Shoreline Changes along the North Yucatán Coast

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Abstract

The north Yucatán coast in the vicinity of Progreso, consisting of a multiple beach ridge barrier complex backed by a wetland-fringed lagoon, has undergone many changes since the late 19th century. The sand-and-shell beaches are characterized by east-to-west longshore sediment transport but also shoreline retreat ranging from 0.5 to 1.0 m/yr. Natural coastal erosion is attributed to storm passage associated mostly with Arctic cold fronts (nortes) but also with occasional hurricanes. As a result of both port development and recreational urbanization, extensive shorefront engineering has taken place, and erosion rates locally have increased. Jetties constructed at the Yucalpetén safe harbor entrance caused increased downdrift erosion at the recreational communities of Chelem and Chuburná, and property owners responded by illegally placing groins (espollones) along the beach, a federal public easement. As the locus of illegal groin construction gradually moved westward, so did the zone of critical erosion. By the mid-1980s, local officials recognized the haphazard groins as causing increased erosion, and removal of groins had begun when Hurricane Gilbert struck in September 1988. Although the hurricane led to sand accretion along the north Yucatán beaches, most beachfront structures and groins were severely damaged by wind and waves. Four years later, the cleanup process continues. Between past engineering modifications and storms such as nortes and Hurricane Gilbert, the north Yucatán coast has suffered much environmental and aesthetic degradation, and more effective coastal management has been called for.

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Introduction

The sand/shell beaches of the north Yucatan coast have comprised a popular destination for Mexican tourists and weekend recreationists since the great henequen boom of over a century ago. Since World War II, beachfront urbanization has spread outward along the coast from the nodal point at the Port of Progreso, and a 20-km reach of contiguous housing has resulted. Although the shoreline exhibits signs of natural erosion (much of it resulting from winter cold fronts, or nortes), human modifications to the shorefront have been much more significant in causing locally severe erosion problems. Human responses to shoreline erosion, mostly in the form of groins— or espollones, have only seemed to accelerate such problems. It is the aim of this paper to present an overview of shoreline changes along Yucatan's north coast by examining the following aspects: 1) the natural setting, 2) the history of shorefront development, 3) the history of structural shorefront modification, 4) the impacts of Hurricane Gilbert in 1988, and 5) the present patterns of shoreline change and human adjustments to shoreline erosion.

Natural Setting

The littoral environment of the north Yucatan coast consists of a beach ridge plain accreted onto the limestone platform of the Yucatan peninsula where it dips gently into the Gulf of Mexico (Figure 1). This plain is separated from the rocky “mainland” by a lagoon/mangrove swamp depression generally referred to as La Cienaga, but known as the Estero de Yucalpetén in the vicinity of Progreso. This shallow lagoon system, which extends across most of the northwestern Yucatan peninsula and has natural connections with the sea south of Celestún and east of Dzilam de Bravo, is noted for its variety of waterfowl, fish, and salt-gathering potential (Edwards, 1954; Wilson, 1980). The beach ridge plain varies in width from one or two ridges east of Telchac Puerto and west of Chuburná Puerto to as many as 12 in the vicinity of Progreso, where the plain approaches one km in width. Active dunes are found in unmodified zones of the beachfront, and dunes up to 3 m high may be seen at Chuburná Puerto. The shoreline is generally long and straight, except where interrupted by small Pleistocene limestone outliers, some of which function as natural breakwaters and locally reduce wave energy (Sapper, 1945) (Figure 2). Near Dzilam de Bravo, wave energy decreases and the sand beach is replaced by shorefront swamp. Nearshore beach ridge development is occasionally seen by emergent vegetated bars, and interbar deep muck extends at least 100 m seaward (Edwards, 1954).

The geologic history of the Yucatan shoreline has not yet been thoroughly documented, although a Holocene history of accretion and erosion—documented for other reaches of the Mexican Gulf Coast (Psuty, 1967; Stapor, 1971; Tanner and Stapor, 1971; Tanner, 1975)—may be inferred. The multiple-ridge plain reflects a Holocene phase of sand abundance and accretion, but now a sand deficit and erosion prevail. The beach sands are devoid of quartz sand and contain high proportions of shell fragments (Isphording, 1975), indicative of a nearshore source of the beach material. There is a trend of east-to-west longshore sediment drift, a function of the longshore currents coming into the Gulf through the Yucatan Channel, and several westward-recurving sand spits are found. Although longshore sediment transport rates have not been calculated, estimates could easily be made on the basis of net sediment accretion updrift of jetted harbor entrances (Gutierrez-Estrada et al., 1988).

In spite of past trends of regression and accretion, the north Yucatan coast is now characterized by overall transgression. Clipping of dunes is common along several reaches—especially east of Progreso and near Chuburná Puerto—and beachfront coconut palms are occasionally uprooted. Shoreline erosion rates of 1.8 m/yr over a 110-year period have been reported (Gutierrez, 1983), but retreat rates averaging between 0.3 and 0.6 m/yr were found for Progreso and vicinity for the 1948-1978.
period (Meyer-Arendt, 1987b). Most shoreline erosion has occurred
downdrift of jettied harbor entrances, especially at Yucalpetén just west
of Progreso, where rates of 0.9 m/yr were found for the 1948-1978 period
(Meyer-Arendt 1987b). Although the "normal" shoreline retreat rates
are relatively low—especially in comparison to rates of northern Gulf of
Mexico shores—there is much seasonal as well as annual variability.

Because of its geographic
orientation—facing north and in the lee of the peninsula, the north
Yucatán coast is much more vulnerable to onslaught by wintertime
nortes than by summer or fall hurricanes. On the average, 20-25 nortes
reach Yucatán during the winter season (Mosiño Alemán and Garcia,
1974; Vivo, 1964), and some of these cause erosion and severe lagoonal
flooding. Psuty (1967) noted a pattern of seasonal shoreline change in
Tabasco, Mexico, whereby more seaward summer beaches give way to
norte-dominated winter beaches. Hurricanes pass over or near the
Yucatán peninsula on a east-to-west track usually once a year (Wilson,
1980), but often nearshore water levels are depressed rather than ele-
vated along the north coast. Hurricane may refract south into the shore
and cause severe damage, but this is infrequent and has not occurred
since 1944 (Frias and Frias, 1984). Occasionally, a hurricane stalls for a
prolonged period in the central or northern Gulf of Mexico and initiates
a reversal of currents along the north Yucatán coast. This reversal,
driven by the rare west wind called Chikin-Ik by the Maya, may cause
erosion along localized reaches that normally lie in sheltered lee loca-
tions.

The Yucatán limestone platform dips very gradually into the Gulf
of Mexico and the shallow nearshore zones precludes significant levels
of wave energy, except during storm events. Although the "normal" shoreline retreat rates
are relatively low—especially in comparison to rates of northern Gulf of
Mexico shores—there is much seasonal as well as annual variability.

Shorefront Development

The north Yucatán coast was settled by the Yucatecan Maya long
before arrival of the Spanish, but significant development did not begin
until the mid-1800s (Meyer-Arendt, 1987a; 1991b). Salt production and
fishing were the major aboriginal economic activities (Eaton, 1978), and
these activities are still quite important to the modern descendants of the
Maya. Salt production is evident at several locales east of Telchac Puerto,
and a major industrial saltworks exists at Las Coloradas. The original
stimulus for modern coastal development was commerce, specifically
the development of port facilities of export goods such as henequén.

The seaport for Yucatán during most of the colonial period was
Campeche, located 200 km southwest of Mérida. In 1810, the official port
was shifted to Sisal, a fishing settlement about 50 km northwest of
Merida (Moseley and Terry, 1980). Sisal frequently was inaccessible during
the rainy season, and as the export market for henequén increased in
the 1830s, the need for a new port became apparent. (Used for binder
twine, henequén had become known as sisal, after the town stamp im-
printed on the bales of fiber.) In 1856, construction began at a new port,
named Progreso de Castro, 32 km due north of Mérida. By 1861, a crude
road from Mbrida to the new settlement had been constructed (Ferrer,
1945). The first wharf was completed in 1870, and train service between
Mérida and Progreso began in 1881.

Although the primary function of the railroad was to facilitate the
export of henequén, Mérida residents quickly discovered the beaches,
and wealthy families began to build summer residences (casas
veraniegas). By the early 1900s, Progreso boasted of three hotels and had estab-
lished a reputation as a popular local vacation destination (Frias and
Frias, 1984; Meyer-Arendt, 1991b). In 1928, the Mbrida-Progreso highway
was paved, and a malecón, or beachfront promenade, was constructed
east (updrift) of the docks, where restaurants and dance clubs were con-
structed along the landscaped beachfront drive. Opulent summer homes
came to line the Progreso shorefront, and the direction of expansion was
eastward toward Chicxulub Puerto.

A boom in beachfront development began after the end of World
War II. A 2-km-long concrete wharf at Progreso was completed in 1947,
and shorefront urbanization extended east and west from Progreso. The
beaches closest to Progreso remained most popular for development be-
cause of the availability of utilities and proximity to Mérida. After
Progreso's beachfront filled in with summer homes by the 1950s,
Chicxulub Puerto became targeted for vacation home development. A
secondary direction of expansion, in the latter 1950s, was toward Chelem.
Because of its location downdrift of the port of Progreso, Chelem became
more of a middle class resort (Meyer-Arendt, 1987a). Vacation home development continued throughout the 1970s and 1980s, and a contiguous urban strip—from Chuburná Puerto to Chicxulub Puerto—has emerged (Meyer-Arendt, 1990) (Figure 3).

**Structural Modification of the Shoreline**

The adaptation of coastal residents to a storm-prone environment such as the north Yucatan coast has been accompanied by extensive landscape modification. The impoundment of lagoonal waters for purposes of solar salt production has been one such long-term modification. Periodic inundation of coastal settlements resulting from lagoonal flooding stimulated environmental modification by the early twentieth century, when ditches (zanjas) were first cut through the beach ridge plain in the vicinity of Progreso to allow high lagoon waters to drain into the Gulf (Frias and Frias, 1984; Meyer-Arendt, 1991b).

As to impacts upon shoreline processes, the extensive port modifications at Progreso—from original wooden docks to the modern 4-km long concrete-and-ripnrap wharf—have all accelerated downdrift shoreline erosion because of (at least partial) interruption to longshore sediment drift. The zone downdrift from the Progreso pier has historically experienced the highest local rates of erosion, and a 1944 hurricane destroyed half a residential block in that area. Perhaps not by coincidence, the earlier thrust of beachfront recreational urbanization was to the east.

The earliest structural response to shore erosion was a series of rock-and-timber groins (espolones) designed by government engineers and installed along the Progreso malecón in 1964 to maintain sand on the beach for recreationists (Meyer-Arendt, 1987a). The espolones, still in place today, proved to be relatively successful in trapping sand and widening the beach, at least in the short run.

In 1968, a safe harbor (puerto de abrigo) for the Progreso fishing fleet—christened the port of Yucalpetén—was opened because of lack of adequate docking space as well as protection from storm waves. The port was created out of the backbarrier lagoon (which has forced a relocation of the coastal highway to Chelem), a channel entrance was excavated through the beach ridge plain, and jetties (escolleras) built to preclude sediment infilling. The updrift jetty extends over 500 m seaward from the position of the natural coastline, and much sand has accreted along the updrift side (where in 1987 a luxury hotel and marina were built).

Although the storm-protected safe harbor of Yucalpetén has provided a base for the Mexican navy, the Progreso fishing fleet, and a growing seafood processing industry, the opening of the channel has led to many negative environmental impacts. First, the downdrift shoreline began to retreat rapidly—as much as 30 m. Second, widespread construction of espolones began. Unlike the groin field at the Progreso malecón, the groins extending from the Yucalpetén jetties to west of Chelem were neither authorized nor professionally engineered. Although construction permits were legally required, beachfront property owners perceived groins as a means of saving their property and individually built espolones on a piecemeal basis without obtaining permits (Figure 4). By 1985, over 75% of the vacation home properties west of the Yucalpetén jetties encroached within the 20-m wide federal beach easement (Zona Federal Marítimo Terrestre, or Federal Coastal Zone [Merino, 1987]). Moreover, continual groin construction gradually shifted the zone of local downdrift erosion ever westward. In response, the leading edge of...
Espolón construction has shifted westward also. During a 1984 aerial survey, 178 espolones were noted along a 8.8-km stretch from Yucalpeten to Chuburná Puerto, yielding an average of one every 50 meters (Meyer-Arendt, 1987b). Groin density is highest between the Yucalpeten jetties and Chelem. By the early 1980s, the cause-and-effect relationship between groins and erosion was recognized, and Chuburná Puerto officials formally complained that espolón construction had accelerated shoreline erosion within their jurisdiction. By April 1985 the existing ban on unauthorized groins became more actively enforced, and several groins were removed from Chuburná Puerto beaches (Meyer-Arendt, 1987a).

In other reaches of the north coast, structural emplacements were (and are) much more localized and less dense. Espolones were constructed on a piecemeal basis east of the Progreso malecón and extending into Chicxulub Puerto, but the density was much lower. The jettied Yucalpeten safe harbor, however, served as a model for other coastal fishing communities, and three more safe harbors were constructed in the study area: Dzilam de Bravo (1975), Telchac Puerto (1977), and Chabihau (1990). Outside the study, similar harbors were built at El Cuyo (1979) and Celestún (1980) (Gutierrez-Estrada et al., 1988). In all cases, a pattern of updrift accretion and downdrift erosion resulted, but in none of the harbors has the downdrift erosion impacted beachfront urbanization as it has at Chelem.

During initial extensive field surveys in the mid-1980s, summer home owners in the Chelem/Chuburná area were interviewed to gain knowledge of their perceptions of shoreline erosion, potential storm impacts, and the effectiveness of groins. Not surprisingly, longterm residents were well aware of hazards, retreating shorelines, and the ineffectiveness of groins, and many told (unsubstantiated) tales of the coastline being 100 m seaward of its present location. Most seasonal residents (almost all natives of Mérida) did not share such perceptions, even in the days prior to Hurricane Juan in late October 1985 (Meyer-Arendt, 1987a). Before striking the Louisiana coast, Juan stalled over the Gulf of Mexico for over a week, causing elevated water levels over the entire Gulf and a counterclockwise circulation pattern which led to one of the rare Chikin-Ik (westwind) conditions. Over the course of a week, the beach sands were eroded, and house foundations became exposed to waves. Extensive undercutting of summer home foundations took place, and the façade of the Hotel Costa Azul in Chelem (where the author was staying) collapsed into the sea.

A field survey in 1987 revealed that new structural responses to shoreline erosion had been implemented, particularly in erosion-prone Chelem. Unlike previously, when espolones were regarded as the solution to combat shoreline retreat, the new strategy was one of personal property protection by foundation reinforcement. Most of the Hurricane Juan damage—which primarily had been triggered by foundation undermining—was repaired via the infusion of cement, and several home owners also built seawalls at the seaward limits of their property. (As before, this construction took place within the 20-m federal beach easement and was therefore illegal.) The Hotel Costa Azul had repaired its façade (sans balconies) and reinforced its foundation, directly on the beach. Approximately one-sixth of the beachfront homes between Yucalpeten and Chelem had added seawalls by 1988 (Meyer-Arendt, 1991b).

Impacts of Hurricane Gilbert

In 1988, Hurricane Gilbert struck the northeast Yucatan peninsula as a Force 5 hurricane, only the third such storm to do so this century. As Hurricane Gilbert tracked WNW across the Yucatan peninsula, the eye of the storm almost directly passed over Progreso early in the evening of September 14th (local time). Wind speeds were estimated at about 100 knots, or 185 km/hr (Clark, 1989), and damage in Mérida was extensive. On the north coast, winds and waves dominantly out of the northeast drove a storm surge of about 2-3 m across the coastal zone, causing extensive overwash and breaching in narrow areas (Meyer-Arendt, 1991a). A detailed synopsis of hurricane damage in Yucatan has been reported in previous publications (Dixon, 1991; Meyer-Arendt, 1991b), and will only be briefly summarized here.

The most severe impacts in terms of structural damages and morphologic changes took place in two distinct zones: the highly developed Progreso area (Figure 5) and the narrow beach ridge plain east of Telchac Puerto (refer to Figure 1). In the already erosion-stressed and
of Telchac Puerto (refer to Figure 1). In the already erosion-stressed and ineffectively armored coastal reach downdrift of the Yucalpetén jetties, damage to the limestone-construction vacation homes was severe. East of Telchac Puerto, the narrow barrier (and the coastal highway) was breached at numerous locations, and the extensive flooding of the salt production ponds effectively eliminated the next dry season harvest. In the communities where summer homes had been constructed along the beach, there was similar widespread destruction by wave activity and breaching. Hurricane Gilbert also cut a major channel across the beach ridges at the entrance to the Telchac Puerto safe harbor. Elsewhere, damage was considered moderate because of varying combinations of wide beach ridge plain and sparse development.

In spite of the extensive physical and structural damage, a post-storm survey in October 1988 revealed that the sand beach actually had widened as a result of the storm, as much as 10-15 m in places (Figure 6). Whether this reflected an onshore placement of nearshore sediments or accretionary processes associated with longshore drift was not readily determined. This is in contrast to the east coast of the Yucatan peninsula, where 30-50 m of shore retreat was noted (Dixon, 1991).

In an October 1992 survey of the north Yucatan coast, a much environmentally and aesthetically degraded landscape was found, especially in those areas where development had taken place too close to the shoreline and also where groin density was greatest. Not only was recovery from Hurricane Gilbert not yet completed in the zones of greatest structural damage (notably Chelem and Chabihau), but the post-storm accreted beach had disappeared and active shoreline erosion was again evident (Figure 7). In the absence of any comprehensive coastal management plans, several responses to erosion (and, unwittingly, sea level rise) have taken place. At historically erosion-prone Telchac Puerto, damaged beachfront structures have been completely removed and the downtown waterfront has been armored with a seawall (Figure 8). At
Chelem, individual property owners have rebuilt their homes in more setback locations (Figure 9). This gradual "setting back" of structures in response to shore retreat and sea level rise has been proposed for U.S. shorelines (Titus, 1990), and perhaps the reconstruction of Chelem is indicative of future trends along similar shorelines around the world.

**Figure 9. Setback Reconstruction at Chelem, October 1992.**

Within a broader framework of coastal management, a much improved comprehensive plan for the north Yucatan coast is needed. Credit must be given to the Yucatecan and Mexican governments for incorporating large blocks of undeveloped coastal land as natural parks (Merino, 1987), where "sustainable tourism" presently is encouraged and closely monitored (Murguia Rosote et al., 1991). However, along the recreationally urbanized-and urbanizing-portions of the north coast (the entire reach from Chuburná Puerto to Dzilam de Bravo), effective management has been minimal.

Several conclusions can be made on the basis of past trends:

1) Shoreline erosion rates have not been uniform along this 100-km stretch of the north Yucatan coast.

2) Erosion, whether "natural" or storm-induced, has been most severe where beach ridges are narrowest and where human impacts—in the forms of piers, jetties, seawalls, and groins—have been greatest.

3) Haphazard groin (espolón) construction has not only not effectively trapped longshore sands and preserved beaches, but it actually has led to increases in shoreline erosion.

In view of these conclusions, several management recommendations must be made before past problems are compounded in the future:

1) Government agencies, such as the Secretaria de Desarrollo Urbano y Ecologia (SEDUE, the Urban Development and Ecology Ministry), which has control over the federal coastal easement (Merino, 1987), should be given enforcement powers so that landowners will be required to remove groins and seawalls from in front of the natural dunes.

2) Port construction and improvements should be evaluated as to shoreline impacts, and appropriate measures (e.g., buying up downdrift property for public use, sand-bypassing) should be implemented.

3) Since shoreline erosion is in nature a process rather than a "problem" (Meyer-Arendt, 1992), future development (which presently underway, especially between Chixculub Puerto and Telchac Puerto where power lines have recently been extended) should be better guided. Development should be prohibited in narrow barrier locations (east of Telchac Puerto and west of Chuburná Puerto), and construction should be restricted to behind the dunes in wide beach ridge plain settings.

The recommendations above are most fundamental for proper coastal management, especially if international tourism is to be promoted along the north Yucatan coast. Additional recommendations would include beach nourishment, vegetative plantings, and other aesthetic improvements. In view of the relationships between human activities and coastal impacts documented by this research, proper coastal management for future development becomes especially critical.

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