Late 1800s

Professor Angelo Heilprin led the first scientific expedition to the coral reefs of the southern Gulf of Mexico in 1890. This expedition was sponsored by the Academy of Natural Sciences of Philadelphia (now Philadelphia Academy of Sciences), which Heilprin directed. The expedition’s purpose was to “investigate the natural history of the Yucatan Peninsula and Mexico” (Heilprin 1890). The expedition documented the tropical nature of marine biota of the southern Gulf and described corals and coral reefs (Heilprin 1890) and many other marine invertebrates (Ives 1890, 1891; Baker 1891). Heilprin (1890) also described reefs and islands occurring off the city of Vera-cruz and noted the “vast quantity of coral” used in construction there.

1900s–1970s

With the exception of Joubin’s 1912 map of coral reefs, little research was conducted on southern Gulf reefs until Smith’s (1954) work. Smith utilized Heilprin’s (1890) and Joubin’s (1912) works and various unpublished sources and nautical charts (refer to Tunnell 2007a, his Table 1.1) to create a coral reef distribution map. Smith also compiled a list of coral species from the southern Gulf. In 1955, Moore (1958) briefly visited Blanquilla Reef off Tuxpan. He described 44 invertebrate species from this, the most northerly emergent reef in the southwestern Gulf of Mexico.
During the 1960s, interest and research on all southern Gulf of Mexico coral reefs increased greatly (Tables 20.1, 20.2). Because the reef localities were remote, field studies tended to be performed during extended expeditions to the reef systems. Huerta M. and Barrientos (1965) reported on the algae of Blanquilla and Isla de Lobos reefs, near Tuxpan. Rigby and McIntire (1966) described the geology and ecology of Isla de Lobos Reef, while Chamberlain (1966) reported on gorgonians from Lobos that were studied during the same Brigham Young University expedition. Hidalgo (Hidalgo and Chávez 1967) and Chávez (Chávez et al. 1970; Chávez 1973; Bautista-Gil and Chávez 1977) conducted multiple expeditions to Isla de Lobos Reef with their students from the Instituto Politécnico Nacional in Mexico City. Chávez (1966) reported on the fishes of Triángulos and Cayo Arenas reefs.

Students from the Universidad Nacional Autónoma de Mexico conducted their “professional theses” on a variety of topics within the Veracruz Reef system. Villalobos summarized much of this work in the proceedings of an international symposium on the Caribbean Sea and adjacent regions (Villalobos 1971) and in a later review article.

From 1959 to 1963, the Department of Oceanography at Texas A&M University undertook a major, multiyear study of the Campeche Bank or Yucatan Shelf in the southeastern Gulf. The project was funded by the National Science Foundation, the American Petroleum Institute, the Office of Naval Research, Shell Development Company, and Mobil Oil Company. The project was the longest and most productive study of southern Gulf reefs to that date and contributed greatly to the knowledge of coral reefs and reef and shelf sediments of the region (Logan 1962, 1969a, b; Logan et al. 1969). In addition, Cayo Arenas was studied in more detail as a side project (Busby 1966).

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Figure 20.1. Geographic distribution of coral reefs within the southern Gulf of Mexico. Tuxpan and Veracruz systems are in the southwestern Gulf of Mexico and Campeche Bank Reefs are in the southeastern Gulf of Mexico (reprinted from Tunnell 2007b, with permission of Texas A&M Press.)
Mexican Coral Reefs

late 1980s and 1990s, Universidad Veracruzana in Jalapa, and Centro de Investigaciones y Estudios Avanzados (CINVESTAV)–Unidad Mérida of the Instituto Politécnico Nacional, also contributed to research on Veracruz reefs and Alacrán Reef, respectively. The reefs of northern Veracruz State are the least studied of those in the southwestern Gulf region due to their remoteness. Of the 6 northernmost reefs, Isla de Lobos has received the most attention (Table 20.2).

Over 20 coral reefs exist in the extreme southwestern Gulf, located offshore of the city of Veracruz and offshore of the fishing village of Antón Lizardo. Since these reefs are more accessible than the northern Veracruz reefs, they have received considerably more study (Table 20.2). Per-

Table 20.1. Principal literature by reef or island for certain coral reefs and islands on the Campeche Bank. Listed counterclockwise from Alacrán in the north to Cayos Arcas in the south.

<table>
<thead>
<tr>
<th>Subject by area</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Alacrán</strong></td>
<td></td>
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<tr>
<td>bathymetric mapping</td>
<td>Liceaga-Correa and Euan-Avila 2002</td>
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<tr>
<td>communities</td>
<td></td>
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<tr>
<td>benthic communities</td>
<td>Solis 1990</td>
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<tr>
<td>reef communities</td>
<td>Liddell and Ohlhorst 1988</td>
</tr>
<tr>
<td>organisms</td>
<td></td>
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<tr>
<td>algae</td>
<td>Múzquiz 1961</td>
</tr>
<tr>
<td>fish</td>
<td>Hildebrand et al. 1964; González-Gandara et al. 1999; González-Gandara and Arias-González 2001a, 2001b; Brulé et al. 2003; González-Gandara et al. 2003</td>
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<tr>
<td>foraminiferans</td>
<td>Davis 1964</td>
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<tr>
<td>mollusks</td>
<td>Rice and Kornicker 1962; Aranda et al. 2003</td>
</tr>
<tr>
<td>stomatopods and decapods</td>
<td>Martinez-Guzmán and Hernández-Aguilera 1993</td>
</tr>
<tr>
<td>vegetation</td>
<td>Marion 1884; Millsapgha 1916; Fosberg 1961, 1962; Bonet and Rzedowski 1962; Folk 1967</td>
</tr>
<tr>
<td>reef growth model</td>
<td>Bosscher and Schlager 1992</td>
</tr>
<tr>
<td>sediments</td>
<td>Folk 1962, Folk and Robles 1964; Folk 1967; Folk and Cotera 1971; Novak 1992; Novak et al. 1992</td>
</tr>
<tr>
<td>spatial distribution</td>
<td>Torruco et al. 1993</td>
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<td><strong>Cayo Arenas</strong></td>
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<td>Busby 1966</td>
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<tr>
<td><strong>Triangulos and Cayo Arenas</strong></td>
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<td>organisms</td>
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<td>coral</td>
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<td>Hernández 1997</td>
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<td>Ferre-D'Amare 1995</td>
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<td><strong>Cayos Arcas</strong></td>
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<tr>
<td>coral</td>
<td>Farrell et al. 1983</td>
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<td>environmental</td>
<td>Ferre-D'Amare 1995</td>
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<tr>
<td>meteorology</td>
<td>Salas de Leon et al. 1992</td>
</tr>
</tbody>
</table>


1970s–1990s

From 1970 to 1990, three groups were largely responsible for research on the southern Gulf of Mexico coral reefs: (1) Secretaría de Marina, Dirección General de Oceanografía, (2) Texas A&M University–Corpus Christi, and (3) Universidad Nacional Autónoma de México. In the late 1980s and 1990s, Universidad Veracruzana in Jalapa, and Centro de Investigaciones y Estudios Avanzados (CINVESTAV)–Unidad Mérida of the Instituto Politécnico Nacional, also contributed to research on Veracruz reefs and Alacrán Reef, respectively.

The reefs of northern Veracruz State are the least studied of those in the southwestern Gulf region due to their remoteness. Of the 6 northernmost reefs, Isla de Lobos has received the most attention (Table 20.2).
Perhaps the most studied of all reefs in this region is Enmedio Reef. Gutiérrez et al. (1993) compared the coral reefs of the Veracruz region to those within the Sian Ka’an Biosphere Reserve located along the Caribbean coast of Quintana Roo, Mexico.

The Mexican Navy has contributed oceanographic information, as well as information on reef biology, for the Veracruz reef system through its oceanographic program (Instituto de Investigación Oceanográfica del Golfo y Mar Caribe). This program first operated from a small station (Estación Oceanográfica) in the city of Veracruz, but it is now housed within a new institute building at Antón Lizardo.

The relatively great distance from shore continued to limit the number of reef studies on the Campeche Bank. Macintyre et al. (1977) published a report on the thickest recorded Holocene reef section at Alacrán Reef. During the 1980s, coral diversity and zonation were charac-
terized for Cayos Arcas (Farrell et al. 1983) and Alacrán (Liddell and Ohlhorst 1988) reefs. Additionally, several authors reviewed all Mexican Atlantic coral reefs, including environmental problems and human impacts (Tables 20.1, 20.2).

During the 1990s an increasing number of both organismal and ecological studies continued on the Campeche Bank and Veracruz Reef system. Other studies focused on reef sediments and a computer simulation model of reef growth (Tables 20.1, 20.2).

2000s to the Present

A number of fish studies were conducted during the early 2000s, especially on Alacrán Reef (Tables 20.1, 20.2). Other studies included Montastraea annularis growth rates, other invertebrates, and seabirds on Campeche Bank reef islands. In recent studies, geologic facies were charted through time on Campeche Bank reefs (Tables 20.1, 20.2).

Jordán-Dahlgren and Rodríguez-Martínez (2003) summarized work on all Mexican coral reefs within the Gulf of Mexico and Caribbean. Jordán-Dahlgren (2004) provided a sobering, though brief, environmental status report on southern Gulf reefs. Reefs in the extreme southwestern Gulf, located off the city of Veracruz and the village of Antón Lizardo, have been negatively affected the most, and those on the Campeche Bank have been affected the least. The reefs near Tuxpan in northern Veracruz State are intermediate in terms of negative effects (Tunnell 1992).

Reef Distribution and Structure

There are 46 named coral reefs in the southern Gulf of Mexico: 31 in the southwestern Gulf off the state of Veracruz (Veracruz Shelf reefs) and 15 in the southeastern Gulf on the Campeche Bank (refer to Tunnell 2007b, his Table 2.1) (Fig. 20.1). In addition, Dahlgren (1993) listed approximately 10 named and over 25 unnamed banks on the Campeche Bank for which there is little or no scientific information.

Coral reefs in the southwestern Gulf are typically located at nearshore (<200 m) to mid-shelf (22 km) distances on a narrow, terrigenous shelf (Morelock and Koenig 1967; Ferre-D’Amare 1985). The Veracruz region is characterized by subhumid to humid climates of high rainfall and substantial mainland drainage. Consequently, terrigenous sediment shed from the Sierra Madre Oriental and Trans-Mexican Neovolcanic Belt greatly influences the nearshore reefs. Also, during the rainy season lowered salinities may occur in some areas (e.g., practical salinity of 18.3 at Veracruz compared to 36 for normal oceanic waters) (Ferre-D’Amare 1985; Tunnell 1988). The Tuxpan–Veracruz area is subject to low winter temperatures with lows ranging from 8–10 °C (air) at Veracruz down to, infrequently, 0 °C (air) at Tampico (Ferre-D’Amare 1985). Reefs are absent to the north of the Tuxpan Reef system, most likely due to low winter water temperatures. Reefs are also absent to the south of the Veracruz Reef system, perhaps due to upwelling (Ferre-D’Amare 1985).

In the southeastern Gulf, reefs are located far (130–200 km) offshore on a wide carbonate shelf, the Campeche Bank, primarily along the 55-m depth contour (Logan 1969a, b). In contrast to the southwestern Gulf, southeastern Gulf reefs occur in a semiarid climate, surrounded by oceanic water from the Caribbean and the Gulf of Mexico, and they are not affected by mainland drainage. The general absence of reefs along the Gulf coastal areas of the Yucatan Peninsula may be due to low winter temperatures (8–10 °C air temperatures; Ferre-D’Amare 1985), the effects of which would be more pronounced along the coastline than farther out on the shelf where the bank reefs occur. Freshwater discharge is also possible through the Yucatan karst system into coastal areas. Fringing or barrier-type reefs are conspicuously absent from the northern and western (Gulf) coastal areas of the Yucatan Peninsula, although these reef types are extensively developed along the eastern (Caribbean) side of the Yucatan Peninsula and southward near Belize.

In contrast to adjacent, low-energy coastal areas such as the Florida Keys and Belize where mangroves line the shoreline and seagrasses predominate as nearshore sub-marine vegetation, shoreline areas of the mainland consist of moderate-energy sandy beaches or rocky shores (volcanic) in the southwestern Gulf and low-energy sandy beaches or rocky shores (limestone) in the southeastern Gulf. Also, unlike the scattered, shallow-water patch reefs associated with the former, the southern Gulf reefs are largely submerged, mountain-like structures scattered across the continental shelf.

Southwestern Gulf Reefs

The southwestern Gulf coral reefs are clustered in 2 systems, the Tuxpan Reef system to the north (Fig. 20.2) and the Veracruz Reef system to the south (Fig. 20.3). Most of
Reef system have islands associated with them (La Blanquilla, Isla Verde, and Isla de Sacrificios). The island of La Blanquilla is a sandy cay, always changing shape, whereas Isla Verde and Isla Sacrificios are densely vegetated and fairly stable. Low and mostly natural vegetation is found on Isla Verde. Isla Sacrificios has a large, important lighthouse as well as a public visitor’s area, and includes many exotic transplants among the natural vegetation.

The second, or southern, group of reefs in the Veracruz Reef system consists of 12 larger reefs occurring relatively farther offshore than those of the northern group. These include emergent platform-type reefs (Anegada de Afuera, Topatillo, Santiaguillo, Anegadilla, Polo, Isla de Enmedio, Aviso, Blanca, Chopas, El Rizo, Cabezo, and El Giote) located off the fishing village of Antón Lizardo. This group of reefs contains the 3 largest reefs in the southwestern Gulf (Afuera, Chopas, and Cabezo). El Giote Reef is the smallest and nearest to shore and has a navigational light stand on it.

Four of the reefs off Antón Lizardo have islands (Santiaguillo, Cabezo, Isla de Enmedio, and Chopas). Chopas Reef actually has 2 islands, Isla Salmedina and Isla Blanca; both of these islands have only low natural vegetation. Isla de Enmedio has low, natural vegetation, as well as a dense canopy of transplanted shade trees. El Aguila (on Cabezo) and Santiaguillo islands have little vegetation and are composed almost totally of coral rubble with little or no sand. Topatillo Reef used to have a coral rubble cay consisting of Acropora cervicornis (staghorn coral) rubble, but it no longer exists. After the death of A. cervicornis and A. palmata (elkhorn coral) in the late 1970s and early 1980s (Tunnell 1992), this small island began to erode because of the lack of living Acropora, which protected the island from wave action.

Southeastern Gulf Reefs

In the southeastern Gulf of Mexico reefs occur in a broad arc running from the north-central portion of the Campeche Bank (Alacrán Reef) to the southwest (Cayos Arcas). The reefs occur near the shelf edge, some 100–200 km from the coastline of the Yucatan Peninsula (Fig. 20.1). The absence of reefs on northeastern portion of the shelf may be due to upwelling of cold (17–18 °C) water (Logan 1969b; Glynn 1973; Merino 1997).

Eleven named emergent reefs and 4 named submerged reefs are located along the outer continental shelf of the Campeche Bank. The Campeche Bank reefs have been subdivided (Logan 1969b) into geomorphic categories
with the principal subdivision between submerged reef banks (e.g., Bancos Ingleses, Banco Pera, Bajo Nuevo, and Bajos Obispos) and emergent reef banks or "walls" (see Tunnell 2007b, his Table 2.1) (Fig. 20.1). The latter are further subdivided into (1) solitary reef knolls (Nuevo and Triángulo Oeste), (2) linear reef walls (Triángulo Este-Sur), (3) crescent reef walls (e.g., windward reef at Alacrán Reef and parts of Cayo Arenas and Cayos Arcas), and (4) reef complexes with multiple emergent reef walls. Cayo Arenas, Triángulos, and Cayos Arcas are all considered complexes having multiple emergent platforms and islands. Nuevo Reef has a single emergent platform and ephemeral island. The majority of these reefs form arcs that are convex to the northeast, reflecting the prevalent northeast-southwest wave progression (Logan 1969b).

Alacrán Reef is the most northerly reef in the entire southern Gulf of Mexico. It is also, by far, the largest reef in the southern Gulf, occupying some 13 × 25 km. It has an extensive shallow-water lagoon with small patch reefs and water depths up to 22 m. Alacrán Reef is the most studied Campeche Bank reef and has been the subject of numerous geological and biological investigations (Table 20.1). Liddell and Ohlhorst (1988), as part of a CINVESTAV and Armada de Mexico expedition, quantitatively characterized community structure and diversity of a 20-m windward reef site. They found that the bottom consisted of 76% total living cover comprised of macroalgae (45%), corals (11%), non-coral cnidarians (chiefly gorgonians, 5.4%), coralline algae (5.2%), and sponges (5.2%). Corals consisted of 12 species with a diversity of 1.86 (H', natural log). Torruco et al. (1993) characterized the structure of benthic communities inhabiting the lagoon at Alacrán.

Alacrán Reef has 5 vegetated islands: Desterrada, Desertora, Perez, Chica, and Pájaros. Arenas has one large, named vegetated island, Cayo Arenas, and 3 smaller unvegetated and unnamed coral rubble cays. Triángulos has at least 2 islands, Triángulo Oeste and Triángulo Este. Finally, Cayos Arcas has 3 vegetated islands: Cayo...
del Centro, Cayo del Oeste, and Cayo del Este. Manned lighthouses are found at Isla Perez, Cayo Arenas, Triángulo Oeste, and Cayo del Centro.

In addition to the “true” reefs mentioned above, biostromes lacking scleractinian frameworks also occur on the Campeche Bank, particularly in the 18–60 m depth range (Logan 1969b). These hard banks form relatively thin veneers over previously existing topography. These veneers consist of 1–18 cm diameter, concentrically layered nodules of crustose coralline algae and foraminifera. These nodular crusts are most common on the northern shelf and are much less common on the western shelf, perhaps due to increased terrigenous sedimentation there.

**Reef Sediment Composition**

Numerous studies have examined the composition of Holocene reef sediment from the southern Gulf of Mexico, particularly Alacrán Reef. Studies of certain areas, such as Cayos Arcas and Triángulos on the Campeche Bank and the Tuxpan-Tampico portion of the western Gulf coastal plain, are lacking. Although both geographic (e.g., increased terrigenous sediment in the southwestern Gulf) and bathymetric variation in sediment composition occur, generalizations may be made.

**Southwestern Gulf Reefs**

Relatively little is known about the geology of the Tuxpan reefs. The seafloor north and south of the Isla de Lobos Reef at Tuxpan (Fig. 20.2) is dominated by reef-derived calcareous sand; whereas, the seafloor to the west of the reef has both reef-derived and terrigenous material (Rigby and McIntire 1966) consisting of quartz, ferromagnesium minerals, volcanic rock fragments, and obsidian, presumably transported from the interior by the Río Tuxpan or Río Panuco. The seafloor immediately east of the reef is dominated by rocky reef debris. The linear trend of Isla de Lobos, Medio, and Blanquilla reefs might reflect the control of relict Pleistocene or older topography (Rigby and McIntire 1966).

The Veracruz reefs are somewhat more studied from a geologic standpoint than those to the north. Emery (1963), Edwards (1969), and Freeland (1971) examined the mixed terrigenous-carbonate sediments occurring off the city of Veracruz (Fig. 20.3). Morelock and Koenig (1967) studied the reefs to the south of Veracruz at Antón Lizardo. These reefs are located parallel to the shoreline and perpendicular to the prevailing wave-approach direction. They are strongly influenced by storm waves and are largely barren of sandy sediment on their windward sides, where well-developed boulder ramparts occur. Again, the reefs are thought to have been established on antecedent Pleistocene dunes. The authors concluded that much of the terrigenous sand and gravel present on the shelf is late Pleistocene (Wisconsinan) in age. Present-day terrigenous sedimentation rates are very low, thus allowing the reefs to develop. Even so, carbonate sediments are found to accumulate only in the immediate area of the coral reefs and rarely exceed 50% calcium carbonate by weight (Morelock and Koenig 1967).

**Southeastern Gulf Reefs**

Logan (1969a) sampled sediments from both reef and open shelf settings on the Campeche Bank, noting that sediments from reefs and associated environments (e.g., lagoons) were dominated by coral, coralline and calcareous algae, and foraminifera. In contrast, mollusks, echinoids, and bryozoans were much more important sediment constituents on the open shelf.

Alacrán Reef is the most studied of the Campeche Bank reefs. Kornicker and Boyd (1962) provided a general overview of the sedimentology and biotic zonation of Alacrán Reef and lagoon. They noted that considerable lateral variation occurred in the organisms present and the bottom character around the reef complex.

Folk and Robles (1964) examined the sedimentology of Isla Perez, the largest leeward island on Alacrán Reef. The general composition of the sand-sized fraction was 60% *Halimeda*, 25% coral, and 15% foraminifera and other grains, whereas the coarser fractions were dominated by coral (e.g., coral stick ramparts generated by storms). Folk (1967) and Folk and Cotera (1971) focused on the origin, geomorphology, and size sorting occurring on sand cays off the leeward side of Alacrán Reef, noting that these were areas of intense biotic sediment production.

A core taken from Isla Perez by Macintyre et al. (1977) documented 30 m of Holocene reef growth (principally by the coral *Acropora cervicornis*). This translates into accumulation rates of 12 m/1000 yr, considerably higher than the rates previously described for Jamaica by Land (1974). The Holocene reef that was cored was situated on top of a similar-appearing pre-Holocene reef that extended from 33 m down to 50–60 m and the shelf platform (Bonet 1967).
Mexican Coral Reefs

Hoskin (1963) conducted a detailed facies analysis of Alacrán Reef. Seventeen environments were characterized, based on sediment composition and size, including (from east to west) windward shelf, lower windward slope, upper windward slope, surge channels, boulder rampart, windward reef flat, moat, Thalassia beds, cellular reef surface, cellular reef deep, pinnacle reef, lagoon proper, patch reefs, shallow sand, leeward reef surface, lower leeward slope, and leeward shelf. Halimeda, coral, and fecal pellets were the dominant components of the sand-sized sediment fraction. Halimeda was most abundant on the windward and leeward reefs; coral reached its peak abundance on the tops of lagoon pinnacle reefs; and fecal pellets were most abundant in deeper lagoonal areas. In contrast, foraminifera, coralline algae, mollusks, and aggregate grains varied little across these environments.

Hoskin (1966) examined eodiagenesis (near-surface diagenesis) occurring on pinnacle reefs in the Alacrán Reef lagoon. Diagenetic processes observed included pelletization of lagoon floor muds, macroboring of coral by lithophagid bivalves, microboring of coral and mollusk fragments by endolithic algae, aragonite cementation in cavities, and recrystallization of coral grains.

Novak (1992) and Novak et al. (1992) provided a quantitative description of Alacrán Reef sediment from fore- and back-reef settings. For all samples, coral, the calcareous green alga, Halimeda, and coralline algae constituted well over 70% of all grains by volume. The distribution of grains was similar to the distribution of the living, sediment-producing organisms, with coral grains being relatively more abundant in fore-reef samples and Halimeda grains in back-reef samples. In contrast to the findings of Hoskin (1963), fecal pellets were relatively minor sedimentary constituents of their samples and coralline algae were more important (Novak et al. 1992). The back-reef samples studied by Novak et al. (1992) were from the shallower, eastern portion of the lagoon, not the deeper, pellet-rich lagoon areas and pinnacle reefs sampled by Hoskin (1963). Cluster analysis delineated 3 Alacrán Reef lithofacies: back reef, shallow fore reef (<10 m), and deep fore reef (>10m) (Novak et al. 1992).

Conclusions

The reefs of the southern Gulf of Mexico have a long history of study. They exhibit a diversity of forms, including small, nearshore shelf reefs (e.g., Veracruz Shelf Reefs), fringing reefs (Veracruz), and large, open-shelf atolls (e.g., Alacrán). The overall development of reefs in the southern Gulf of Mexico may be limited by winter temperatures. In addition, reefs along the Tuxpan–Veracruz coast may be limited by the abundant supply of terrigenous sediment being shed from the Sierra Madre Oriental and Trans-Mexican Neovolcanic Belt and possibly by reduced salinities in the rainy season. Unfortunately, most of these reefs increasingly are being affected by economic development (e.g., Farrell et al. 1983; Ferre-D’Amare 1985; Tunnell 1992; Chávez and Tunnell 1993) (Tables 20.1, 20.2), particularly those in the southwestern Gulf off Veracruz (city) and Antón Lizardo.

Acknowledgments

We dedicate this chapter to the memory of our good friend and colleague, Mauricio Garduno Andrade, who participated on many of our expeditions to the reefs of Mexico and whose research contributed to turtle conservation biology. We thank the Texas A&M University Press for permission to use figures 20.1–20.3. Portions of this article were originally published in a different form in Liddell (2007) and Tunnell (2007a, 2007b).

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