, especially when compared to rates typical of the northern Gulf of Mexico. Both temporal and spatial variability in shoreline-change rates were apparent by comparing the aerial photos. Although the scale of the photography (ranging from 1:25,000 to 1:75,000) precluded accurate measurement in areas of little change, rates of 0.3 to 0.6 m/yr were measured for the 1948-78 period west of Progreso, and up to 1.0 m/yr downdrift of the jettied entrance to the Yucalpetén safe harbor (Meyer-Arendt 1987b). East of Chixulub Puerto (historically the port for Chixulub, of Cretaceous impact crater fame) the shoreline position was approximately the same in 1948 and 1991. However, fluctuations were noted in intermediate sets of photos. Short-term phases of accretion appeared to alternate with short-term phases of erosion.

**Coastal Urbanization in Yucatán**

Although the Maya civilization created immense and complex cities throughout the Yucatán peninsula, coastal settlements consisted primarily of fishing or salt-gathering outposts. Such was the case along the north coast at the
time of Spanish colonial rule. In 1856, Mexico began construction of a new port, named Progreso de Castro, 32 km due north of Mérida and more easily accessible than the older colonial port of Sisal (Moseley and Terry 1980). By 1861, a road to the new settlement had been extended from Mérida (Ferrer 1945). The first wharf was finished in 1870, and train service between Mérida and Progreso began in 1881. Although the main function of the railroad was to facilitate the export of henequén (or sisal, a fiber used for making binder twine), Mérida residents soon recognized the potential of the beaches for recreation, and wealthy families began to build opulent summer residences (casas veraniegas) (Frías and Frías 1984; Paré and Fraga 1994).

The coastal landscape changed considerably in the first half of the twentieth century as a result of tourism (Meyer-Arendt 1987a). In 1928, the Mérida-Progreso road was paved, and a malecón, or beachfront promenade, was constructed along the shorefront of Progreso east (updrift) of the port facilities where several wharfs were located (Figure 4). As the malecón area filled in with tourism infrastructure and summer homes, the locus of vacation housing soon spread eastward toward Chicxulub Puerto. Roads were built to Chicxulub Puerto in the east and Chelem in the west, and sand roads were extended eastward to Dzilam de Bravo (70 km east of Chicxulub Puerto) and westward to Chuburná Puerto. By 1945, Chicxulub Puerto was a well-known playa de verano (summer beach), and several of the outlying fishing and salt-producing settlements were considered lugares de recreo (recreation spots)(Ferrer 1945).

A boom in coastal development began in the late 1940s. A 2-km-long concrete wharf at Progreso replaced the old wooden wharf in 1947, and summer-home urbanization extended east and west from Progreso (Meyer-Arendt...
The beaches closest to Progreso were the most popular for development because of the availability of utilities and proximity to Mérida. Summer homes lined the beachfront eastward to Chicxulub Puerto by the late 1940s. A secondary direction of expansion was westward toward Chelem, a traditional Mayan fishing settlement. By the 1970s, a contiguous urban strip—from Chuburná Puerto to Chicxulub Puerto—had emerged (Meyer-Arendt 2001). A condominium “boom” hit the north coast of Yucatán beginning in the late 1980s (Meyer-Arendt 1999), and land use began to intensify. This trend continued throughout the 1990s and into the early 2000s.

**Structural Modification of the Shoreline**

Structural modification and environmental impacts along the north Yucatán coast are traced back to the initial development of Progreso as a port city (Meyer-Arendt 1993). When the first wharf was constructed in 1870, the western (downdrift) zone experienced shoreline erosion. Dutch engineers designed a 2-km-long replacement wharf in 1947 to allow throughflow of water and sediments (Campos 1990) (see Figure 4), but downdrift shoreline erosion continued. As the west side of Progreso became to be perceived as being negatively impacted by the port, the east side remained pristine and thus attractive as the earliest zone of summer-home and other tourism development. The lower real-estate values of the west side attracted seasonal residents of more modest incomes, and they soon encountered threats to their properties from wave action. Not surprisingly, the first groins were built in Yucatán to protect private beachfront residences and properties.

Groins became popular in Yucatán in the 1950s and 1960s, because they were perceived as an effective means of trapping longshore sands and reducing erosion elsewhere in the world, including the United States, during that period. The first rock-and-timber groins (espigones), locally known in Yucatán as “spurs” (espolones), were constructed by homeowners in Chelem and Chicxulub Puerto in the late 1950s (Sánchez and Vera 1963). These espolones, or “folk groins,” were not designed very well; hence they weren’t very effective and accelerated downdrift erosion. In 1964, government engineers designed and installed a set of groins along the Progreso malecón to reclaim a beach that had narrowed over the years as a result of storm activity (Meyer-Arendt 1987a). These engineered espolones proved to be relatively successful in trapping sand, and Yucatán summer-home owners tried to replicate their success.

In 1968, a safe harbor (puerto de abrigo) for the Mexican navy and Progreso fishing fleet was created and the port of Yucalpetén established. A navigation channel was excavated through the beach-ridge plain (which forced a relocation of the Chelem highway), and tetrapod-and-riprap jetties (escolleras) were built to prevent sediments from filling in the channel (Figure 5). The east jetty extends over 500 m seaward from the position of the natural coastline, and much sand
has accreted since 1968 (a hotel and marina were built in this accretion zone in the late 1980s). Downdrift of the west jetty, however, shoreline retreat immediately set in—as much as 30 m within a few years, and widespread construction of espolones began. The Yucalpetén jetties initiated a phase of erosion that has not abated to this day.

Unlike the groin field fronting the Progreso malecón, the espolones extending westward from the Yucalpetén jetties were neither authorized nor professionally engineered (Figures 6 and 7). Although construction permits are (and were) legally required, beachfront property owners perceived groins as their only hope of saving their property. Individuals built espolones on a piecemeal basis without obtaining permits or even informing their neighbors. The village council (comisario ejidal) of Chelem did not initially object to the shoreline armoring, nor did any regional, state, or federal authorities (perhaps because it was realized that state and federal port and harbor improvements caused the problem).

Continued groin construction gradually shifted the locus of erosion westward, and, as it did so, the leading edge of espolón construction moved westward also. In 1984, 178 espolones were documented along an 8.8-km stretch from Yucalpetén to Chuburná Puerto, an average of one every 50 m (Meyer-Arendt 1987b). By the mid-1980s, the cause-and-effect relationship between groins and erosion was recognized, and officials in Chuburná Puerto removed several espolones and began to enforce the existing ban on their construction (Meyer-Arendt 1987a). It was noted that over 75% of the vacation home properties west of the Yucalpetén jetties encroached onto the 20-m-wide federal
beach easement known as the *Zona Federal Marítimo Terrestre*, or Federal Coastal Zone (Merino 1987) (Figure 8).

During the 1990s and early 2000s, other methods of erosion control were experimented with, including offshore submerged breakwaters (near the Chelem-Chuburná boundary) and dome-like “artificial reefs” (Progreso). Neither of these appeared to be very successful, and property owners continued to construct the inexpensive espolones with little regard for state and federal legislation.
Whereas the Yucalpetén-to-Chelem groins were built in response to erosion created by port and jetty construction, east of Progreso the causal relationships were not so clear. In Chicxulub Puerto, a short “mosquito-fleet” wharf may have contributed to downdrift shoreline erosion and associated groin construction in the late 1950s and early 1960s. East of Chicxulub Puerto, however, there was no record of any structural modification until the area began to fill in with vacation homes and condominiums. The first groin was built in the early 1990s, perhaps in response to erosion stimulated by Hurricane Gilbert in 1988 or by the 5-km extension to the 2-km-long Progreso wharf, now the world’s longest wharf. (Unlike the original 1947 wharf that was arched and allowed throughflow of currents, the 5-km extension was composed mostly of riprap, cement, and asphalt, and many local residents believe that currents are deflected landward and have accelerated the rate of erosion in this area.) By 2000, a 6-km-long stretch east of Chicxulub Puerto had become armored with approximately 100 espolones, causing the coastal landscape to resemble the erosional, debris-strewn beachfront of Chelem (Meyer-Arendt 2001) (Figure 9).

**Hurricanes along the North Coast of Yucatán**

The Yucatán Peninsula is impacted by one hurricane or tropical storm a year on the average (Wilson 1980), but because of the north coast’s orientation—facing north and in the lee of prevailing Caribbean and Atlantic tropical cyclones—the frequency of direct strikes is much lower. One of the first references to hurricanes along the north Yucatán coast is contained in a report of a 1903
hurricane, which caused extensive roof damage to homes, rearranged boats on the beach, and topped trees in Progreso (Frías and Frías 1984). Following the lagoonal flooding that resulted from the hurricane, federal officials proposed draining the lagoon to minimize danger from disease outbreaks and also building a seawall along the entire shoreline to “impede the invasion of water” (Frías and Frías 1984). In 1916, high waters in the lagoon again threatened to cause serious flood damage in Progreso, and a zanja (ditch) was cut through town to allow the lagoon waters to drain out. This ditch functioned for several years until it eventually sealed (Frías and Frías 1984). A 1944 hurricane caused significant shore erosion west of the Progreso wharf, and half a residential block was destroyed. A second zanja was dug through the barrier to drain the high lagoonal waters (Meyer-Arendt 1987a). Geographer Clinton Edwards, on a reconnaissance in 1954, noted that many of the cocales contained open spaces where palms were obviously uprooted by storm activity (Edwards 1954). Since the 1980s, hurricanes and their impacts have been more closely documented, including by this author (e.g. Meyer-Arendt 1991b, 1993).

Hurricane Juan caused much shorefront damage in October 1985, only days after residents in the Chelem/Chuburná area were interviewed about their perceptions of shoreline erosion and potential storm impacts. As Hurricane Juan formed in the western central Gulf of Mexico, local Mayan fishermen recounted significant shoreline retreat since summer homes first appeared, but most summer-home owners felt there had not been any problems. Although Juan made landfall in south Louisiana as a minor hurricane, some of the greatest damage occurred along the north coast of Yucatán. Hurricane Juan was nearly

![Figure 9. The shoreline near Chicxulub Puerto, 2002.](image)
stationary over the Gulf of Mexico for over a week, and this led to elevated water levels around the entire perimeter of the Gulf. Over the course of a week, the author witnessed progressive sea-level rise and beach erosion, especially at vulnerable groin locations, where human-caused shore erosion was already evident. Extensive undercutting of summer-home foundations took place, and the façade of the Hotel Costa Azul in Chelem (where the author enjoyed the beach view while it lasted) collapsed into the sea (Meyer-Arendt 1991b).

Within a few years of Hurricane Juan, new structural responses to shoreline erosion had been implemented along the north coast, particularly in Chelem. Unlike before, when espolones were regarded as the solution to combat shoreline retreat, the new strategy was foundation reinforcement or seawall construction. Both raw material (limestone) and labor are relatively inexpensive in Yucatán, and much cement was mixed and placed between 1985 and 1988. The Hotel Costa Azul repaired its façade (sans balconies) and reinforced its foundation, which essentially functioned as a seawall. Severe nortes in the late 1980s reinforced the building of private seawalls, and from Yucalpetén to Chelem, approximately one-sixth of the beachfront homes had added seawalls by 1988 (Meyer-Arendt 1991b) (Figure 10).

All the new shoreline structures were put to the test when Hurricane Gilbert passed by in 1988. Gilbert had slammed into Cozumel Island as a Category 5 hurricane with sustained wind speeds of over 145 knots (268 km/hr), air pressure below 900 mb, and a storm-surge height estimated at between 4.5 and 6.0 m (Meyer-Arendt 1991a). Gilbert thus joined the Florida Keys Labor Day
Storm (1935), Hurricane Camille (1969), and Hurricane Andrew (1992) as the only Category 5 storms to make landfall in North America in the twentieth century. As Hurricane Gilbert tracked WNW across the Yucatán Peninsula, the eye of the storm passed just south of Progreso early in the evening of September 14 with wind speeds still about 100 knots, or 185 km/hr (Meyer-Arendt 1991b). A storm surge—estimated at between 2- and 3-m high—caused much overwash and breaching. Property damage resulted from wind and wave activity and also because of lagoonal flooding. Near Progreso, however, the jettied channel to the Yucalpetén safe harbor functioned as an outflow valve for elevated hurricane waters in the ciénaga.

Damage to property was extensive. The Hotel Costa Azul was reduced to rubble as were practically all shorefront summer homes within the study area. Shore-normal roads functioned as conduits for the Gulf waters to cross the barrier to the lagoon, resulting in much road-scouring and foundation undermining. Progreso’s popular malecón was severely damaged, as was the 5-km-long wharf extension. Overwash processes dominated along the wide, sparsely developed beach-ridge barrier complex between Chicxulub Puerto and Telchac Puerto. However, Gilbert cut a major breach across the barrier complex where the entrance to the Telchac Puerto safe harbor had been dredged into the beach ridges in 1977 (Figure 11). As at Yucalpetén, the connection between the sea and lagoon allowed more rapid outflow and probably minimized flood hazards along the lagoon edges.

Although Hurricanes Roxanne (Avila 1995) and Dolly crossed the Yucatán Peninsula in 1995 and 1996, respectively, the first significant hurricane to affect the north Yucatán coast since Gilbert was Hurricane Isidore (Isodoro) in 2002,

Figure 11. Entrance to Telchac Puerto safe harbor.
coincidentally while this author was updating his field research. Tracking westward just north the Yucatán Peninsula, Isidore turned southward to make landfall as a Category 3 storm just east of Progreso early on September 23, 2002. Wind speeds were estimated at 110 knots (over 200 km/hr) just prior to landfall, and—like Gilbert—the storm surge at Progreso was on the order of 2-3 m. The storm track moved inland, caused extensive wind and flooding damage in Mérida, made a loop, and then exited the peninsula to head north across the Gulf. Isidore spawned much rainfall, which continued for four or five days (long after landfall was made in Louisiana). Most of the dozen or so deaths were attributed to flooding or electrocution. Coastal impacts included foundation undermining and structural collapse of numerous beachfront homes (Figure 12). As during Gilbert, a ship washed up on the beach in Chelem (in background on Figure 10).

Ironically, the first beach nourishment ever undertaken in the area was underway at the time of hurricane landfall. Along the public beach fronting the Progreso malecón, nourishment material had been excavated from the wide beach west of the Progreso wharf and trucked to the fill site. The project was nearly complete, and bulldozers were grading the beach only two days before Isidore made landfall (Figure 13). The public beaches west of the Yucalpetén jetties, where a government-owned resort complex had been built, were soon to be nourished. A small dredge was about to begin pumping sand from a fill site east of the jetties to nourish this critically eroding stretch of shoreline. It is assumed that Isidore caused only minor delays in completion of this project.
Conclusions

Along the north coast of Yucatán, a 20-km stretch of shoreline has been altered by humans to a large degree. Wharves and piers have been built out into the shallow nearshore waters, so much so that the Progreso wharf is the longest in the world. Excavations have been made into the beach-barrier complex, both to drain lagoonal flood waters and also to provide access to safe harbors. In areas affected by port and harbor improvements, downdrift erosion has resulted in the construction of groins and other structural modifications that have, in turn, accelerated the problem of beach erosion even further downdrift. The Yucalpetén and Chelem shorefronts still today exhibit a post-hurricane landscape of concrete rubble instead of a sand beach. Lagoonal shorelines, although not a focus of this article, have experienced extensive reclamation activities (Paré and Fraga 1994). The latest human modification—beach nourishment—was temporarily interrupted by the landfall of Hurricane Isidore in 2002.

Human-altered shorelines need not necessarily be bad in terms of environmental and aesthetic impacts, and the world is full of examples of positive improvements. In this corner of Mexico, however, there has been severe degradation. The degradation of the Yucalpetén and Chelem beaches has resulted from both port/harbor construction and ineffective groin- and seawall-building efforts, and both government agencies and private landowners must share the responsibility. East of Progreso, government agencies cannot be blamed (unless the wharf prolongation is indeed found to be partly responsible for accelerated shoreline erosion). Here seasonal beachfront residents are responsible for the recent (1990-2002) degradation of the beaches. Poor placement of vacation houses, an inability to accommodate a naturally fluctuating shoreline, and a predisposition to build espolones are all to blame for the physical and aesthetic deterioration of the beachfront. Historic photos
have shown that this shoreline is fairly stable and that phases of erosion and accretion are normal. The construction of over 100 groins east of Chixulub Puerto since 1990 has made this once pristine beach look like the disaster of a shoreline west of Progreso. Unfortunately, recent observations confirm that both the leading edge of coastal development and the leading edge of groin construction are moving eastward.

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