Chapter 2
The Echinoderms of Mexico: Biodiversity, Distribution and Current State of Knowledge

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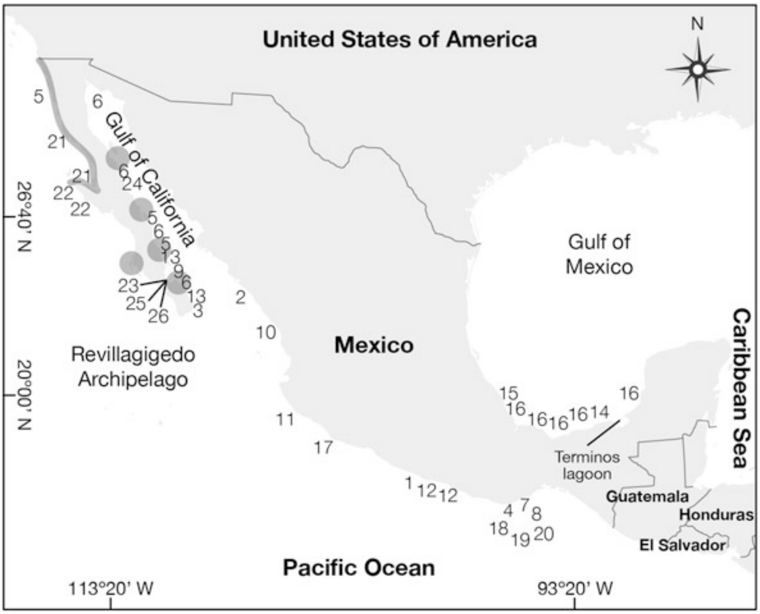

Fig. 2.1 Mexico with its principal islands, archipelago, marine lagoons and coasts. Fishing area of sea urchins: *Strongylocentrotus franciscanus* (*grey areas*), fishing areas of *Isostichopus fuscus* in the Gulf of California and Bahia Magdalena (*grey circles*), and the geographic location where ecological studies of echinoderms have been carried out. (*1*) Salcedo-Martínez et al. (1988); (*2*) Caso et al. (1994); (*3*) Reyes-Bonilla and Calderon-Aguilera (1999); (*4*) Benítez-Villalobos (2001); (*5*) Reyes-Bonilla et al. (2005); (*6*) Cintra-Buenrostro et al. (2005); (*7*) Zamorano and Leyte-Morales (2005a); (*8*) Zamorano and Leyte-Morales (2005b); (*9*) Holguín-Quiñones et al. (2008); (*10*) Rios-Jara et al. (2008); (*11*) López-Uriarte et al. (2009); (*12*) Zamorano and Leyte-Morales (2009); (*13*) Herrero-Perezrul et al. (2010); (*14*) Caso et al. (1996); (*15*) Celaya-Hernández et al. (2008); (*16*) Vazquez-Bader et al. (2005); (*17*) Espino-Barr et al. (1996); (*18*) Herrera-Escalante et al. (2005); (*19*) Benitez-Villalobos et al. (2008); (*20*) Benitez-Villalobos et al. (2009); (*21*) Tapia-Vasquez et al. (1996); (*22*) Fajardo-Leon et al. (2008); (*23*) Herrero-Perezrul et al. (1999); (*24*) Reyes-Bonilla et al. (2008); (*25*) Herrero-Perezrul and Reyes-Bonilla (2008); (*26*) Skarbnik-López et al. (2010)

2.1 Oceanography and Marine Environments in Mexico

Mexico is the twelfth largest country in the world in terms of extent of coastline and marine surface area. It has an exclusive economic zone of 314,992,000 ha, a continental platform of 39,460,300 ha and a coastline of 11,500 km. 1,600,000 ha are estuarine areas and about 1,250,000 ha are coastal lagoons. Approximately 6,000 km^2 of islands are found in the Pacific Ocean (including the remote Guadalupe Island and the Revillagigedo Islands), Gulf of Mexico, Caribbean, and Gulf of California (Fig. 2.1), which explains the country's extraordinary biodiversity in terms of coastal and marine resources and ecosystems (wetlands, mangrove forests, barrier islands, dunes, coral reefs, sea grass meadows and nearshore islands) that are distributed along these four seas (INEGI 2007).

The Pacific coast of Mexico extends from 14° to 33°N, and from 92° to 117°W. This includes the Baja California Peninsula, the second largest in the world (about 1,600 km in length), numerous islands and the eastern coast of the Gulf of California; the Gulf of Tehuantepec, making a total coast line well above 8,000 km in length (Fig. 2.1).

The Gulf of California (GC) has several oceanographic features that make it unique among semi enclosed seas of similar latitude and dimensions, the most important being strong tidal mixing, some of it close to the deep stratified oxygen concentration zone. The GC is 1,400 km long and its width in the inner region is 150–200 km, with an area of 177,000 km^2, a mean depth of 818 m, and a volume of 145,000 km^3. The GC is an evaporative basin, but in general it gains heat through the surface. Lacking a sill at the point of connection with the Pacific Ocean, the GC is constantly affected by a wide spectrum of signals coming from the Pacific Ocean, including tides and El Niño, which is the most important interannual anomaly (Lavin and Marinone 2003) (Fig. 2.1).

The Revillagigedo Archipelago or Revillagigedo Islands are a group of four volcanic islands off the Mexican Pacific coast, known for their unique ecosystem. They have been part of the Mexican State of Colima since 1861, but are under Mexican federal jurisdiction. They lie 386 km southwest of Cabo San Lucas, the southern tip of Baja California and between 720 and 970 km west of Manzanillo. They are located around 18°49′N and 112°46′W. The Revillagigedo Islands are home to many endemic plant and animal species and often are called Mexico's "little Galapagos". They are recognized as a distinct terrestrial ecoregion, part of the Neotropic ecozone. Socorro Island is the largest and has the most diverse flora, fauna, and topography (Fig. 2.1).

The Gulf of Mexico (GM) consists of several ecological and geological provinces, such as the continental shelf, the continental slope, and the abyssal plain. The coastal zone consists of tidal marshes, sandy beaches, mangrove-covered areas, and many bays, estuaries, and lagoons. The continental shelf forms an almost continuous terrace around the margin of the GM. Its width varies from a maximum of more than 320 km to a minimum of about 40 km. Off the coast of Campeche and the Yucatan Peninsula, the continental shelf consists of a broad area composed primarily of carbonate material. Off the states of Campeche and Yucatan, the bank of Campeche extends from 19° and 23° N, and 89° and 93°W in the southern GM (Gore 1992). It is delimited in the north by the Campeche slope; in the south by the shoreline of the states of Campeche, Yucatan and Quintana Roo; in the west by the Campeche canyon; and in the east by the Yucatan strait. This area is an almost flat carbonate plateau that has an average depth of about 51 m (Fig. 2.1).

The remainder of the GM shelf consists of sand, silt, and clay sediments. On the shelf and the slope that dips downward to the abyssal plain, buried salt domes occur at various depths. The abyssal plain, which forms the floor of the gulf, consists of a large triangular area near the centre, bounded by abrupt fault scarps toward Florida and the Yucatan Peninsula and by more gentle slopes to the north and west. The basin is very flat, having a gradient of only about 0.3 m per 2,440 m. The deepest point in the Mexico Basin (Sigsbee Deep), is 5,203 m.

The Terminos Lagoon, the largest lagoon-estuarine ecosystem in Mexico, is located in the southern GM. Terminos Lagoon is a large ($\sim$2,500 km^2), shallow (mean depth 3.5 m) coastal lagoon bordering the southern Gulf of Mexico in Campeche, with 200,108 ha of open water including associated lagoons and channels, surrounded by about 259,000 ha of mangroves and cattail marshes. The lagoon borders two geological provinces: to the east the Yucatan Peninsula (low rainfall, calcareous soils, and no significant surface drainage); to the west and south, the lowlands of Tabasco and the highlands of Chiapas and Guatemala. Offshore is the Bay of Campeche, a region supporting one of the largest marine fisheries in Mexico. The Usumacinta-Grijalva river systems discharge into the Gulf by three main rivers: the Candelaria, the Chumpan, and the Palizada. The lagoon is surrounded by shores and is fully incorporated into a National Flora and Fauna Reserve that comprises 705,016 ha of open water and associated wetlands and upland (Yañez-Arancibia et al. 1983) (Fig. 2.1).

The Mexican Caribbean and the Yucatan Peninsula is a northeastern projection of Central America, lying between the GM to the west and north and the Caribbean Sea to the east, encompassing some 197,600 km^2. It includes the Mexican states of Campeche, Quintana Roo, and Yucatan and, to the south, large parts of Belize and Guatemala. The peninsula has a mean width of about 320 km and a coastline of about 1,100 km (De la Lanza-Espino 1991). The Yucatan Peninsula subsurface Caribbean water (16–20 °C, 36.1–36.5 ‰) upwells along the eastern slope of the Yucatan shelf. This water, which originates at depths of about 220–250 m in the Yucatan Channel, rises at about 10 cm s^{-1} into the euphotic zone and only occasionally breaks the ocean surface. This upwelling follows a seasonal cycle. During spring and summer the upwelled water intrudes over the Yucatan shelf to create a two-layered water column. Yucatan is one of the most important upwelling regions on a western oceanic margin (Merino 1997) (Fig. 2.1).

2.2 Echinoderm Fauna of Mexico: An Inventory and Analysis

2.2.1 Historical Review

Studies on Mexican echinoderms started in the nineteenth century, when some specimens were collected and analyzed by Louis Agassiz in 1841. He reported the presence of the sand dollar *Mellita quinquiesperforata* (as *Mellita hexapora*) in the Gulf of Mexico (Veracruz). Later, Verrill (1870, 1871) published on some specimens collected by Yale University in Mexican waters. The *Blake* expeditions to the Gulf of Mexico and Caribbean (1878 and 1884) produced several papers, such as Perrier (1881) on Asteroidea, Lyman (1883) on Ophiuroidea, Théel (1886) on Holothuroidea and Agassiz (1878–1879, 1888) on Echinodea. The *Challenger* expeditions in the Mexican Pacific produced papers by Lyman (1879, 1882), Théel (1879), Agassiz (1881a, b), Carpenter (1884) and Sladen (1889). The *Albatross* expedition in 1884 to the Mexican Caribbean resulted in the reports of Rathbun (1885) for some sea urchins. The Mexican Pacific expedition in 1891 resulted in reports by Ludwig (1893) and Hartlaub (1895).

Few expeditions have been made during the twentieth century. Several non-Mexican authors wrote different reports that included echinoderms from Mexican waters. The reports of Ludwig (1905) and Clark (1917, 1920a, b) were based on material collected by the last *Albatross* expedition from 1899 to 1905. The expeditions to the East Pacific made by the *Velero III* under the direction of Captain Allan Hancock during 1931–1941 resulted in the description of Mexican echinoderms by Clark (1948), Ziesenhenne (1940, 1942), Deichmann (1941, 1958) and Domantay (1953, 1961). The Templeton Crocker Expedition on board of the *Zaca* took place in the Gulf of California in 1936, Deichmann (1937) and Ziesenhenne (1937) described the holothuroids and echinoids of that area. In 1937 and 1938, again on board of the *Zaca*, the Eastern Pacific Expeditions of the New York Zoological Society resulted in publications by Deichmann (1938) and Clark (1940). In 1940, Steinbeck and Ricketts made an expedition to the Gulf of California on board the *Western Flyer* and cataloged more than 550 species of animals, including echinoderms (Steinbeck and Ricketts 1941). Fisher (1906), Clark (1913, 1923a, b, 1933, 1916, 1918, 1954), Boone (1926) and Deichmann (1930) published on Mexican echinoderms from different collections.

During the second half and the end of the twentieth century, several authors continued to describe new species or published checklists of the echinoderms of Mexico, such as Clark (1940), Deichmann (1941, 1954, 1963), Fell (1962), Thomas (1962), Parker (1963), Schroeder (1964), Phelan (1970), Downey (1972, 1973), Brusca (1973, 1980), Litvinova (1975), Lessios et al. (1984a, b), Hendler and Turner (1987), Hendler and Peck (1988), Maluf (1988), Kerstitch (1989), Solís-Marín et al. 1993), Hendler et al. (1995), Cutress (1996), Hendler (1996), Roux and Pawson (1999), Sagarin et al. (2008) and Pawson et al. (2009).

Massin and Hendrickx (2010) described a new species of the genus *Synallactes* (*S. virgulasolida*) collected during a deep-water benthic fauna survey off the Pacific coast of Mexico in the East Pacific, on board the R/V *El Puma.* This was the first record of a *Synallactes* in the Gulf of California.

Massin and Hendrickx (2011) studied the deep-water holothurians (377–2,200 m) collected during the research cruises aboard the R/V "El Puma" from the Mexican Pacific and Gulf of California, recording 13 species, two of which were new to science (*Ypsilocucumis californiae* and *Mitsukuriella unusordo*). The small number of specimens collected during this survey compared to other areas of the world could be linked to the limiting effect of the Pacific Mexico Oxygen Minimum Zone.

Honey-Escandón et al. (2011) described a new of species of holothuroid (*Holothuria carere*) from the shallow waters of the Mexican Pacific.

Mexican expeditions did not take place until 1939 and added more species to the list of echinoderms. The Universidad Nacional Autónoma de México (UNAM)

Fig. 2.2 Maria Elena Caso Muñoz (December 1915–October 1991)

started the first attempt to organize and classify mainly the Mexican echinoderm fauna into a comprehensive scientific collection. Dr. Maria Elena Caso began a series of taxonomic studies that lasted for more than 50 years and that resulted in more than 50 papers.

Maria Elena Caso Muñoz (Fig. 2.2) was born in Mexico City (December 18, 1915). She was the daughter of Antonio Caso (a noted Mexican philosopher and rector of the former Universidad Nacional de Mexico, now the National Autonomous University of Mexico) and Josefina Muñoz. Maria Elena childhood was in a warm and loving family environment. The end of the Spanish Civil War, with Franco's victory in 1939, sparked the start of one of the most dramatic exoduses in contemporary history. Exiled scientists carried out tremendously important work in the countries offering them asylum, helping to promote scientific and technological progress. Enrique Rioja Lo-Bianco arrived to Mexico in 1939 to work at the Instituto de Biologia, Universidad Nacional de Mexico (UNAM). There, Ma. Elena Caso fell under the tutelage of Enrique Rioja and immediately started the systematic study of the Mexican echinoderms by collecting specimens from Mexican waters, initiating the Mexican Echinoderm National Collection (MENC).

She studied in the Faculty of Sciences at the UNAM (Mexico City) (1937–1940) where she obtained her Masters degree in 1943. In 1961 she received the degree of Doctor of Philosophy at the same University, presenting a thesis on the present knowledge of the Mexican echinoderm fauna. In the course of her career she published 56 papers on echinoderms and one book honoring Rioja's scientific endeavor. She described eleven new taxa (five species, one subfamily, one subgenus and two varieties). It was Ma. Elena Caso's intention to provide for future researches reference works that would eliminate the need to study the older literature. Consequently, her work (all exclusively written in Spanish) contains a staggering amount of details pictured in highly illustrated volumes. After her death (October 23, 1991) some of her papers were still in press. They were published *postmortem* (Caso 1992, 1994a, b, 1996a, b, c, d). Her ideas on the taxonomy of echinoderms were often controversial but were always respected. Maria Elena Caso will always be regarded as the pivotal figure in the systematic study of echinoderms in Mexico.

Currently, the Mexican Echinoderm National Collection (MENC) that Dr. Caso started holds more than 74,000 specimens belonging to ~620 species distributed along Mexican coasts. The MENC also holds specimens from different parts of the world. Recently, the collection has entered a rapid growth phase both in terms of numbers and of geographic and taxonomic coverage. Since 1984, yearly expeditions of Mexican research vessels "Puma" in the Pacific Ocean and "Justo Sierra" in the Atlantic, and since 1992, twice-yearly expeditions to both shallow and deep sea areas in Mexican waters, have added numerous taxa previously unrepresented in the collection. Important collections previously minor at MENC, such as frozen tissues, have grown quickly, establishing MENC as an important national repository. The MENC also possesses an excellent echinoderm library, with more than 5,100 reprints, books, proceedings, dissertations, etc., covering a great variety of topics from Aristotle to the present. Such records have been much more complete with generous requests from people around the world since 1939.

Knowledge of Mexican echinoderms continued to increase in the MENC at the end of the twentieth century and the beginning of the twenty-first century, with new curators and several students. The papers published include description of new species, checklists, taxonomic and biogeographic studies as well as morphological and molecular phylogenies. Some examples are Buitron and Solis-Marin (1993), Reyes-Bonilla (1995), Solís-Marín et al. (1997a, b, 2003, 2005, 2007a, b, 2009), Cintra-Buenrostro et al. (1998), Bravo-Tzompantzi et al. (1999), Godinez-Dominguez and Gonzalez-Sanson (1999), Solis-Marin and Laguarda-Figueras (1999, 2008, 2010a, b), Barbosa-Ledesma et al. (2000), Laguarda-Figueras et al. (2001, 2002, 2004, 2005a, b, 2009), Duran-Gonzalez et al. (2005), Fuentes-Farias et al. (2005), Luna and Gonzalez-Vallejo (2006), Hernandez-Herrejon et al. (2008, 2010), Honey-Escandón et al. (2008), Solis-Marin (2008), Torres-Martinez et al. (2008), Laguarda-Figueras and Solis-Marin (2009) and Martinez-Melo and Solis-Marin (2010).

The number of thesis or dissertations on the taxonomy of echinoderms increased during this period, with the highest number between 2001–2010: Orbe-Mendoza (1971), Gamboa-Contreras (1978), Worbis-Torres (1986), Olivares-Gonzalez (1986), San Juan-Ruiz (1988), Herrero-Perezrul (1990), (Sánchez-Domínguez 1993), Anzo-Martinez (1994), Bravo-Tzompantzi (1996), Castañeda-Sarabia (1996), Hernandez-Pliego (1998), Solis-Marin (1998), Cortes-Fernandez (1999), Benitez-Villalobos (2000), Gomez-Carriedo (2001), Frontana-Uribe (2002, 2005), Celaya-Hernandez (2006), Arriaga-Ochoa (2007, 2010), Dominguez-Castanedo (2007), Hernandez-Herrejon (2007, 2010),

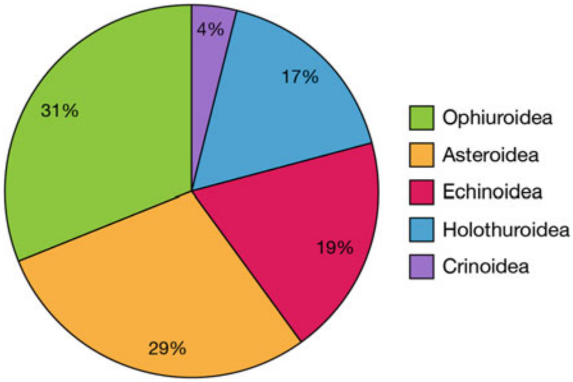

Fig. 2.3 Echinoderm composition (number of species per class) in Mexican waters

Gonzalez-Azcarraga (2009), Bribiesca-Contreras (2011), Estrada-Rodriguez (2011), Hernandez-Diaz (2011), Pineda-Enriquez (2011) and Zarate-Montes (2011).

2.2.2 Biodiversity and Distribution of the Mexican Echinoderms

Mexico's extensive littoral zone and great diversity of habitats supports 643 species of echinoderms (see Appendix), approximately 10 % of the world total. Class Crinoidea is less well represented with 29 species (4 % of the world total), while the Class Ophiuroidea is the richest of all with 197 species (31 %); Class Asteroidea is second with 185 species (29 %); Class Echinoidea is the third most diverse group with 119 species (19 %); Class Holothuroidea is represented by 113 species (17 %) (Fig. 2.3). Diversity and distribution of echinoderms in Mexico is described for the four coastal regions of this country: Gulf of California, Pacific Ocean, Gulf of Mexico and Caribbean Sea (Fig. 2.4).

2.2.3 Gulf of California

Although the Gulf of California is a diverse zone for some classes of echinoderms, there are no records of crinoids in this area. The asteroids in Mexico are well represented in all the coasts. In the Gulf of California there is a vast variety and abundance of specific generic types of asteroids higher than the Caribbean Sea. There are 58 species. Twenty nine occur in deep waters (>200 m depth). The most conspicuous genera are: *Astropecten, Luidia, Nidorellia, Oreaster, Pharia, Phataria* and *Heliaster* (Solis-Marin et al. 1993) (Fig. 2.5).

Seventy one ophiuroid species occur in the Gulf of California in two orders, 14 families and 34 genera. *Ophiactis savignyi* has the widest distribution in shallow

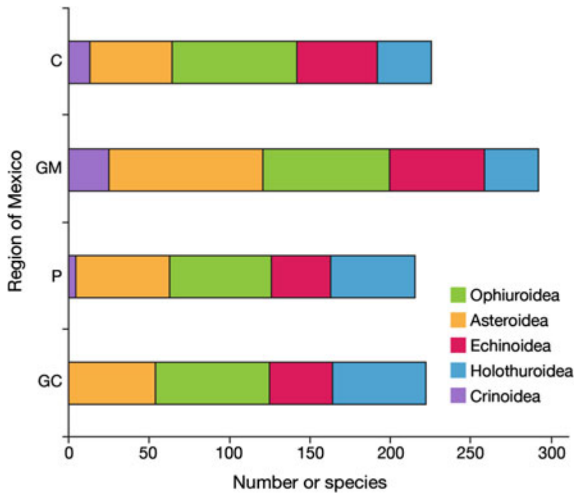

Fig. 2.4 Number of echinoderm species per class in each region of Mexico. *C* Caribbean, *GM* Gulf of Mexico, *P* Pacific Ocean and *GC* Gulf of California

waters. *Ophiothrix spiculata* is the most abundant and frequent species in the deep waters (Fig. 2.6).

The Gulf of California is the second area in terms of diversity of echinoids, with a total of 39 species (Solis-Marin et al. 2005), 12 of them in deep water. The most characteristic are: *Hesperocidaris asteriscus*, *H. perplexa*, *Arbacia incisa*, *Astropyga pulvinata*, *Centrostephanus coronatus*, *Echinometra vanbrunti*, *Lovenia cordiformis*, *Encope wetmorei*, *E. micropora*, *Clypeaster europacificus, Agassizia scrobiculata* and *Mellita grantii* (Figs. 2.6 and 2.7).

This region holds the greatest diversity of the sea cucumbers in Mexico, with 64 species. Most (48 species) have wider distributions; they occur from the Gulf of California to Central America or Galapagos Islands. Only two have a northern distribution, from Alaska to the Gulf of California. The majority of the species have shallow bathymetric distributions. Only 20 of the 58 species were collected from depths greater than 200 m. The most characteristic species of sea cucumbers are *Holothuria* (*Selenkothuria*) *lubrica*, *H.* (*Thymiosycia*) *arenicola*, *H.* (*T.*) *impatiens*, *H.* (*Halodeima*) *inornata*, *H.* (*Stauropora*) *fuscocinerea*, *H.* (*Platyperona*) *difficilis*, *Isostichopus fuscus*, *Neothyone gibbosa* and *N. gibber* (Solis-Marin et al. 2005, 2009) (Fig. 2.8).

2.2.4 Mexican Pacific Ocean

On the Pacific coast, the crinoids are represented by four species (13.7 % of the total for Mexico) off the western coast of the Baja California peninsula, and in the polymetallic nodule fields near the Revillagigedo archipelago and the Clarion

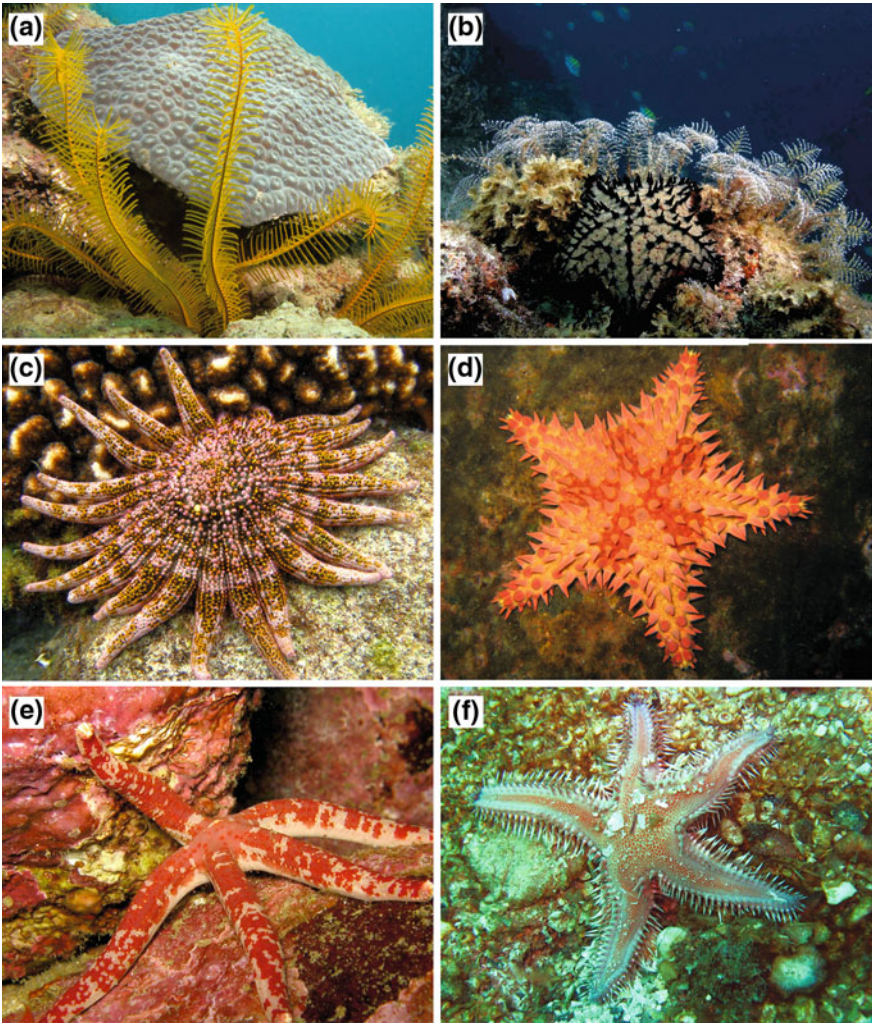

Fig. 2.5 **a** *Davidaster* sp., Mexican Caribbean. **b** *Nidorellia armata* (Gray, 1840), Gulf of California. **c** *Heliaster kubiniji* Xantus, 1860, Gulf of California. **d** *Amphiaster insignis* Verrill, 1868, Gulf of California. **e** *Linckia columbiae* Gray, 1840, Gulf of California. **f** *Astropecten armatus* Gray, 1840, Gulf of California. Images **a** by Valeria Mas, **b** and **e** by Carlos Sanchez-Ortiz, **c**, **d** and **f** by Israel Sanchez

fracture zone. These species, one stalked crinoid and three comatulids, are well adapted to thrive in extreme depths. The stalked crinoid is known from 3,000 to 4,500 m, while the comatulids occur from 12 to 3,234 m. The hyocrinid species *Hyocrinus foelli* Roux and Pawson, 1999, has been reported only near the Revillagigedo archipelago.

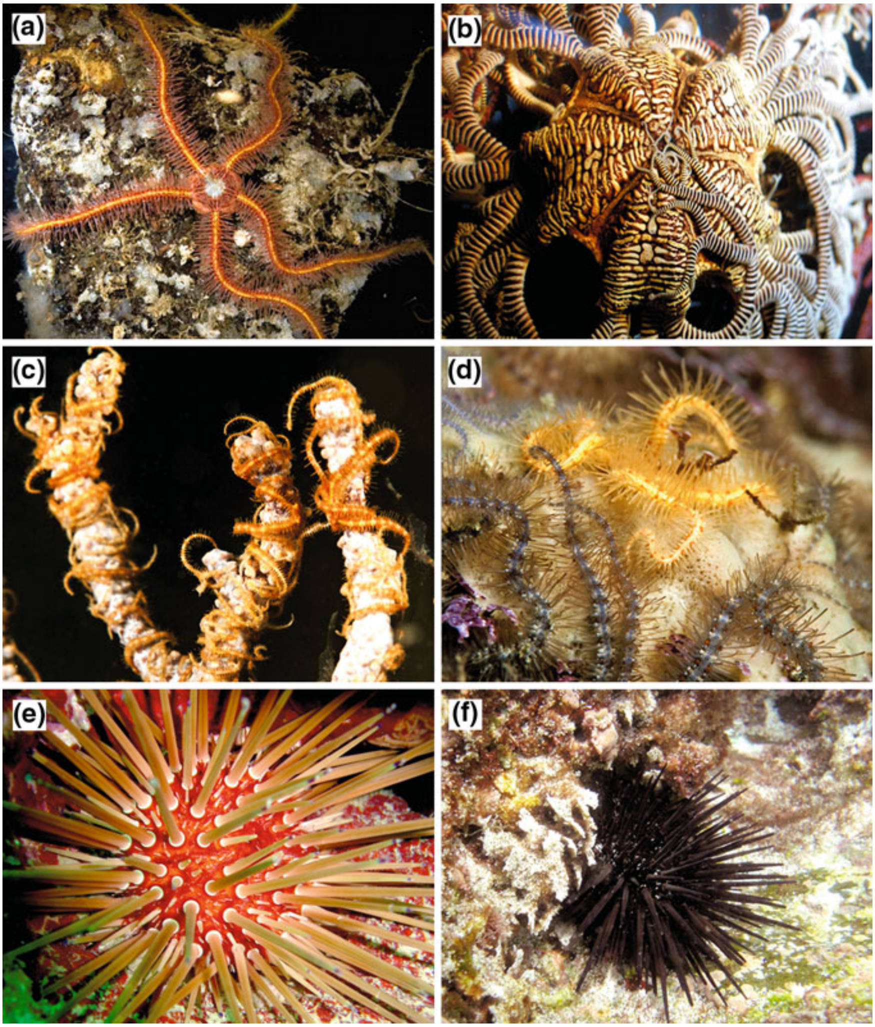

Fig. 2.6 **a** *Ophiothrix galapagensis* Lütken and Mortensen, 1899, central Gulf of California. **b** *Astrodictyum panamense* (Verrill, 1867), central Gulf of California. **c** *Ophiothela mirabilis* Verrill, 1867, Guerrero, Mexican Pacific. **d** *Ophiothrix rudis* Lyman, 1874, Guerrero, Mexican Pacific. **e** *Echinometra viridis* A. Agassiz, 1863, Veracruz, Gulf of Mexico. **f** *Echinometra vanbrunti* A. Agassiz, 1863, Jalisco, Mexican Pacific. Images **a** and **b** by Carlos Sanchez-Ortiz, **c** and **d** by Valeria Mas, **e** by Fred Boulag and **f** by Magali Honey-Escandón

The Class Asteroidea off the Mexican Pacific coast is of great interest, not only because of the high number of genera characteristic of this area, but also for the close relationships that the endemic species have with species in the Indo-Pacific, the Mediterranean and the Caribbean (Laguarda-Figueras et al. 2004). There are 59 species in total; 68 % (41 species) are shared with the Gulf of Baja California, 47

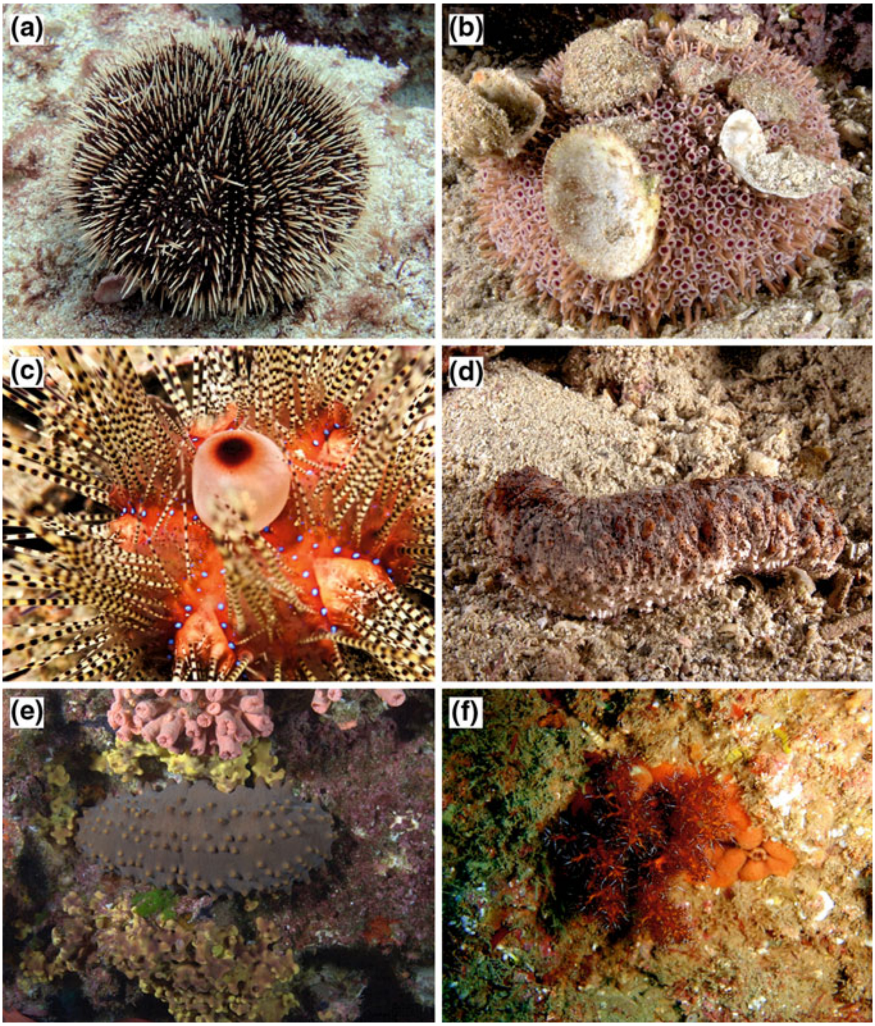

Fig. 2.7 **a** *Tripneustes depressus* A. Agassiz, 1863, Jalisco, Mexican Pacific. **b** *Toxopneustes roseus* (A. Agassiz, 1863), Jalisco, Mexican Pacific. **c** *Astropyga pulvinata* (Lamarck, 1816), Guerrero, Mexican Pacific. **d** *Holothuria pluricuriosa* Jaeger, 1833, Gulf of California. **e** *Isostichopus fuscus* Ludwig, 1874, central Gulf of California. **f** *Cucumaria flamma* Solis-Marin and Laguarda-Figueras, 1999, Jalisco, Mexican Pacific. Images **a** by Magali Honey-Escandón, **b** by Francisco Solis, **c** by Valeria Mas, **d** and **e** by Carlos Sanchez-Ortiz, **f** by Mauricio Valdes

are distributed in shallow waters and 12 occur only in the West coast of Baja California Peninsula (Fig. 2.4). Only 10 species are found also in the Revillagigedo Islands (Honey-Honey-Escandón et al. 2008). Conspicuous genera of asteroids include: *Astropecten, Luidia, Nidorellia, Pharia, Phataria, Heliaster,* and *Henricia* (Solis-Marin et al. 1993) (Fig. 2.5).

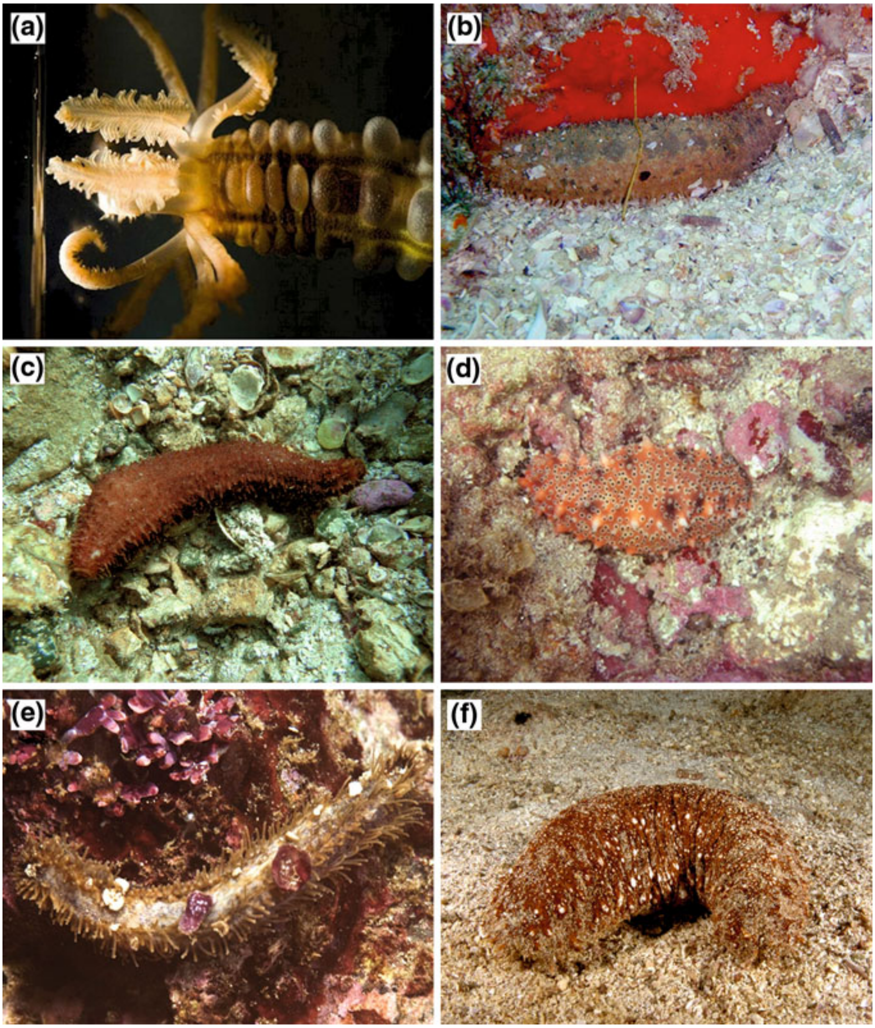

Fig. 2.8 **a** *Euapta godeffroyi* (Semper, 1868), central Gulf of California. **b** *Holothuria arenicola* Semper, 1868, Jalisco, Mexican Pacific. **c** *Labidodemas cf. macullochi* (Deichmann, 1958), Jalisco, Mexican Pacific. **d** *Holothuria kefersteini* Selenka, 1867, south of Gulf of California. **e** *Pentamera chierchia* (Ludwig, 1887), Guerrero, Mexican Pacific. **f** *Holothuria cf. inhabilis* Selenka, 1867, central Gulf of California. Images **a** by Offer Keter, **b** and **c** by Francisco Solis, **d** by Luis Carballo, **e** by Valeria Mas and **f** by Carlos Sanchez-Ortiz

The Pacific Ocean has the lowest diversity of ophiuroids of all Mexican waters, with only 63 species distributed in two orders, 12 families and 28 genera. Only 23 species are restricted to the Mexican Pacific Coast and the rest (40 species) are common to the Pacific Ocean and the Gulf of California. The order Ophiurida is the richest from the class Ophiuroidea, with nine families. The most speciose genus is *Amphiodia*, with seven species. *Ophiactis savignyi* is the ophiuroid species with the widest distribution in the shallow waters of the Pacific Ocean; it is distributed along the Gulf of California, the Gulf of Mexico, and also in the Mexican Caribbean. It has been recorded for eight States, the Revillagigedo Islands, and for the Maria Islands. Also, *Ophiocoma aethiops* is widely distributed in the shallow waters of the Pacific Ocean and it has been recorded for seven States, as well as for the Revillagigedo Islands.

Thirty seven species of echinoids are found in the Mexican Pacific Ocean, including the west coast of Baja California. These are classified in 25 genera, 14 families and seven orders. Twenty seven species are shared with the Gulf of California. The most common species are: *E. thouarsii*, *D. mexicanum*, *C. coronatus*, *A. incisa*, *Echinometra vanbrunti*, *Clypeaster europacificus*, *Encope micropora*, *E. perspectiva* and *E. wetmorei* (Honey-Escandón et al. 2008) (Figs. 2.7 and 2.8).

The Pacific coast of Mexico is the second in biodiversity for holothuroids, with 53 species (Fig. 2.4). Ten occur only on the west coast of Baja California. Seven occur also in the Pacific Coast. Of these 53 species, 46 also occur in the Gulf of California and the range of distribution can extend south to the Galapagos Islands. The characteristic species are almost the same for the Gulf of California: *Afrocucumis ovulum*, *Holothuria* (*Selenkothuria*) *lubrica*, *H.* (*Semperothuria*) *imitans*, *H.* (*Thymiosycia*) *arenicola*, *H.* (*T.*) *impatiens*, *H.* (*Halodeima*) *inornata*, *H.* (*Mertensiothuria*) *hilla*, *H.* (*Stauropora*) *fuscocinerea*, *Isostichopus fuscus*, *Neothyone gibbosa* and *N. gibber* (Honey-Escandón et al. 2008) (Figs. 2.7, 2.8).

2.2.5 Gulf of Mexico

The Gulf of Mexico is the most diverse area for the Classes Crinoidea, Asteroidea, Ophiuroidea and Echinoidea. Twenty five species (86 % of the total for Mexico) of crinoids live in the Gulf of Mexico and most of them occur in Campeche Bank. This Bank holds 22 of the 25 species present in the entire Gulf; about 75.8 % of the total species of crinoids in Mexican waters. Most of those crinoids can be found in both shallow (<200 m), and deep (>200 m) water environments; 17 species (68 % of the species in the Gulf of Mexico) are found in waters of less than 200 m depth, while 23 species inhabit the deepest part of the gulf. The unstalked or comatulid crinoids represent 76 % (19 species) of the total number of species present in the Gulf of Mexico, the stalked crinoids comprise 21 % (six species) and there is one species (4 %) of cyrtocrinid crinoid, *Holopus rangii,* present on Campeche Bank (Fig. 2.4).

There are 96 species of sea stars in the Gulf of Mexico. Half (48 species) are distributed in deep waters (>200 m depth), and 29 species have a wide bathymetric range. The most common genera are *Luidia*, *Astropecten*, *Cheiraster*, *Linckia*, *Pteraster* and *Echinaster* (Duran-Gonzalez et al. 2005).

Seventy nine species of ophiuroids occur in the Gulf of Mexico. Yucatan has the greatest number of species (46). *Ophiactis savignyi* is the species most frequently found in the Gulf of Mexico, especially in the State of Veracruz.

The number of species of echinoids in the Gulf of Mexico is 59. Of these, 30 (52 %) are present in deep waters (>200 m depth). The most common shallow water species with wide bathymetric (0–80 m) distribution are *Eucidaris tribuloides, Astropyga magnifica, Arbacia punctulata, Lytechinus variegatus carolinus* and *Encope michelini*. On the outer shelf *Clypeaster ravenelii* and *Brissopsis* are present in 80–190 m. Finally, *Plesiodiadema antillarum* and *Brissopsis atlantica* occur on the slope to 200 m. Geographically, *Encope aberrans*, *Clypeaster subdepressus* and *Echinolampas depressa* are restricted to Campeche Bank, Yucatan and Cape Catoche, Quintana Roo (Laguarda-Figueras et al. 2005a).

The Gulf of Mexico has the lowest diversity of sea cucumbers with only 33 species. Two species also occur off the Pacific coast and 20 are distributed also in the Mexican Caribbean in shallow waters. The rest (15 species) are present in deep waters of the Gulf of Mexico (Fig. 2.4), more than 200 m deep. The most common species are: *Holothuria* (*Halodeima*) *grisea*, *H.* (*H.*) *floridana*, *H.* (*Selenkothuria*) *glaberrima*, *H.* (*Semperothuria*) *surinamensis* and *Isostichopus badionotus* (Duran-Gonzalez et al. 2005).

Mexican Caribbean

In the Mexican Caribbean Sea, the crinoid fauna is not as diverse as it is in the Gulf of Mexico; nonetheless, the diversity of ecosystems (coral reefs, sandy bottom plains, deep slopes) provide habitats for 13 species, that represent 45 % of the sea lilies and feather stars reported in Mexican waters. In the Caribbean, the stalked crinoids represent 23 % with three species reported, inhabiting the Arrowsmith Bank and the Yucatan Channel area; while the comatulids comprise the major percentage (76 %) with 10 species in the same area. In this area, the isocrinid stalked crinoid *Endoxocrinus parrae* is the most frequently found species, along with the unstalked *Davidaster rubiginosus* (Fig. 2.5), *Comactinia meridionalis* and *Crinometra brevipinna*. A total of 13 species (84 %) are shared with the Gulf of Mexico (Fig. 2.4). Stalked crinoids are present in the Bank of Campeche and the Caribbean at depths that range from 86 to 143 m in the shallow areas; and from 747 to 1,245 m as the deepest limit. In the same region, the comatulid crinoids can be found from 2 to 200 m in the shallow range; and from 200 to more than 3,500 m in the deepest areas.

For the Asteroidea, the Mexican Caribbean is least diverse, with only 51 species. Forty two (79 %) of these are shared with the Gulf of Mexico. Of these 51 species, 14 occur in deep waters (>200 m depth) and 29 have a batimetric range at depths from 0 to more than 200 m. The most common genera are almost the same as in the Gulf of Mexico: *Luidia*, *Astropecten*, *Cheiraster* and *Echinaster* (Laguarda-Figueras et al. 2005b) (Fig. 2.5).

The Mexican Caribbean is the second most species-rich area of ophiuroids with 78 species. The distribution patterns of the species are diverse. The ones with the widest distribution in shallow waters of the Gulf of Mexico and Mexican Caribbean Sea are *Ophiolepis elegans, O. impressa, Ophiocoma echinata, Ophioderma cinereum, Ophiactis savignyi,* and *Ophiothrix angulata*. The deep-sea species with the widest distribution for both areas are *Ophiolepis elegans, O. impressa, Ophioderma cinereum,* and *Ophiothrix angulata*. Forty nine species are shared with the Gulf of Mexico.

Echinoids of the Mexican Caribbean coast are less studied than the other areas. Nevertheless, it is the second area in diversity with 50 species; 39 of them shared with the Gulf of Mexico. The most characteristic species occur in shallow waters. These are *Encope aberrans*, *E. michelini*, *Clypeaster subdepressus*, *Cassidulus caribaearum*, *Diadema antillarum, Echinometra lucunter*, *E. viridis*, *Eucidaris tribuloides* and *Tripneustes ventricosus* (Duran-Gonzalez et al. 2005).

The Mexican Caribbean has 33 species of holothuroids. The great majority of them (27 species) also occur throughout the Caribbean Sea and the Florida Keys. The most characteristic species are *Holothuria* (*Halodeima*) *floridana*, *H.* (*H.*) *grisea*, *H.* (*H.*) *mexicana*, *H.* (*Semperothuria*) *surinamensis*, *H.* (*Thymiosycia*) *arenicola*, *H.* (*T.*) *impatiens*, *H.* (*T.*) *thomasi*, *Isostichopus badionotus*, *I. macroparentheses* and *Euapta lappa* (Laguarda-Figueras et al. 2005b).

Endemism

The delimitation of endemism in marine species is difficult due to dispersion of larvae through oceanic currents. Nevertheless, Mexico possesses a few species that are endemic to a biogeographic province.

The Gulf of California, due to its unique oceanographic and geologic characteristics, has the majority of endemismic species (5). The echinoid *Encope grandis* is reported only for the Gulf of California and is present both along the continental coast and the islands within the Gulf. Three species of ophiuroids are endemic. These are *Ophiacantha hirta*, *Amphiophiura oligopora* and *Amphiura seminuda*. One species of shallow-water holothuroid *Athyone glasselli* is endemic.

For the North Pacific Ocean of Mexico, two species of crinoids, *Fariometra parvula* and *Florometra taneri* appear as endemic to the Californian province. In the southern part of Mexico, the sea star *Luidia latiradiata* (formely *Platasterias latiradiata*) seems to be endemic to the region from Chiapas, Mexico to Colombia. This species possesses archaic characters that can describe it as a “living fossil” (Caso 1945, 1970, 1972a; Fell 1962; Solis-Marin et al. 1993).

The only reported endemic species of ophiuroid in the Gulf of Mexico is *Amphiodia guillermosoberoni* from Terminos Lagoon, in Campeche State. This species was discovered and described by Caso (1979b). The species is more abundant inhabiting sites were the salinity ranges from 16 to 21 ppm. *Amphiodia* *guillermosoberoni* is the only Mexican ophiuroid species known to inhabit low salinity sites.

Only one species of sea star is endemic to the Mexican Caribbean, *Copidaster cavernicola*. This species, described by Solis-Marin and Laguarda-Figueras (2010a) is the only known asteroid that inhabits an anchialine-water cave ("Aerolito") in Cozumel Island (Solis-Marin et al. 2007a, Solis-Marin and Laguarda-Figueras 2008).

2.2.6 Mexican Fossil Echinoderms

The records of fossil Mexican echinoderms have been the subject of numerous publications since Nyst and Galeotti (1839). Buitron (1968) produced the first catalog on fossil echinoids of Mexico. Buitron (1990a) published an illustrated catalog of the echinoids from the Upper Jurassic and Lower Cretaceous of Mexico. Nieto-Lopez and Garcia-Barrera (2006) reviewed the Cretaceous echinoids of Mexico. Research on this matter has been carried out in extended areas such as the northern region (Boese 1910; Boese and Cavins 1927; Cooke 1955; Buitron 1970a, 1974a), the eastern region (Dickerson and Kew 1917; Lambert 1928; Maldonado-Koerdell 1953) and the northeastern region (Caso 1951b). Studies on the Baja California fossil echinoderms are mainly by Jordan and Hertlein (1926), Jackson (1937), Durham (1950, 1961), Wilson and Rocha (1955), and Chase (1956).

The fossil crinoids of Sonora State have been reported by Vachard et al. (2004) and Buitron et al. (2007a, 2007b, 2008). Strimple (1971) mentioned the crinoids from Coahuila State. The fossil echinoderms from Tamaulipas State have been reported by Dumble (1918), Israelsky (1924), Muir (1936) and Caso (1956). The fossil echinoderms of Veracruz State were studied by Boese (1906), Dickerson and Kew (1917), Caso (1956), Buitron (1978a) and Buitron and Silva (1979). Buitron et al. (1987) studied the fossil crinoids of Hidalgo State. Buitron (Buitrón 1973a, b) and Garcia-Barrera and Pantoja (1991) described the fossil echinoid fauna from Michoacan, Guerrero and Colima States. Fossil echinoderms from Puebla State were reported by Alencaster and Buitron (1965), Buitron (1970b), Esquivel-Macias et al. (2004), Martin-Medrano and Garcia-Barrera (2006), Applegate et al. (2009), and Martin-Medrano et al. (2009). Buitron (1976) and Garcia-Barrera and Pantoja (1991) studied the fossil echinoids from the State of Guerrero, and Buitron (1990b) from Oaxaca State. Lambert (1936), Jackson (1937), Muellerried (1951) and Buitrón (1974b, 1974c, 1978b) have recorded the fossil echinoids from Chiapas State.

The fossil echinoderm fauna in Mexico is represented by approximately 248 species. The Eocrinoidea (an extinct class of echinoderms that lived between the Early Cambrian and Late Silurian periods) is represented by one species (*Gogia granulosa* Robison 1965) (Nardin et al. 2009). Seventeen species of fossil Crinoidea have been recorded for the Mexican Paleozoic and Mesozoic; Class Asteroidea with only one species reported for the Cretaceous (*Pentasteria* sp.).

Six species of Ophiuroidea have been recorded from the Mexican Cretaceous and Paleogene-Neogene (Pliocene) from different localities in the mainland territory (*Ophiactis applegatei*, *Ophiura* sp., aff. *Amphiura*, aff. *Ophiomusium*; aff. *Stegophiura* and aff. *Ophiura*). The Echinoidea is the most diverse and widely distributed echinoderm fossil group in Mexico, with 221 species. One hundred of these are from the Mesozoic and 121 species are from the Cenozoic. Both groups are represented in 17 States of Mexico (Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon, Tamaulipas, San Luis Potosi, Hidalgo, Veracruz, Jalisco, Michoacan, Colima, Puebla, Guerrero, Oaxaca, Chiapas and Yucatan States). The Holothuroidea is represented by two Cretaceous species (Applegate et al. 2009).

The distribution of Mexican echinoderms in the Mesozoic and Cenozoic indicates that there was a large marine faunal province in eastern North America, which differs at the species level from the marine faunal province on the west coast of North America. This implies the existence of some kind of barrier during the Tertiary that prevented the faunal interchange between these two provinces. Echinoderms and other invertebrate groups in the region of the Atlantic and Pacific show the mark of a moderate exchange, superposed on the old pattern of Tertiary provincial aforementioned.

2.3 Research

2.3.1 Ecology and Reproduction Studies on Mexican Echinoderms

Ecological studies of the Echinodermata in Mexico have contributed to the knowledge of species richness, diversity and communities of echinoderms in several zones, mainly in the Gulf of California, southern Pacific and the Gulf of Mexico (Fig. 2.1).

Gulf of California

Salcedo-Martinez et al. (1988) generated a benthic inventory of echinoderms in Zihuatanejo, Guerrero. Data for each species were provided on bathymetric distribution, substrate, and some characteristics of the habitat.

Morgan and Cowles (1996) studied the effects of temperature on the behaviour and physiology of *Phataria unifascialis* and its implications for species distribution in the Gulf of California. They determined whether cool temperature was an important factor limiting this species distribution in the northern regions of the Gulf. Pyloric caecae and gonads showed that food limitation or lack of reproductive potential was a principal limiting factor. They also suggested that low temperatures of the northern gulf may well be an important factor limiting the northern distribution of this species in the Gulf.

Caso et al. (1996) performed qualitative and quantitative analyses of the echinoderm fauna from the littoral of Mazatlan Bay, Sinaloa and identified 25 species. The results showed that *P. unifascialis, Ophiocoma alexandri* and *Echinometra vanbrunti* were conspicuous because of their density and abundance. Cluster analysis showed the existence of three groups: the first included species with a limited distribution and low abundance, the second and the third had species widely distributed on sandy substrates in the bay. The highest diversity and specific richness index values corresponded to the species located in protected areas of the Bay, whereas the lowest diversity and specific richness index values corresponded to the species found in the exposed areas.

Reyes-Bonilla and Calderon-Aguilera (1999) analyzed the abundance, spatial distribution and consumption rate of *Eucidaris thouarsii* and *Acanthaster planci* at Cabo Pulmo, Gulf of California. The results showed that the action of corallivore organisms in terms of their population density and consumption rates was not a key factor determining scleractinian abundance in the reef of Cabo Pulmo.

Holguin-Quiñones et al. (2000) analyzed the spatial and temporal variation of Asteroidea, Echinoidea and Holothuroidea from shallow water at Loreto Bay, Gulf of California. The greatest mean abundance by transect and mean densities in order of importance for Echinoidea were *E. vanbrunti*, *Centrostephanus coronatus, Tripneustes depressus*, *E. thouarsii* and *Diadema mexicanum*; and for Asteroidea, *P. unifascialis*, *Mithrodia bradleyi* and *A. planci*. Asteroidea was the dominant class with 12 species, followed by Echinoidea.

Reyes-Bonilla et al. (2005) examined and compared the community structure of asteroids in four regions of the Gulf of California, characterized by the presence of rocky reefs. They found Loreto Bay had the highest richness and abundance of asteroids. However, there were no statistically significant interregional differences among ecological indices and no groups of locations singled out in terms of species composition. *Phataria unifascialis* was the dominant species followed by *Pharia pyramidatus*. There were statistically significant positive associations between three pairs of species, indicating competition between these asteroids in the Gulf of California is not particularly relevant.

Cintra-Buenrostro et al. (2005) determined the correlation between species richness of shallow water (depth < 200 m) asteroids and key oceanographic factors in nine sections of one degree latitude (from 23 to 31°N) of the Gulf of California. They reported continental shelf area (at 100 and 200 m depth), mean temperature and range at three depth levels (0, 60 and 120 m), thermocline depth, surface nutrient concentrations (nitrates, phosphates and silicates), surface photosynthetic pigment concentration, and productivity. Sea star species were assigned to different feeding guilds: predators of small mobile invertebrates, predators of colonial organisms, generalist carnivores, detritivores, and planktivores. The results showed that total species richness and guild species richness had strong latitudinal attenuation patterns and were higher in the southernmost Gulf. Nutrients and surface pigments always presented negative relationships with species richness, indicating that productive environments set limits to the diversity of sea stars in the study area.

The number of echinoderm species varies along the Gulf of California, increasing towards tropical latitudes (Cintra-Buenrostro 2001). However it seems the community structure of echinoderms in the Gulf is relatively homogeneous and dominated by asteroids (Reyes-Bonilla et al. 2005; Herrero-Perezrul et al. 2008). However, echinoderm distribution is probably related to habitat type. For instance, shallow bays favor coral communities and species associated with them.

Holguin-Quiñones et al. (2008) analyzed the spatial and temporal variation of Echinoidea and Holothuroidea in shallow water at Isla San Jose, Gulf of California. The most abundant species were *T. depresus*, *E. vanbrunti*, *P. unifascialis*, *C. coronatus*, *D. mexicanum* and *E. thouarsii*. There were no statistically significant spatial or temporal differences in diversity, evenness and species richness. The analysis identified two groups from locations of the eastern and western coasts.

Herrero-Perezrul et al. (2010) analyzed the community structure of conspicuous species of echinoderms of three islands in the southern Gulf of California: San Jose, Espiritu Santo and Cerralvo. They identified 23 species. The ecological indices showed similar values between the islands. However, the species composition was different. The community structure was stable in the study area. It seems that habitat type has a strong influence on the distribution and abundance of echinoderms.

Luna-Salguero and Reyes-Bonilla (2010) compared the community and trophic structure of rocky bottom asteroids in two regions of the Gulf of California. The starfish assemblages in both zones were dominated by a single species, *Phataria unifascialis*, and the Loreto area had higher values of richness, abundance and diversity of asteroids than the Ligüi area. In both areas, herbivores predominated above detritivores and carnivores. Abundance at each trophic level was statistically significantly higher in Loreto with more trophic groups per transect. These higher values of richness, abundance and diversity in Loreto are probably a consequence of a higher number of habitats and food resources.

South Pacific

Benitez-Villalobos (2001) characterized the community of echinoderms at two coral reef communities (La Entrega and Casa Mixteca) in Bahias de Huatulco region, Oaxaca State. The La Entrega community showed the lowest values of diversity and evenness and the highest values of dominance, associated with a more intense human activity. At the same locality Zamorano and Leyte-Morales (2005a) repeated the analysis of Benitez-Villalobos (2001) and compared the results obtained by both studies. Species richness and abundances they recorded were higher than those obtained in 2001. However there were no statistically significant differences in the diversity calculated by both studies. Ophiuroidea was the dominant class of echinoderms in 2001, whereas Holothuroidea was dominant in 2005. The authors attributed this change in dominance to the intense dredging that had occurred in Santa Cruz Bay. This probably produced an increase in suspended matter in the water column, supporting the holothuroids, whereas ophiuroids had been affected by the loss of natural refuges.

Zamorano and Leyte-Morales (2005b) worked in La Entrega and assessed population densities at two depth ranges (0–6 m and 6–12 m) of four echinoid species: *E. thouarsii, E. vanbrunti*, *T. roseus* and *D. mexicanum*. Density of the four populations varied considerably with the highest densities in the deep zone. Total abundance of sea urchins, including shallow and deep samples, did not vary significantly over time. However, the abundance per depth range was different over time for all species except for *E. thouarsii*. The authors established that the reef at La Entrega was undergoing an advanced state of erosion that could favor an increase in sea urchin abundance and therefore an increase in bioerosion activity.

Rios-Jara et al. (2008) described the specific composition of echinoderms from Isla Isabel National Park, in the central Mexican Pacific, on rocky and sandy substrates in subtidal areas to 19 m depth. The most important species according to the biological value index were *D. mexicanum, T. roseus*, *P. unifascialis, Pharia pyramidatus*, *Ophicoma alexandri*, *Holothuria lubrica*, *Isostichopus fuscus* and *E. thouarsii*. They established these species showed more affinity to the Gulf of California than to the central-south Pacific region.

Lopez-Uriarte et al. (2009) described the specific composition and community structure of the macrobenthic invertebrates from Bahia de Chamela, Jalisco, using quadrants along transects of 50 m length. Echinoderms showed the highest species richness, and the abundance and number of species were related to the heterogeneity of the substrate, which was characterized by stable mixed substrates including rocks, medium sized sand and scattered coral colonies. These kinds of substrates provide shelter in their cavities and crevices, and surfaces for the attachment of sessile species.

Zamorano and Leyte-Morales (2009) described and characterized the community of echinoderms associated with coral reefs in Zihuatanejo and Acapulco, Guerrero during the rainy and dry seasons. The authors proposed the mean values obtained for diversity in the 13 study sites are low compared to the maximum possible diversity, due to the dominance of the sea urchin *D. mexicanum* and the sea star *P. unifascialis*. These species, *T. roseus* and *Hesperocidaris asteriscus* were the most frequent and predominant species. Compared to other sites of the Eastern Tropical Pacific, densities were considered low. However, they did not find statistically significant differences in the densities of *D. mexicanum* between localities, depths, and seasons, although in some localities, the sea urchin densities increased considerably during the rainy season. The results also showed that, in localities close to Acapulco, Guerrero, a heavily visited touristic place, the diversity of echinoderms was lower and the abundance of *D. mexicanum* was higher.

Gulf of Mexico

In terms of ecology of Echinodermata, the Gulf of Mexico is one of the less studied zones. Only four studies have been published presenting ecological analyses of the communities of echinoderms in the region (Fig. 2.1).

Caso et al. (1994) carried out qualitative and quantitative studies on the echinoderm community from the Laguna de Terminos, Campeche. The relative abundance, geographic and local distribution, type of nutrition and habitat of 12 species of Echinodermata were analyzed. *Lytechinus variegatus*, *Luidia clathrata*, *Echinaster serpentarius*, *Ophiophragmus würdermanii* and *Amphiodia guillermosoberoni* stood out because of their relative importance and abundance. The higher diversity and specific richness index values corresponded to the species located in the areas with major oceanic influence, and the low diversity and specific richness index values corresponded to species found in the lagoons.

Celaya-Hernandez et al. (2008) analyzed the diversity, abundance, distribution and substrate preferences of the regular sea urchins found at the southern region of the Isla Verde lagoon reef, Veracruz. The substrate types considered in the analysis were: coral-rocks, rocks, rocks-sand, and sand and *Thalassia testudinum* beds. *Diadema antillarum, Echinometra lucunter lucunter* and *E. viridis* were mainly associated with coral-rock, rock and sand substrates, whereas *Lytechinus variegatus* and *Tripneustes ventricosus* were mainly associated with sea grass. The authors established that the distribution of the sea urchins is dependent upon substrate type and feeding habits which are intimately linked. The seven species reached their largest abundances during the rainy season. Jorgensen et al. (2008) recorded the high population density survival of *D. antillarum* after a category five hurricane in the southern Mexican Caribbean.

Vazquez-Bader et al. (2008) described the distribution and relative abundance of epifaunal echinoderms in the southwestern region of the Gulf of Mexico, based on 181 collections by the use of an Otter Trawl during different years. This study recorded 25 species of Asteroidea, 15 species of Ophiuroidea, 14 species of Echinoidea, four species of Crinoidea, and one species of Holothuroidea. The most frequently found species was *L. clathrata,* reported at 68 % of all stations. The highest seasonal density of echinoderms was recorded in autumn on carbonate substrate, whereas the highest species richness was found in summer.

Gonzalez-Azcarraga (2009) compared the community structure and morphological diversity of regular sea urchins in the Gulf of Mexico "Veracruz Reef System" and the Cozumel reefs in the Mexican Caribbean. They found statistically significative differences for all indexes among localities and at all depths. Veracruz Reef System showed the highest values due to their greater substrate heterogeneity and a high organic material deposition.

2.3.2 Population Ecology Studies

Few population ecology studies focused on particular species of echinoderms have been carried out in Mexico. This is regrettable, especially in the case of echinoids and holothurians, considering their importance as key organisms in the structure and dynamics of benthic communities, and their potential for commercial exploitation. Important species include the sea urchin *D. mexicanum* and the sea cucumbers *Isostichopus fuscus* and *Parastichopus parvimensis*.

Echinoids

Espino-Barr et al. (1996) analyzed the density and population structure of *D. mexicanum* on the rocky shore of the state of Colima in the Mexican Pacific as part of a technical assessment for requests of permission for sea urchin fishing along Colima and Jalisco shores. The results indicated an average density of 17,000 ind ha^{-1}. There was an increase in gonad weight with respect to body weight from May to August, followed by a decrease, indicating spawning during those months. They propose the commercial exploitation of the species between May and September when the gonads reach the greatest weight. Nevertheless they proposed it be restricted to protect the species.

Herrera-Escalante et al. (2005) evaluated the importance of *D. mexicanum* as a bioerosive agent of coral carbonate at Bahias de Huatulco and the relative magnitude of coral accretion and bioerosion. The results showed that, in general, *D. mexicanum* did not exert a significant role on coral reef community structure at the study area, probably because of their relatively small size and low numbers. Regarding the balance between bioerosion and carbonate production, they established that coral accretion exceeded sea urchin erosion at all sites examined, indicating that at Bahias de Huatulco coral reef communities were actively growing.

Benitez-Villalobos et al. (2008) evaluated the temporal variation of population densities and bioerosion by *D. mexicanum* at Isla Montosa, La Entrega, Isla Cacaluta and San Agustin, Bahias de Huatulco. Mean density of the sea urchins was relatively constant during the study at all localities and there were significant differences between La Entrega and the other localities. The calculated amount of $CaCO_3$ removed by *D. mexicanum* showed variations between localities. The lowest rate of bioerosion occurred at San Agustin and the highest at La Entrega. They compared their results with those obtained by Herrera-Escalante et al. (2005) and established that the recent urchin population decrease means a reduction in their removal of coral $CaCO_3$, and this reduction could be beneficial for coral reef growing and recovery from stress. Nevertheless it could also signify an increase in algal biomass and competition with corals for light and space.

Benitez-Villalobos et al. (2009) reported that until May 2009, the density of *D. mexicanum* at the different reef communities of Bahias de Huatulco remained relatively constant over time, with the highest density at La Entrega, where up to aggregations of up to 100 ind m^{-2} were observed. However, in May 2009, not a single individual was observed in the entire reef area (4–12 m) between 2.30 and 3.20 m and surrounding rocky bottom. Instead there were a high number of spines and hundreds of bare tests scattered over the reef, indicating a mass mortality event in the sea urchin population. Observations made by the authors during further monitoring suggested disease as the cause (Benitez-Villalobos et al. 2009). The observed signs were similar to those described during the mass mortality event of *D. antillarum* that occurred in the 1980s throughout the geographical range of this species in the Western Atlantic.

Fodrie et al. (2007) studied the mechanisms that regulate the feedings position and feeding mode selection of the sand dollar *Dendraster excentricus* in some Mexican localities. Zamorano and Leyte-Morales (2009) worked on the association of the echinoderms with reef formations on the central Mexican Pacific (Guerrero). Torres-Martinez and Solis-Marin (2010) analyzed sediment utilization and feeding niche breadth of the echinoid *Meoma grandis* in the central Mexican Pacific (Guerrero). Ebert (2010) studied the demographic patterns of *Strongylocentrotus purpuratus* along a latitudinal gradient and included one site on the Mexican Pacific territory.

Francisco and Herzka (2010) measured the role of physical and biological factors regulating the mode of feeding of the sand dollar *D. excentricus* in a shallow estuary in Baja California. The percentage of inclined sand dollars was strongly and positively correlated with tidal level but no relationship was found with current velocity, density and organic matter content of the water. The prone position, indicative of deposit feeding, was largely limited to low tidal levels. Sand dollars were only oriented parallel to the prevailing currents during the strongest currents of spring tides (>20 cm s^{-1}). The regulation of the feeding mode of sand dollars in shadow and hydrodynamically complex estuarine systems differs from the feeding mode found in exposed coastal environments.

Sonnenholzner et al. (2010) evaluated the effect of three tagging methods on the growth and survival of *Strongylocentrotus purpuratus*. The tags tetracycline and two internal tags, Decimal Coded Wire Tags (CWT) and Passive Integrated Transponder tags (PIT) were used alone or in combination to evaluate growth rates, survival, tag retention and post-tagging stress. The results suggested that the tags used did not affect growth or survival of the urchins. Post-tagging stress was significantly affected by urchin size but not by tagging methods.

Palleiro-Nayar et al. (2011) analyzed spatial variation in *Strongylocentrotus franciscanus* recruitment and assessed the impact of substrate availability and adult sea urchin density on recruitment along the west coast of Baja California. There were significant differences in recruit density among sites. Substrate structure was the main factor that explained these differences. Adult densities did not explain recruitment differences among sites. Temporal analysis showed that both substrate structure and adult densities were important in explaining recruit densities at both sites. The absence of a clear spatial pattern suggests other factors may explain the differences observed in density and recruitment among sites.

Holothuroids

Reproduction is maybe the most studied trait of sea cucumbers in Mexico, especially for commercial species (*Isostichopus fuscus* and *Parastichopus parvimensis*) (Herrero-Perezrul 1994, 2004; Fajardo-León et al. 1995; Tapia-Vasquez et al. 1996; Herrero-Perezrul et al. 1999). However, some other sea cucumbers (*Holothuria pluricuriosa* and *H. lubrica*) have been studied (Herrero-Perezrul 1994; Skarbnik-Lopez 2006; Skarbnik-Lopez et al. 2010).

Tapia-Vasquez et al. (1996) analyzed the gonadal cycle of *P. parvimensis* at the west coast of Baja California. They showed that the gonad develops during spring and spawning occurs during summer (July and August). They estimated first maturity at lengths between 25 and 29 cm. The reproduction in this species was similar at Isla Natividad and Bahia Tortugas, Baja California Sur (Fajardo-Leon et al. 2008). One interesting trait they described is evisceration prior to gonad development from August to October. Therefore they proposed a "reproductive ban" from February to May and another from August to October because the evisceration process.

Herrero-Perezrul et al. (1999) analyzed the reproduction and growth of *I. fuscus* at Isla Espiritu Santo, Baja California Sur. They described an annual reproductive pattern, with a single spawning period during summer, which was also influenced by sea surface temperature. The reproductive cycle was monitored histologically. Five gonadal stages were described according to cell types present in the gonad. Reyes-Bonilla et al. (2008) evaluated the abundance of *I. fuscus* in the National Park Bahia de Loreto, Gulf of California, during the fishing season 2005–2006 at 29 sites or "banks". The average abundance of *I. fuscus* in the park was 1.41 $\pm$ 0.02 individuals per transect, with an average density of 0.0280 $\pm$ 0.0004 ind m^{-2}. The density was slightly higher in the southern banks. The lowest density was at Isla Montserrat, which is close to the coastline of the Baja California Peninsula where most of the fishery occurs. They concluded that the low levels of density do not represent a critical situation for the populations.

Herrero-Perezrul and Reyes-Bonilla (2008) estimated the relative condition of an exploited population of *I. fuscus* at Isla Espiritu Santo, Baja California Sur. Length and weight were monitored each month and the weight-length relationship and the index of relative condition were calculated. The weight-length relationship showed that *I. fuscus* grew allometrically at this site. The index of relative condition exhibited a parabolic relationship with total length, and peaked at 21 cm length, which is the size of first maturity. They concluded this pattern may indicate the condition of individuals improves slowly with age up to a certain point and then decreases gradually. This finding is important because provides possible evidence of aging. It is the first indication of senescence in holothurians.

Skarbnik-Lopez et al. (2010) described the reproductive biology and growth of *Holothuria* (*Selenkothuria*) *lubrica* at Bahia de la Paz, Baja California Sur. According to data of the length-weight relationship they determined this species grows allometrically at the site. Five gonadal stages were described according to cell types present in the gonad. The results showed this holothurian spawns annually during summer. Variations of the gonad index were directly related to gonad development and sea-surface temperature, with highest values in summer corresponding with ripe gonads and the highest sea-surface temperature.

Some other studies have been directed to chemical analysis. Bakus (1974) demonstrated the toxicity to fishes of some holothurian species (*Isostichopus fuscus*, *Holothuria impatiens*, *H. imitans*, *Neothyne gibbosa* and *Parastichopus parvimensis*) occurring in the Mexican Pacific (Gulf of California). The evidence supports the hypothesis that toxicity in this species has evolved as a chemical defense mechanism against predation by fishes.

The small number of publications about ecology of echinoderms in Mexico provides evidence of unequal and limited development of ecological studies related to this group (Fig. 2.4). There are few papers analyzing echinoderm communities in Mexico, and only four species have been studied in terms of population ecology. Furthermore, basically all the studies have been focused mainly on the Gulf of California and the Mexican Pacific, leaving the rest of the shoreline practically unstudied ecologically, except for two projects performed in the Gulf of Mexico (Fig. 2.1). This is an indicator of the geographical location and field of influence of the institutions that hold specialists who are dedicated to the study of ecology of echinoderms; therefore it is important and essential to become involved with other institutions in order to develop collaborations that make possible an increase of knowledge of the current status and the dynamics of populations of echinoderms, in terms of their relationships with their biotic and abiotic environments, in order to obtain a more comprehensive knowledge of echinoderm communities in the entire country.

2.3.3 Chemical Studies of Echinoderms in Mexico

There are few studies about the chemistry on Mexican echinoderms. The first was by Lara-Guadarrame (1985), who determinated the basic biochemical compounds in the gonads of the sea urchin *Strongylocentrotus franciscanus*. Encarnacion et al. (1989) isolated the first marine natural product from a Mexican echinoderm, “Neothyside A” from the sea cucumber *Neothyone gibbosa*. This tryterpenoid tetraglycoside was isolated with cromatographic techniques. Another natural product isolated from *N. gibbosa* is Neothyoside B, a triterpenoid diglycoside (Encarnacion et al. 1996).

Encarnacion et al. (1996) wrote a book about the traditional southern California medicine. They mentioned that Indians used some marine organism as traditional drugs, including the sea urchin *Echinometra vanbrunti* and the sea star *Astropecten armatus*. Both are still used as traditional medicines as anti-abortion agents, as agents to remove scars and as a preventive for vaginal bleeding.

Table 2.1 Mexican echinoderms used in the assays of biological activity by Bryan et al. (1996, 1997)

	Antibacterial	Antifouling		Feeding deterrence		
		B. amphirite	*B. neritina*	*L. rhomboidies*	*C. variegatus*	*L. emarginata*
Class Asteroidea						
Anthenoides piercei		√			√	
Echinaster sp.			√	nt	nt	nt
Astropecten articulatus		√	√	√	√	
Goniaster tesselatus	√	√	√	√	√	
Linckia nodosa			√	√		
Luidia clathrata	√				√	
Narcissia trigonaria		√		√	√	
Oreaster reticulatus		√		√	√	
Tamaria halperni				√	√	√
Tethyaster grandis					√	
Tosia parva (=*Pawsonaster parvus*)				√	√	
Class Holothuroidea						
Holothuria lentiginosa				√	√	
Isostichopus badionotus				√	√	
Class Ophiuroidea						
Astrocyclis caecilia				√	√	
Asteroporpa annulata		√	√	√	√	
Astrophyton muricatum	√			√	√	
Class Crinoidea						
Comactinia merdionalis			√	√	√	

√ Activity significative, *nt* No tested

Bryan et al. (1996) studied the antibacterial and antifouling activity of the ethanolic extracts of 20 species of echinoderms (11 asteroids, three holothuroids, three ophiuroids and one crinoid) collected in the Gulf of Mexico. They used cultures of *Deleya marina* and *Alteromonas luteo-violacea* for antibacterial assays, and larvae of the barnacle *Balanus amphirite* and the bryozoan *Bugula neritina* in the antifouling assays. They found that only three species had significant antibacterial activity and 11 species antifouling activity (Table 2.1). Bryan et al. (1997) determinated the chemical defense of 19 species of echinoderms (10 asteroids, three holothuroids, three ophiuroids and crinoid). For this assay they made pellets with a tissue of every species and used them in feeding assays with two marine fish *Lagodon rhombodies* and *Cyprinodon variegatus* and a crustacean *Libinia emarginata*. They found that 15 species deterred feeding by *L. rhombodies* and 17 species deterred feeding by *C. variegatus*. Only two species deterred feeding *L. emarginata* (Table 2.1). Juárez-Espinoza (2010) screened antibacterial, antioxidant and hemolitic activity from ethanolic extracts of *D. antillarlum*.

2.3.4 Molecular Systematics Studies on Mexican Echinoderms

McCartney et al. (2000) sequenced 630 bp of the cytochrome oxidase I (COI) mitochondrial gene of seven species of the genus *Echinometra* (including *E. vanbrunti* from the Mexican Pacific) to provide comparable information on the eastern Pacific and Atlantic species, to estimate dates for cladogenic events. They found that an earlier split, assumed to have been coincident with the completion of the Isthmus of Panama, separated the eastern Pacific *E. vanbrunti* from the Atlantic common ancestor and concluded gene flow within species is generally high.

Lessios et al. (2001) reconstructed the phylogeny of the sea urching genus *Diadema* using mitochondrial DNA sequences from individuals around the world to determine the efficacy of barriers to gene flow and to ascertain the history of dispersal and vicariance events that led to speciation. They used *D. mexicanum* from the Gulf of California in the analysis. The *D. mexicanum* specimens grouped with species from the West Pacific and western and central Atlantic (*D. antillarum*, *D. savignyi* and *D. paucispinun*). They found that Indo-Pacific populations apparently maintained genetic contact with Atlantic populations around the southern tip of Africa for some time after the Isthmus of Panama was completed.

2.3.5 Biogeography Studies

Studies on echinoderm distribution patterns in Mexico are relatively recent. In addition, they are poorly documented. The first approaches have been made to understand the affinities between faunal provinces or regions in the Mexican territory. One of the earliest works in Mexico was made by Parker (1963). His study analyzed the zoogeography and ecology of benthic invertebrates in the Gulf of California, recognizing 11 faunal assemblages based on the characterization of its environments. He found that, compared with benthic communities elsewhere in the world, the diversity of shallow-water species in the Gulf of California is striking. No single species is dominant. Comparisons between the macro-invertebrate assemblages of the Gulf of California and those of the Gulf of Mexico and other parts of the world demonstrate that great similarities, generally at the subgeneric level, exist in similar environments throughout the subtropical and tropical regions of the world.

Laguarda-Figueras et al. (2002) analyzed the geographical and bathymetric distribution of Mexican Caribbean asteroids, evaluating the distributional patters and their affinities. They found that the “extended-Western Atlantic” and “warm

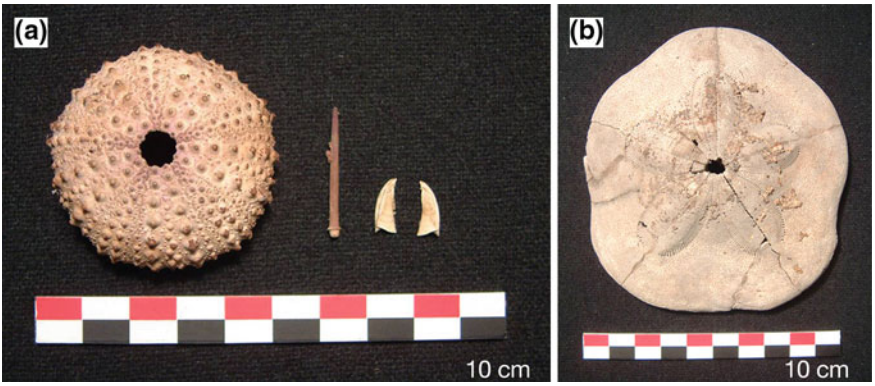

Fig. 2.9 **a** *Echinometra vanbrunti* A. Agassiz, 1863. Test, primary spine and teeth from the offerings at the great temple of the Aztecs; **b** *Clypeaster speciosus* Verrill, 1870. Test from the offerings at the great temple of the Aztecs

water Eastern Atlantic" were the patterns best represented, suggesting that the asteroid fauna in the Mexican Caribbean includes an important group of tropical species that have extended towards the north in zones of colder waters like the northern Gulf of Mexico and east coast of USA. Work by Caballero-Ochoa and Laguarda-Figueras (2010) used Parsimony Analysis of Endemism (PAE) to analyze the holothurian faunal affinities between the provinces of the Mexican tropical Pacific Ocean.

They found that the Cortes Province was the most diverse, including 62 holothurian species. The Panamic Province was not closely related with the Mexican, Cortes, Californian, Clipperton, Revillagigedo and Islas Marianas Provinces. Another important work is that of Hernandez-Diaz (2011) who also used PAE method to solve the relationship between echinoderms of the reefs of Yucatan. She found a nested pattern of distribution, which suggests they all belong to the same zoogeographic region with faunal elements from the Gulf of Mexico and Caribbean Sea.

2.3.6 Ethnobiology of Echinoderms in Mexico

Animal remains have been part of the archaeological discoveries around the world and are present in different cultures. Ethnobiology is defined as the study of the past and present interrelationships between human cultures and the animals in their environment. It includes classification and naming of zoological forms, cultural knowledge and use of wild and domestic animals (Seixas and Begossi 2001).

In 1978, the Aztec Great Temple ruins were discovered beneath the central plaza of Mexico City. Over the next few decades, this sacred structure was excavated and studied, revealing a wealth of information about Aztec religious life. Five-hundred years ago, this multi-tiered pyramid marked the literal center of the Aztec universe, where elaborated ceremonies were performed to maintain cosmic order and sustain the gods. Among the abundant offerings entombed in the foundations, the seventh constructive stage of the Great Temple held the remains of complete tests and fragments of three species of echinoids: *Echinometra vanbrunti* (Fig. 2.9a), *Clypeaster speciosus* (Fig. 2.9b), *Mellita* sp., *Meoma grandis*. *Echinometra vanbrunti* represents the most abundant echinoderm remains buried beneath the Great Temple (Solis-Marin et al. 2010). Only one arm tip fragment of the starfish *Astropecten* sp. has been found, showing that starfish were also used during the burial ceremonies. The remains are dated between the years 1502–1521 and were found at the deepest excavation level.

Because the Aztecs received tribute of other towns that they had dominated, we believe these echinoderms came from the tribute payment of some group dominated by the Mexicas. For example, *C. speciosus* presently occurs along the northwestern coast of Mexico. We believe it was transported from that zone. The Mexica Empire at that time (1502–1521) had conquered part of the national territory (Guerrero, Oaxaca, Chiapas States) and other coastal areas of the Mexican Pacific. This record is very important because it indicates they received materials far more to the north than normally considered (limits of the Michoacan and Guerrero States). Some specimens found in the offerings probably have they origin from the west coast of North Mexico, perhaps Mazatlan, Sinaloa. Although the Aztecs did not conquer the groups of these areas, we believe that the settler groups of "Zihuatlan" province gave tributes to the Aztecs. Although they never knew the exact limits of their empire, they knew that it was in the North of Mexico. The Mexicas never defeated the Tarascos, but they dominated the province of Zihuatlan. There is reason to believe they received tribute of some group or groups that were more to the north of the country.

Animal offerings in the burials were made by the highest priests. Their rituals were closed events. In the massive events they were not celebrated with this type of offerings. The offerings were made to inaugurate and to consecrate new building structures and possibly to commemorate festivities of the ritual calendar. The marine animals, including the sea urchins and starfish (and very probably other classes of echinoderms) were brought alive to the site. *Echinmetra vanbrunti* found in the offerings have remains of pedicellariae on the top of the test and some fragments of the Aristotle's lantern. The transport was made using emissaries who ran very long distances and for a time. In average they ran 30 km daily.

2.4 Aquaculture and Fisheries

Echinoderm fisheries in Mexico are based mainly on the sea urchins *Strongylocentrotus franciscanus* and *S. purpuratus*, the sea cucumbers *I. fuscus* and *Parastichopus parvimensis,* on the Pacific coast of Mexico and in the Gulf of California. Except for *P. parvimensis*, the other species were heavily exploited during the 1990s. It is important to mention that all echinoderm catch is exported to other countries, mostly Eastern countries. In the same way, other echinoderms are also captured for aquarium trade (Micael et al. 2009). Mexico is considered one of the main exporters together with Indonesia, Singapore, Fiji, Sri Lanka, Philippines and Vanuatu. For instance, the populations of the Atlantic sea star *Oreaster reticulatus*, used as souvenir, have declined in the Mexican Caribbean (Lunn et al. 2008). Also in the Gulf of California there are other sea stars (*P. unifascialis, P. pyramidatus* and *Pentaceraster cumingi*) that are currently extracted for ornamentation purposes. However, artisanal fishing has no regulations and the limited information available comes from the results of a survey of the Mexican echinoderm trade. Currently, an estimated 62 stakeholders in Mexico collect an average of 12,000 sea stars annually for the souvenir industry.

Some studies have focused on the effect of chemicals related to metamorphosis of commercially important sea urchins. Carpizo-Ituarte et al. (2002) tested the response of three species of sea urchin (*L. pictus*, *S. purpuratus*, and *S. fransicanus*) to excess K^+ in sea water as artificial inducers of metamorphosis. The results showed that K^+ was an effective metamorphic inducer in all three species. The response depended on concentration and length of exposure. Castellanos-Kotkoff et al. (2004) showed the effect of thyroxine on metamorphosis and the presence of the nuclear receptor COUP-TF in the larvae of three species of sea urchins (*L. pictus*, *S. purpuratus*, and *S. fransicanus*) from the Mexican Pacific.

Salas-Garza et al. (2005) summarize some of the basic studies and main achievements in the larval development of the red sea urchin *S. franciscanus* in Baja California. Spawning of red sea urchins was routinely induced with KCl; eggs were fertilized using a 100,000 sperm ml^{-1} solution. KCl proved the most consistent metamorphic inducer, regularly yielding metamorphosis percentages higher than 90 %. Metamorphosis was considered complete when the functional jaw that juveniles use for first benthic feeding appeared (as soon as 20 days after induction). With this method several thousands of red sea urchin juveniles were produced.

Amador-Cano et al. (2006) used artificial inducers to study signal-transduction pathways involved in metamorphosis of *S. purpuratus* postlarvae. Participation of protein kinase C (PKC), G-protein-coupled receptors (GPCRs), and calcium were investigated during its metamorphosis, showing that the GPCRs may be shared between the artificial (KCl) and natural (biofilm) inducers.

2.4.1 The Fishery of Sea Urchins in the Baja California Peninsula, Mexico

The Baja California fishery is based on two species, the red urchin *S. franciscanus* and the purple urchin *S. purpuratus*. Both species are found in the Pacific coast of North America, including the Baja California peninsula (Ebert and Southon 2003). The former is one of the largest species in the world, growing to about 200 mm test diameter, weighing more than 1 kg and can live for more than 100 years. The purple sea urchin is small, growing to about 70 mm test diameter.

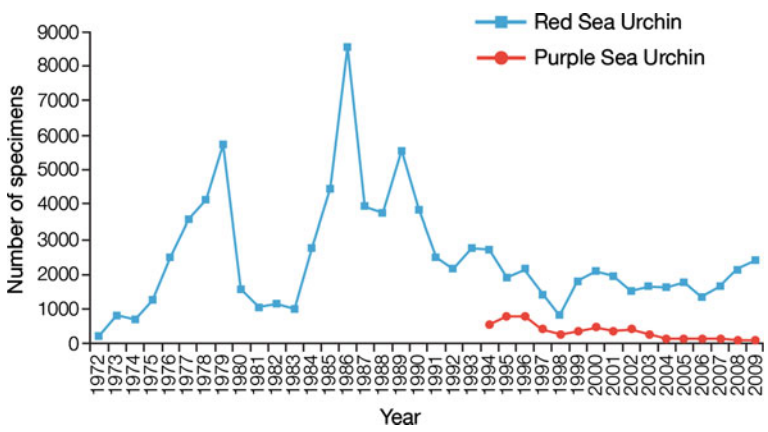

Fig. 2.10 Red and purple sea urchin catch in Baja California, Mexico

The fishery is limited from Coronado Islands to Isla Natividad in Baja California Sur (Fig. 2.10). The fishery for *S. franciscanus* began in 1972 to supply the Japanese market. The fishery grew quickly and is characterized by three peaks in catch, in 1979 (5,707 tons), 1986 (8,493 tons) and 1989 (5,536 tons). On the other hand, *S. purpuratus* has been harvested only since 1993. Although catches have remained relatively small (Fig. 2.10). Densities of this echinoid have risen in the last ten years, but inconsistent roe quality has retarded development of the fishery (Palleiro-Nayar et al. 2008).

Sea urchins are collected by "hooka" or air compressor to depths up to 30 m. The divers use short-handled rakes to dislodge the sea urchin from the reef. Because other fishermen are paid on the basis of roe recovery rather than the whole animal, divers test roe quality as they work. There is no recreational fishery and illegal harvest has not been estimated. However, is believed to be relatively small (Palleiro-Nayar 2009). To date there are some management measures, including reduction in fishing effort (300 divers in 1987, 229 divers in 2010). Catch rates for *S. franciscanus* have declined significantly from 309 kg day^{-1} in 1988 to 87 kg day^{-1} in 2002 and to 176 kg day^{-1} in 2009. The sea urchin roe produced over 1.3 million US dollars in 2009. However, the maximum profits were obtained in 1994 with 10.4 million US dollars (Fig. 2.10).

*2.4.2 The Brown Sea Cucumber Fishery (*Isostichopus fuscus*) in the Gulf of California, Mexico*

The brown sea cucumber *I. fuscus* is a common inhabitant of coral and rocky bottoms from the Gulf of California, Mexico to Ecuador (Maluf 1988; Hearn et al. 2005; Solis-Marin et al. 2009). The fishery of this sea cucumber is without a doubt a most peculiar story. From the beginning, there were no regulations for fishing activities, and the only information that existed was related to taxonomy (Caso 1961b, 1967a). The fishery started in the late 1980s, mostly in the Gulf of California, although some trade was done in Jalisco and Oaxaca (Sierra-Rodriguez 1994; Nuño-Hermosillo 2003) (Fig. 2.1). The maximum recorded catch occurred in 1991, with 1,800 tons but mean annual catch was around 300 tons (Herrero-Perezrul and Chavez-Ortiz 2005). In 1994, due to overfishing, authorities closed the fishery and included *I. fuscus* in the list of protected species (Anonymous 1994). The fishery was closed until 2000. With biological data that had been generated by then, some regulations were established and the fishery reopened in Baja California Sur. Stakeholders were required to record biological data (size, fishing logs, reproduction, etc.) in exchange for the license. Currently the fishery in Baja California Sur represents a sustainable activity which is been going now for 10 years with no evidence of overfishing (Herrero-Perezrul 2010). The fishery management plan in Baja California Sur includes a minimum size of 20 cm and 400 g, total allowable quotas, estimations of biomass and population density, and a reproductive ban from June 1st to October 31.

*2.4.3 The warty Sea Cucumber Fishery (***Parastichopus parvimensis***) in the Baja California Peninsula, Mexico*

The warty sea cucumber *P. parvimensis* can grow to a length of 60 cm and a width of 5 cm. Mobility is limited, though individuals can move up to 4 m day^{-1} while feeding (Morris et al. 1980). It is commonly found in rocky bottoms from 0 to 60 m (Woodby et al. 2000). However, exploitation takes place mostly at depths no deeper than 30 m. The distribution along the west coast of Baja California Peninsula is from Coronado Islands to Punta Abreojos (Fajardo-Leon and Turrubiates-Morales 2009).The fishery started in 1989. In general, fishing takes place when the sea urchin season closes, from March to June. The stock is exploited by the same fishermen exploiting sea urchins. Until 2004, the fishery was only in Baja California, but expanded to Baja California Sur in 2004 (Fajardo-Leon and Turrubiates-Morales 2009). The maximum catch of warty sea cucumber in Baja California was 1992 with 723 tons. However, landings have decreased to around 230 tons in recent years with around 100 divers (Salgado-Rogel et al. 2009). In Baja California Sur the maximum catch was in 2008 with 381 tons. The sea cucumber is boiled, dried and salted before export, while lesser quantities are frozen. In Asia, sea cucumber are claimed to have a variety of beneficial health enhancing properties like lowering high blood pressure, aiding proper digestive function, and others (Rogers-Bennett and Ono 2006).

2.5 Echinoderm Threats in Mexico

The marine biodiversity of Mexico is threatened by various human activities. The main factors are pollution and fishing activities.

2.5.1 Over Exploitation

Of the five classes of echinoderms, sea urchins and sea cucumbers are most heavily exploited. The sea cucumbers (bêche-de-mer or trèpang) that are fished commercially include 42 species from around the world. They are consumed for their high-protein content of the body wall, which is boiled and dried (Purcell et al. 2010). During the 1990s, the number of producing countries increased worldwide with established fisheries in Canada, USA, Mexico and Ecuador. Despite efforts to regulate the sea cucumber fisheries in Mexico, illegal fishing continues. One of the greatest dangers to unregulated fishing of this resource is potential population collapse and therefore the risk of species extinction (Pech 2010). This situation is not new. In the late 80's began in the Gulf of California: *I. fuscus* catches exceeded one thousand tons in 1991 (Reyes-Bonilla et al. 2008). However, only 5 years later the fishery authorities declared it endangered and prohibited its capture. This species is currently on the list of protected species (NOM-059-ecol-2001).

So far, there have been four species of sea cucumbers exploited in the Gulf of Mexico and the Mexican Caribbean: *Holothuria mexicana*, *H. floridana*, *Astichopus multifidus*, *Isostichopus badionotus* (Zetina-Moguel et al. 2003) and two species in the Mexican Pacific, *I. fuscus* and *P. parvimensis*.

Fisheries are also a threat to sea urchins in Mexico. Two species of sea urchins from the Mexican Pacific have been exploited: *S. purpuratus* and *S. franciscanus*. One of these fisheries occurs in Baja California Mexico, with the exploitation of *S. purpuratus*, the purple sea urchin. Gonads are exported to the Northeast Pacific (Micael et al. 2009). The organisms are collected by hand or with dredges. Since the quantity and quality of roe cannot be assessed externally, the individuals are cracked open, causing a high level of mortality and discard of animals.

2.5.2 Trawling and Accidental Catch

The catch depends on the gear used in particular fishery and the amount of effort applied. One of the major problems in trawl fisheries is the large numbers of other species that are caught and discarded. Northwestern Mexico, and in particular the Gulf of California, is the most important fishing area in the country (Robadue 2002). Seventy-seven percent of the volume of fish production in Mexico is obtained from the Pacific Ocean, and discharged in Baja California, Baja

California Sur, Sonora, Sinaloa and Nayarit States. Most of the catch (80 %) is from the Gulf of California, where coastal fishing generates 114,000 tons y^{-1}: 31 % in Baja California Sur, 28 % in Sonora, 22 % in Sinaloa and 19 % in Baja California. In general, 10 % of coastal catches are sharks and dogfish, 17 % bony fish, 15 % mollusks, 6 % crustaceans and 52 % unidentified (Rodriguez-Valencia and Cisneros-Mata 2006).

Echinoderms are affected directly by incidental catch when fishing with trawls because of the significant bycatch effect. The number of species collected this way is difficult to estimate because they are not recorded in catches. Discards from trawling are dumped at sea and sink to the bottom where their decomposition reduces the levels of oxygen and make the habitat less suitable for benthic organisms. Invertebrates account for up to 90 of the numbers of animals discarded and up to 73% of these are echinoderms (Pranovi et al. 2001).

2.5.3 Ornamental Species

Many species of echinoderms are popular in aquarium trade. Mexico is included in the main exporters together with Indonesia, Singapore, Fiji, Sri Lanka, Philippines and Vanuatu. One Caribbean sea star captured for souvenir industry is *Oreaster reticulatus*. Other countries in the Caribbean, including Mexico, allow the extraction of this species without apparent restrictions.

Little is known about the use of echinoderms as souvenirs or for aquariums. The limited information available comes from the results of a survey of the Mexican echinoderm trade. Currently an estimated 62 fisheries in Mexico collect an average of 12,000 sea stars annually for the souvenir industry (Lunn et al. 2008).

2.5.4 Management and Conservation

Among the possible actions for conservation and management of marine resources, one of the most important is the recognition of priority sites. Protected areas have been advocated as one of the most important and effective tools for safeguarding the world's biodiversity. A major reason for this is that they protect species from their greatest threat: habitat loss. In March 2007, Mexico had 61 Marine Protected Areas with valid establishment decrees, occupying 13,336,390 ha or 58.5 % of its total federal protected area ($\sim$42 % of its total marine exclusive economic zone) (Ortiz-Lozano et al. 2009). It is noteworthy that most of the known species of echinoderms are distributed in shallow water areas, and many of them are located within protected sites.

Until now, no comprehensive work on the population dynamics of the different exploited species have been made. There is no current information on the number of possible species that might suggest its economic importance and its distribution along the Mexican littoral (for example the genus sea star *Pisaster*). Likewise, we need to control and regulate the sea cucumbers fisheries in Mexico. For the sea cucumber *I. fuscus*, the permit holders have to fish in specific areas called management unit for wild life or UMA (*Unidad de Manejo Ambiental*). The exploitation permits are given to organized fishermen who must submit reports on this activity. UMA controls a harvest quota for each area. It has restricted collection to sea cucumbers with a minimum 370 g of total weight and has established a closing season from June to September. On the other hand, there is no official management plan for *P. parvimensis*, although the permit holders must collect the sea cucumber in specific areas and observe a minimum size limit of 200 g body wall (without gut) (Perez-Plascencia 1995). Assessments of the sea cucumber fishery are based on annual analyses of fishery-derived information such as catch rate and mean size of individuals in the landed catch as well as fishery-independent surveys. These are used to determinate biomass and set a quota of no more 10 % of the total biomass estimation.

The main life history traits of holothurians suggest that they constitute fragile stocks. For instance, they are big, slow growing organisms which hardly move, and therefore easily detected by divers. Population density is less than 1 ind m^{-2}, similar to values for many of the most important species around the world (Herrero-Perezrul et al. 1999; Uthicke et al. 2009). Consequently overfishing is likely to occur due to their high vulnerability. Conservation efforts have been made, especially for the fished populations. The permits are based on management regulations. They limit the number of boats and divers in order to control fishing effort, and assess the population before and after the fishing season. A private company has been successful in culturing larvae to produce juvenile *I. fuscus* (F.A. Solis-Marin pers. obs.).

The red sea urchin fishery was unregulated until 1987 when a suite of management reforms transformed the fishery from an open-access competitive model to one in which individual permit holders (with one or more divers) had exclusive access to one area. Prior to 1987, divers were able to fish everywhere, with the result that many areas became severely overfished. In 1994, the Federal Government strengthened the holders permit rights by giving them long term concessions (20 years) for exclusive areas access. The permits are tradable. These changes were designed to provide investment security and promote greater commitment to long-term sustainable use. Other management measures introduced in 1987 included the introduction of a minimum legal size of 80 mm test diameter, a closed season between April and June (later extended to March–June), and a catch and effort reporting scheme (Palleiro-Nayar 2004).

Assessments of the red sea urchin fishery are based on annual analyses of fishery-derived information such as catch rate and mean size of individuals in the catch as well as fishery-independent surveys. Video surveys of reefs also indicate declines in densities of red sea urchins and increased in density of purple sea urchins that have replaced red urchins in deeper water (Salgado-Rogel and Palleiro-Nayar 2008).

In addition, FAO recognizes that some countries have established measures to reduce bycatch in certain fisheries, through which the ships find it much easier to avoid capture of unwanted species (Sommer 2005). The pervasive trend of overfishing, and increasing examples of local extinctions requires immediate action for conserving stocks, biodiversity, ecosystem functioning and resilience from other stressors than overfishing (e.g. global warming and ocean acidification) to ensure the ecological, social and economic benefits of these natural resources (Toral-Granda et al. 2008).

2.6 Concluding Remarks and Recommendations

The geographic position of Mexico surrounded by two oceans, two gulfs and its tropical location, explains its extraordinary biodiversity in terms of coastal and marine resources and ecosystems, making this country one of the most biodiverse on the planet.

The earliest published article that included work on echinoderms from Mexico dates back to Louis Agassiz in 1841, who reported the existence of the sand dollar *Mellita hexapora* (as *M. quinquiesperforata*) for the Gulf of Mexico (Veracruz). Thus began a period of exploration in which most of the species from Mexican waters were described (Verrill 1870, 1871; Perrier 1881; Lyman 1883; Théel 1886; Agassiz 1878–1879, 1888). During the twentieth century, few expeditions took place but several non-Mexican authors wrote reports that included echinoderms from Mexican marine waters (Ludwig 1905; Clark 1913, 1917, 1920a, b, 1923a, b, 1933, 1948, 1916, 1918, 1954; Boone 1926; Ziesenhenne 1937, 1940, 1942; Deichmann 1930, 1937, 1951, 1958; Steinbeck and Ricketts 1941; Domantay 1953, 1961). It was not until 1939 when Mexican expeditions began and more species were added to the developing list of species (Caso 1941, 1943, 1944, 1945, 1946, 1947, 1948a, b, 1949, 1951a, 1953, 1954, 1955, 1958, 1961a, b, 1962a, b, 1963, 1964, 1965, 1967a, b, 1968a, b, c, 1970, 1971a, b, c, 1972a, b, c, 1974a, b, c, 1975, 1976, 1977, 1978a, b, 1979a, b, c). The UNAM began the first attempt to organize and classify Mexican echinoderm fauna into a comprehensive scientific collection. The knowledge of the Mexican echinoderms continued to increase in the Mexican Echinoderm National Collection at the end of the twentieth century and the beginning of the twenty-first century, with new curators and the incorporation of several students. The papers published include description of new species, checklists, taxonomic and biogeographic studies as well as morphological and molecular phylogenies (Caso 1979a, b, c, 1980a, b, 1983a, b, 1984, 1986a, b, 1990, 1992; Buitron and Solis-Marin 1993; Caso et al. 1994a, b, 1996; Caso 1996a, b, c, d; Solis-Marin et al. 1997a, b, 2003, 2005, 2007a, 2007, 2009; Cintra-Buenrostro et al. 1998; Bravo-Tzompantzi et al. 1999, Solis-Marin and Laguarda-Figueras 1999, 2010a, b; Godinez-Dominguez and Gonzalez-Sanson 1999; Barbosa-Ledesma et al. 2000; Laguarda-Figueras et al. 2001, 2002, 2004, 2005a, b, 2009; Duran-Gonzalez et al. 2005; Trujillo-Luna and Gonzalez-Vallejo 2006;

Solis-Marin 2008; Honey-Escandón et al. 2008; Torres-Martinez et al. 2008; Hernandez-Herrejon et al. 2008, 2010; Laguarda-Figueras and Solis-Marin 2009; Martinez-Melo and Solis-Marin 2010; Honey-Escandón et al. 2011).

Mexico has 643 species of echinoderms in its territorial seas. The Class Crinoidea is the least represented with 29 species (4 %) while the Class Ophiuroidea is the richest class with 197 species (31 %). The Class Asteroidea is the second richest class with 185 species (29 %) and the Class Echinoidea is the third most diverse group with 119 species (19 %) reported in both Pacific and Atlantic oceans. The Class Holothuroidea has 113 species (17 %).

It is important to make some recommendations: It is necessary to carry out more ecological studies. The low number and limited scope of publications about the ecology of echinoderms in Mexico provides evidence of an unequal and limited development of ecological studies of echinoderms. Few papers exist concerning analyses of echinoderm communities in Mexico. It is important to generate more information about their density and other population parameters, including growth, reproduction, feeding and their relation with the biotic and abiotic environment. Evaluation must be made of environmental factors that could influence their presence in a certain location, including studies about their vulnerability to climatic change. This information will be of great importance, not only for the scientific knowledge but for verification of ecological theories and a better description of the autoecologic (individual) and synecologic (community) relations. It could also establish strategies leading towards the sustainable production and administration of economically important echinoderms as a resource and search for alternatives to increase their production through aquaculture.

The study of sea cucumber aquaculture in Mexico has not begun despite their high market value and their detritivorous feeding which makes them attractive for cultivation. Since the body wall is the commercial product from sea cucumbers, it is necessary to perform studies on the optimization of its production. Considering that the techniques for holothurian aquaculture are being optimized, particularly in Asiatic regions, we should take advantage of this technological expansion to set up culture programs for our own species (i. e. *I. fuscus* and *I. badionotus*). This could also bring environmental profit, since it would diminish the illegal fishery that is currently observed extensively in Mexican waters.

It is very possible that the list of echinoderms present in Mexican waters is larger than the one presented here. In particular, the deep sea of the country has been little studied. Most expeditions covering this area have been made by institutions of other countries where a great amount of information that is difficult to access is deposited. Because of this, it is necessary to have available catalogues of echinoderms with information about their biology, ecology, distribution and fisheries, in order to improve the access to information and with it the promotion of studies on echinoderms of Mexico.

As we prepare and train more specialists in echinoderm studies in our country, it will be possible to amply advance the range of studies that are now required.

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