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Macrofaunal Diversity in the Gulf of California

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History of Research on the Fauna of the Gulf of California

The Gulf of California (Sea of Cortez) has held a growing fascination for naturalists over the past 150 years (Lindsay 1983). The first serious collectors of marine life in the region were not professional biologists. One was John Xantus (de Vesey), a U.S. government tidal observer stationed at the tip of the Baja California peninsula (April 1859 to mid-1861), most of whose collections are now at the Smithsonian Institution (e.g., Gill 1862–1863; Jordan and Gilbert 1882). Another was Frederick Reigen, a Belgian citizen who lived in Mazatlán from 1848 to 1850 and amassed one of the largest collections of marine molluscs of all time—14 tons of specimens! The Reigen collection found its way to Liverpool, and from there it was partly dispersed. Much of it was published on by Philip Carpenter (Carpenter 1857; see also Hendrickx and Toledano-Granados 1994). During the next 4 decades, a few ichthyologists made collections of fishes at some readily accessible sites, notably Guaymas and Mazatlán, that were reported on mainly by David Starr Jordan and colleagues (e.g., Streets 1877; Jenkins and Evermann 1889; Evermann and Jenkins 1891; Jordan 1895). Oceanographic data were recorded and marine organisms trawled by the U.S. Fish Commission steamer *Albatross* in the late 1880s/early 1890s, and again in 1911, and most of these specimens are also at the Smithsonian Institution (e.g., Gilbert 1892).

Modern oceanography in the Gulf of California began with the 1939 *E.W. Scripps* cruise to the region, which made 53 detailed hydrographic stations throughout the Gulf and sampled both phytoplankton and zooplankton (Sverdrup 1941; Roden and Groves 1959). In 1940, modern marine biology in the Gulf of California had its birth with the remarkable pioneering expedition of Edward F. Ricketts and John Steinbeck aboard the *Western Flyer*, a purse seiner out of Monterey, California. The biology (and philosophy) of that amazing voyage is chronicled in *Sea of Cortez. A Leisurely Journal of Travel and Research* (Steinbeck and Ricketts 1941; see also Astro and Hayashi 1971; Hedgpeth 1978a,b; Brusca 1993). Ricketts pioneered the concept of "community ecology" on the Pacific coast of America, bringing it west from his experience with W. C. Allee at the University of Chicago (Allee 1923; Hedgpeth 1978a,b). Ricketts was perhaps also the first person to codify the concept of intertidal zonation, based in part on his research in the Gulf of California, and many of his ideas were liberally borrowed and published upon by scientists with university degrees, such as M. Doty and T. A. A. Stephenson.

Expeditions from Scripps Institution of Oceanography, the University of California at Los Angeles, Stanford University, the California Academy of Sciences, and the University of Southern California's

Allan Hancock Foundation in the 1940s and 1950s ushered in an era of organized research effort in the Gulf. The fieldwork and taxonomic publications of the former Allan Hancock Foundation stand above all others in documenting the invertebrate biodiversity of the Gulf (Brusca 1980a). Between 1942 and 1983, the Hancock publications on Pacific marine life produced an astonishing 23,000 pages of primarily taxonomic text that was a watershed in marine biodiversity research (U.S.C. Press 1985). Since the late 1960s, our knowledge of the Gulf of California and its biodiversity has increased substantially through research by scientists at a number of U.S. and Mexican institutions (appendix 9.1). This body of work has resulted in many publications describing the flora, fauna, and environment of the region, much of it cataloged in Schwartzlose et al. (1992). However, compared to many of the world's seas and coastlines, exploration and documentation of the biodiversity of the Gulf of California are still in their early stages, and we estimate that more than half of its macrofauna is yet to be described, and the natural history of almost all species remains unknown.

The information in this chapter was derived largely from 2 projects. First, the Macrofauna Golfo Project has been a 10-year effort, which we have led, and it has produced a comprehensive database of the macrofauna of the Gulf of California containing taxonomic, distributional, and ecological information. "Macrofauna" is defined as those animals visible to the naked eye and generally larger than a few millimeters in size (but excluding copepods and ostracods). This database is planned for publication by Conservation International's Center for Applied Biodiversity Science as a CD-ROM and website component (Findley et al. in press). Data for the Macrofauna Golfo Project were derived from a variety of sources, including published literature, museum collections, and the personal field notes and records of the 6 principal investigators (having >150 years of collective research experience in the Gulf). The second source of data is a case study on the Upper Gulf of California/Colorado River Delta Biosphere Reserve, prepared for the UNESCO 2000 Conference on Biodiversity and Society (Brusca et al. 2001; Brusca and Bryner 2003).

Geography of the Region

Baja California encloses the Gulf of California and is one of the most remote peninsular areas in the world, exceeded in length only by the Malay and Kamchatka peninsulas. The Gulf is a large, semi-enclosed sea exceeding 1100 km in length, 100–200 km in width, with 258,593 km^2 (99,843 mi^2) of surface area (calculation by F. Zamora and S. Carroll), spanning more than 9° of latitude to traverse the Tropic of Cancer in its southern reaches, which extend to Cabo San Lucas (Baja California Sur) and Cabo Corrientes (Jalisco). The Gulf is home to more than 900 islands and islets, creating a region rich in habitat diversity and ripe for the forces of evolution to shape its flora and fauna.

In this chapter, we divide the Gulf into 3 faunal regions following the Macrofauna Golfo Project and based on the principal faunal regions established by Walker (1960) as modified by Thomson et al. (1979; see also Castro-Aguirre et al. 1995; fig. 9.1). The Northern Gulf extends from (and includes) the marine-influenced Colorado River Delta, southward to (and including) the Midriff Islands or las Islas del Cinturón or las Grandes Islas del Golfo (the largest being Islas Tiburón and Ángel de la Guarda), and to Bahía San Francisquito (Baja California) and Bahía Kino (Sonora). The Central Gulf ranges from the southern limit of the Northern Gulf to Guaymas (Sonora) and to Punta Coyote (Baja California Sur, north-northeast of La Paz). The Southern Gulf extends from the southern limit of the Central Gulf southward to Cabo Corrientes, Jalisco (the southern limit of the large Bahía Banderas) on the mainland, and on the Baja California peninsula to Cabo San Lucas. A number of species in the Southern Gulf have distributions extending around the Cape Region and up the southwestern coast of Baja California Sur. Many workers consider this area on the outer coast of the Baja California peninsula from Cabo San Lucas to Punta Eugenia (just below 28° N) to be a region of overlap (mixed tropical and temperate species), whereas others regard the Bahías Magdalena–Almejas lagoon complex as the northernmost boundary of the Tropical Eastern Pacific Fauna (reviewed in Brusca and Wallerstein 1979; Brusca 1980b; see also Hubbs 1960; Castro-Aguirre et al. 1992, 1993; Castro-Aguirre and Torres-Orozco 1993; Hastings 2000). Bahía Tortuga (Bahía Tortola) is the northernmost location on the west coast of Baja California Sur where the number of tropical species outnumbers temperate species (and where the giant North Pacific kelp, *Macrocystis*, makes its last southern stand), and Bahía San Ignacio (to the south) is home

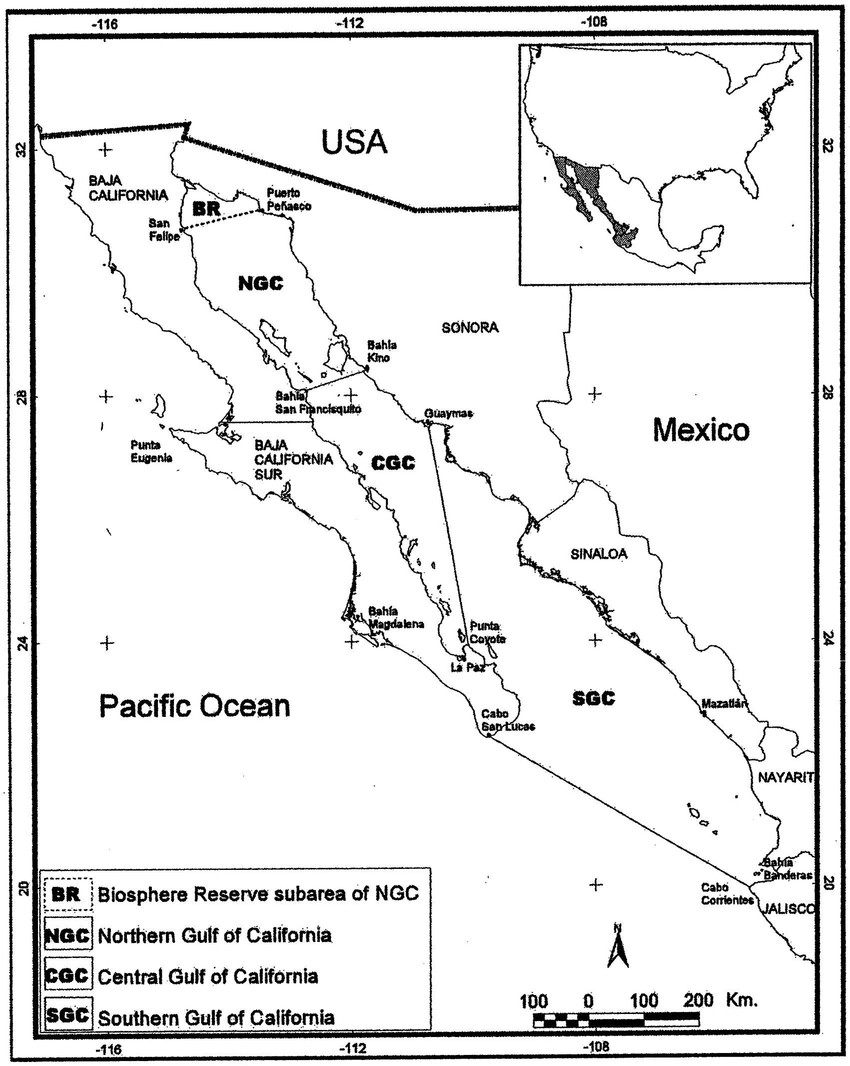

Figure 9.1. Faunal regions of the Gulf of California.

to the northernmost stand of mangroves along this coast (Brusca 1975).

We recorded biodiversity in the Upper Gulf of California/Colorado River Delta Biosphere Reserve (hereafter the "Biosphere Reserve"), at the head of the Gulf, as a subregion of the Northern Gulf. The southern boundary of the Biosphere Reserve forms a line extending from Punta Pelícano (Roca del Toro; the southern margin of Bahía Cholla and the larger Bahía de Adair), Sonora, across the Gulf to Punta El Machorro (Punta San Felipe), at San Felipe, Baja California.

Oceanography of the Gulf of California

The Northern Gulf covers about 60,000 km^2 (24,000 mi^2) of ocean surface, spans 3° latitude, and is a unique body of water in many ways. The climate is very dry, with an annual rainfall of less than 100 mm. The range of monthly mean air temperatures in the Northern Gulf is 18°C. The Northern Gulf has some of the greatest tides in the world. The annual tidal range (amplitude) at San Felipe and Puerto Peñasco is about 7 m, and on the Colorado River Delta at the head of the Gulf it is nearly 10 m.

The low delta islands of Montague and Pelícano (Isla Gore) are largely under water during high spring tides. Most of the Northern Gulf (north of the Midriff Islands) is shallow, less than 50 m deep, with the deepest areas reaching about 200 m in the small Wagner Basin, and in the larger Delfín Basin above Isla Ángel de la Guarda and extending into the deeper Salsipuedes Basin that separates the island from the peninsula (Alvarez-Borrego 1983; Maluf 1983; Lavín et al. 1998). Coastal seawater temperatures throughout the Northern Gulf are very low in the winter, dropping to 8°–12°C (equivalent to southern California shores), but rise to 30°C or more in the summer. Circulation patterns in the Northern Gulf are still not well understood, although there is evidence of a net counterclockwise rotation (Alvarez-Borrego et al. 1975; Lepley et al. 1975; Lavín et al. 1998; Carriquiry and Sánchez 1999).

Nutrient levels are high year-round and show little seasonality, although in recent years the primary sources of nutrients have probably been from agricultural drainage and the release of nutrients trapped in Colorado River sediments that are now eroding. Bray and Robles (1991) argue that influx of cold, deep water into the Southern Gulf brings nutrients into the Sea of Cortez and elevates productivity, but it is not clear to what extent this effect might reach the Northern Gulf. Although lower in biodiversity compared to the Central and Southern Gulf, high nutrient levels, shallow waters, and strong tidal mixing combine to make the Northern Gulf one of the most productive marine regions in the world. Standing crops of both phytoplankton and zooplankton are high year-round. Large fishes, sea turtles, and at least 12 species of whales and dolphins, including the critically endangered vaquita porpoise (Vidal et al. 1999; chapter 14), exploit these productive waters. Suspension-feeding clams, crustaceans, and polychaete worms also occur in great abundance throughout this region.

The Central and Southern Gulf maintain more oceanic conditions. South of the Midriff Islands depth increases quickly. The basins of the Central and Southern Gulf reach considerable depths, such as the Guaymas Basin (2000 m), Carmen Basin (2700 m), Farallón Basin (3150 m), and Pescadero Basin (3700 m) (Maluf 1983; Bray and Robles 1991). With a length of 220 km, the Guaymas Basin is the largest depression in the Gulf; it is an active, spreading center with hydrothermal vents and their unique community of benthic organisms. The Carmen, Farallón, and Pescadero Basins together form a trough along the long axis of the Gulf, and these also are probably spreading centers. At the mouth of the Gulf, the trough approaches Cabo Corrientes, the southwestern extremity of the large Bahía Banderas and the probable original attachment site of the Cape Region of Baja California (Gastil et al. 1983). The famous sublittoral "sand falls" of Baja California's Cape Region lead to deep submarine canyons (to 2400 m) that extend off the tip of the peninsula. Rainfall is fairly high in the Southern Gulf, averaging 1000 mm per year along the coast of Sinaloa/Nayarit. The mean annual air temperature range at Cabo Corrientes is just 6°C. Tides in the Southern Gulf have much lower amplitudes than in the Northern Gulf; in Sinaloa they have a maximum annual range of 2.7 m, and at La Paz (on the Baja California peninsula) only 2.3 m. The mouth of the Gulf is a complex mix of waters from several sources, including cold California Current water, warm eastern tropical Pacific water, and warm saline Gulf of California water, and below these are Equatorial (Tropical) Subsurface Water, Antarctic Intermediate Water, and Pacific Bottom Water. The formation of fronts at the entrance to the Gulf is a major feature of the region and one that has attracted the attention of numerous commercial and sport fisheries. Because evaporation exceeds precipitation in the Gulf, there is a net influx of cold Pacific water into the basin, estimated at 1.7×10^4 m^3/s (Roden 1958).

Oxygen concentrations tend to be high throughout the Northern Gulf, decreasing from about saturation values at the surface (5–6 ml/l) to about 1 ml/l at 300–500 m depth in the Delfín Basin (north of Isla Ángel de la Guarda). However, in the Central and Southern Gulf low oxygen concentrations are typical at intermediate depths (Alvarez-Borrego 1983). Concentrations in these regions often fall to less than 0.5 ml/l below 150 m. Deep waters in the Central and Southern Gulf have an intrusion of the Equatorial Subsurface Water Mass (from the south) characterized by an oxygen minimum layer, and oxygen concentrations of less than 0.2 ml/l have been found between 450 and 750 m (and occasionally deeper) in many areas (Robison 1972). Below about 750 m, oxygen begins increasing, reaching about 2.4 ml/l at 3500 m.

Few data exist for bottom conditions in the Gulf. Although strong tidal currents in the Northern Gulf keep the water column well mixed (Alvarez-Borrego 1983), it seems almost certain that bottom areas chronically disturbed by the numerous shrimp trawlers (and accumulation of their discarded bycatch on the sea floor) experience hypoxia (less than 0.2 ml/l dissolved oxygen), at least periodically, or even anoxia, but few data are available, and no reports of anoxia have yet been published for this region. In the southeastern Gulf, near anoxic values have occasionally been recorded at bottom depths of 60 m (Hendrickx 2001), but it is not known whether this is a natural phenomenon or directly related to bottom disturbance by trawling activities. In deeper waters, a wide fringe of oxygen-depleted bottom water occurs along the east coast of the Central and Southern Gulf (Parker 1964; Díaz and Rosenberg 1995). In this region, hypoxia or anoxia generally occurs from 100 m to about 700 m on the bottom (and in the water column), and benthic macrofaunal biomass in this region is very low. A highly tolerant (surviving in oxygen concentrations of 0.3 to 0.8 ml/l oxygen) and distinct benthic invertebrate and fish community is found on the outer edge of this oxygen minimum zone in water deeper than 800 m (Hendrickx 2001).

Because evaporation exceeds freshwater input, the entire Gulf is regarded as an evaporation basin, particularly its northern part (Bray and Robles 1991). The estimated mean evaporation rate for the Northern Gulf is 1.1 m/year, while precipitation is only 4–8 cm/year (Alvarez-Borrego 1983; Lavín et al. 1998). Salinities have increased here in response to a dramatic reduction of freshwater discharge over the past 70 years (loss of river input), the increase of saline agricultural drainage, and probably global warming (enhancing evaporation). Summer surface salinities may reach 39 parts per thousand (ppt) in the shallow coastal areas and inner channels of the Río Colorado Delta region, and in Northern Gulf *esteros* (hypersaline coastal lagoons). Over deeper water in the Northern Gulf surface salinities are 35.3–37.2 ppt (Lavin et al. 1998), whereas in the Central and Southern Gulf they are closer to typical oceanic waters (35.0–35.8 ppt).

Biogeography

The Gulf of California is a subtropical system with exceptionally high rates of primary productivity. Alvarez-Borrego (1983) concluded that the rates of primary productivity in the Gulf are comparable to those of the Bay of Bengal and to the upwelling areas off the west coast of Baja California or North Africa. Productivity rates are 2 or 3 times greater than that of the open Atlantic or open Pacific at similar latitudes (Zeitzschel 1969).

The flora and fauna that inhabit the Gulf arrived there from diverse sources: tropical Central and South America, the Caribbean Sea (before the uplift of the Panama Isthmus), the temperate shores of California (during past glacial periods), and even across the vast stretch of the Pacific Ocean from the tropical Indo-West Pacific (Walker 1960; Rosenblatt 1967; Briggs 1974; Thomson et al. 1979; Brusca 1980b; Rosenblatt and Waples 1986; Castro-Aguirre et al. 1995; Hastings 2000; Bernardi et al. 2003). Community composition at any given locality in the Gulf comprises a reasonably predictable mix of species, combined with a much larger suite of "unpredictable" species, the unpredictability being driven by complex networks of interacting physical and biological factors. However, relative species richness (diversity) is predictable and largely a function of habitat and substrate type. Benthic species richness is highest on reefs, relatively stable shores, and intertidal or shallow bottoms composed of softer sedimentary rocks such as sandstones or eroded volcanic tuffs and rhyolites. Benthic diversity is lowest on beaches composed of smooth, hard rocks such as granites and basalts and on unstable beaches of sand or cobble, the latter perhaps having the lowest (benthic) diversity of any coastal habitat. Areas that have a variety of substrate types harbor more species than do more homogeneous ones (Walker 1960; Parker 1964; Brusca 1980b, 1989). Mangrove estuaries (including true positive estuaries) and *esteros* (moderately hypersaline coastal lagoons, or "negative estuaries") are notably diverse areas, and these habitats provide important nursery and feeding grounds for the young of many coastal fishes and shellfish, including most commercial finfish and shrimps (Findley 1976; Cervantes et al. 1992; Flores-Verdugo et al. 1993; Güereca-Hernández 1994). Whitmore et al. (chapter 15) report 160 fishes and 214 invertebrates occurring in the mangrove lagoons of Baja California Sur. The islands of the Gulf also harbor an extraordinarily high species diversity (Thomson and Gilligan 1983), and these areas serve as important refugia for species that have lost habitat or been extirpated on the mainland coast, as well as being important seabird breeding sites (chapter 23). The Gulf islands also tend to harbor a fauna more typical of mainland coastal communities hundreds of kilometers to the south.

Species diversity is also influenced by seasonal oceanographic conditions, especially in the Northern Gulf where marked seasonal changes occur. This shallow region is strongly influenced by the climate of the surrounding Sonoran Desert and, as noted above, it experiences extreme annual variations in seawater temperatures. As a result, it is essentially a warm-temperate marine environment during the winter, but a tropical marine environment during the summer. Here, distinct seasonal changes occur with respect to many invertebrates, algae, and some vertebrates as certain tropical species disappear or emigrate during the cold winters and other, more temperate species, vanish during the warm summers (Thomson and Lehner 1976; Brusca 1980b). The Southern Gulf, with its greater area, deeper basins, and proximity to the open Pacific, is strongly influenced by the open ocean and is largely a stable tropical environment year round. As one moves northward from the Midriff Islands, benthic species diversity gradually declines, reaching its minimum in the homogenous mud bottoms of the Colorado River Delta. Based on the above, Brusca (1989) speculated that the Northern Gulf is a more physically controlled environment, whereas the Southern Gulf is a more biologically accommodated environment.

The rich pelagic waters of the Gulf are famous for supporting large numbers of fishes, marine mammals, sea turtles, and marine birds. Nearly 50% of Mexico's fisheries production comes from the Gulf, and 15% comes from the Northern Gulf alone (Cudney-Bueno and Turk Boyer 1998; Cudney-Bueno 2000). In general, benthic communities throughout the Gulf are species rich, although in subtidal areas that are susceptible to bottom trawling much diversity has been lost over the past 50 years due to high disturbance (Nava-Romo 1994; Nava and Findley 1994). However, we have almost no knowledge regarding community composition and food web structure for the Gulf's offshore benthic or pelagic communities. Notably high biodiversity occurs on the very limited intertidal beachrock ("coquina") formations that occur at just 4 sites in the Northern Gulf: Puerto Peñasco and Punta Borrascoso (Sonora), and San Felipe and Coloradito (Baja California). These small, rare, eroding beachrock habitats harbor a disproportionately high species diversity, giving them high priority for protection.

Macrofaunal Biodiversity in the Gulf of California

The following information, as noted above, derives primarily from the Macrofauna Golfo Project and from a Case Study on the Upper Gulf of California/Colorado Delta Biosphere Reserve. The marine macrofauna of the Gulf is diverse, comprising at least 5969 named species and subspecies: 4854 invertebrates and 1115 vertebrates (891 fishes; 224 nonfish vertebrates) (tables 9.1–9.5). Due to the presence of many undescribed invertebrate species, including many members of the planktonic community, this total is estimated to be less than half of the actual animal diversity of the Gulf. Overall faunal diversity decreases from the south to the north (table 9.1), the highest diversity being in the Southern Gulf, with 4095 taxa (69% of the total Gulf diversity). From the Central Gulf, 4025 taxa have been recorded (67% of the Gulf's diversity). The Northern Gulf houses 2802 taxa (47% of the Gulf's diversity), 1457 of which are within the Biosphere Reserve (24% of the Gulf's total diversity). One of

Table 9.1. Summary of macrofaunal diversity in the Gulf of California by region.

Region[a]	Fishes	Nonfish Vertebrates	Invertebrates	Totals
SGC	778	204	3113	4095
CGC	562	170	3293	4025
NGC	367	177	2258	2802
BR	258	149	1050	1457

[a]SGC = Southern Gulf of California; CGC = Central Gulf of California; NGC = Northern Gulf of California; BR = Upper Gulf/Delta Biosphere Reserve subregion of northern Gulf.

the richest areas in the entire Gulf is the Cabo Pulmo Reef (between La Paz and Cabo San Lucas, Baja California Sur), and this is the only true coral reef in the Sea of Cortez. We are aware of only 1 published faunal inventory of this reef, which reported 121 species of invertebrates and 108 species of fishes from cursory surveys (Brusca and Thomson 1975; also see Squires 1959; Glynn and Wellington 1985; Brusca 1985). Recent coastal and offshore (shelf) surveys in Sinaloa have revealed an unexpectedly high invertebrate diversity in the southeastern Gulf. For example, 300 species of decapod crustaceans have now been collected from coastal Sinaloa (Hendrickx 1996, 2001; Hendrickx and Brusca 2002), and the Sinaloan fish fauna comprises at least 600 species (van der Heiden and Findley 1990). Other notably high-diversity regions in the Gulf include Cabo San Lucas, Bahía Banderas, several stretches of rocky shoreline and coastal lagoons in Sonora and Sinaloa, and most of the Gulf islands. Puerto Refugio, at the northern end of Isla Ángel de la Guarda, and the isolated Rocas Consag, have long been recognized as biodiversity hot spots (Thomson et al. 1979; Thomson and Gilligan 1983).

Of the 891 fish taxa recorded from the Gulf, 801 are bony fishes (ray-finned fishes, or Actinopterygii) belonging to the Teleostei or "higher bony fishes" (table 9.2). Of these 801 taxa, 719 are neritic (continental shelf) and 82 are deep sea (strictly oceanic, mostly mesopelagic). In addition, there are 3 hagfishes (Myxini) and 87 other cartilaginous fishes (Chondrichthyes) in 3 groups: 3 chimaeras (rattails, Holocephali), 46 sharks, and 38 rays (Findley et al. 1996). About 10% of the fish fauna is endemic to the Gulf (87 taxa), comprising 80 species and 4 subspecies of bony fishes, 2 chondrichthians, and 1 hagfish (*Eptatretus sinus*, known only from deep waters of the Northern and Central Gulf). Although 13 fish species are endemic to the Northern Gulf, only 1 of them is strictly endemic to the Biosphere Reserve (the delta silverside, or *pejerrey delta*, *Colpichthys hubbsi*), thought to be a euryhaline relict from truly estuarine conditions before the Colorado River was dammed (Crabtree 1989; Hastings and Findley, in press). However, the fish fauna of the Reserve also includes the endangered totoaba (*Totoaba macdonaldi*) and the currently overfished gulf corvina (*corvina golfina*, *Cynoscion othonopterus*) (Cisneros et al. 1995; Findley et al. 1996; Hastings and Findley in press). An estimated 10,000 tons of this corvina were taken by fishers in the Reserve between 1996 and 2000 (José Campoy-Favela and Martha Román-Rodriguez, pers. comm.; see also Román-Rodríguez et al. 1998).

Although 8 fish species and 1 subspecies are recorded as endemic to the Southern Gulf, they are poorly known, reported from only a few specimens, and often from deep water. The same can be said for the Central Gulf, where 5 endemic fish species are recorded, most of them poorly known, including 3 species of rockfishes (*rocotes*, *Sebastes*). In contrast, the more isolated Northern Gulf contains 13 endemic fish species, including a number of soft-bottom–associated forms with very restricted distributions, and another 2 species of *Sebastes* restricted to deeper (cold) waters around the Midriff Islands (Chen 1975; Rócha-Olivares et al. 1999). A majority of endemic fishes in the Gulf occur in more than 1 region, and their diversity is especially notable in rocky-shore, small-bodied species of the families Gobiidae, Chaenopsidae, Labrisomidae, and Gobiesocidae (Walker 1960; Findley et al. 1997). Although not endemic, several fishes in the Northern Gulf are members of the Gulf's "disjunct fauna."

Table 9.2. Fish diversity in the Gulf of California.

	Total for Gulf	Present in SGC	Present in CGC	Present in NGC	Present in BR
Myxini (hagfishes)	3 (1)	1 (0)	2 (0)	1 (0)	0
Chondrichthyes (sharks, rays, chimaeras)	87 (2)	80 (0)	72 (0)	58 (0)	39 (0)
Actinopterygii: Teleostei (bony fishes)	801 (84)[a]	697 (9)[b]	488 (5)	308 (13)	219 (1)[c]
Totals	891 (87)[a]	778 (9)[b]	562 (5)	367 (13)	258 (1)

Numbers of endemic species/subspecies per region given in parentheses. SGC = Southern Gulf of California; CGC = Central Gulf of California; NGC = Northern Gulf of California; BR = Upper Gulf/Delta Biosphere Reserve subregion of Northern Gulf.
[a]Includes 4 subspecies-rank taxa.
[b]Includes 1 subspecies-rank taxon.
[c]*Colpichthys hubbsi* (Atherinopsidae), also included in count for NGC.

These are eurythermal or cold-water adapted species found in the Northern and (sometimes Central) Gulf, but not to the south, reappearing again in the colder waters of the California Current on the outer coast of the Baja California peninsula and northward to California (Walker 1960; Thomson and Gilligan 1983; Present 1987; Castro-Aguirre et al. 1995; Terry et al. 2000; Huang and Bernardi 2001; Bernardi et al. 2003).

Of the 224 nonfish marine vertebrates known from the Gulf, 181 are birds, 36 are mammals, and 7 are reptiles (table 9.3). The aquatic bird fauna includes species in 10 orders, the most diverse being the Charadriiformes (including plovers, gulls, terns and sandpipers) with 76 species, and the Anseriformes (ducks and geese) with 35 species. The Southern Gulf houses the most diverse bird fauna, with 165 resident and seasonal species, whereas 131 species have been reported from the Biosphere Reserve. Although no aquatic birds are wholly restricted in their range to the Gulf, 1 species is essentially endemic, with only a few records outside the Gulf: the yellow-footed gull (*Larus livens*). This bird, plus 4 other species (least storm petrel, *Oceanodroma microsoma*; Heermann's gull, *Larus heermanni*; elegant tern, *Sterna elegans*; Craveri's murrelet, *Synthliboramphus craveri*) rely almost wholly on the Gulf for their breeding sites, and 90% (or more) of their breeding populations are found in the Gulf, mostly on only a few small islands (Anderson 1983; chapter 23).

The marine mammal fauna of the gulf is surprisingly diverse (Vidal et al. 1993; chapter 14), with 36 species representing 31 cetaceans (whales, dolphins, porpoises), 4 pinnipeds (sea lions, seals), and 1 bat (the coastal fishing bat, *Myotis vivesi;* Patten and Findley 1970; Bogan 1999). Among the cetaceans, the Odontoceti (toothed whales, most in the family Delphinidae) are represented by 23 species, 8 of which have been recorded from the Biosphere Reserve. The Mysticeti (baleen whales) are represented by 8 species, 5 of which enter the Biosphere Reserve. Four species of pinnipeds have been recorded from the Gulf, with the California sea lion, *Zalophus californianus*, being the only true resident and by far the most abundant and ubiquitous, occurring in all regions and seasonally occupying several important breeding sites on Gulf islands and coastal headlands (Le Boeuf et al. 1983; Vidal et al. 1993; Aurioles-Gamboa and Zavala 1999). The presence of 36% (13 species) of the Gulf's marine mammal fauna, either permanently or seasonally, in the Biosphere Reserve demonstrates the importance of this area to conservation efforts in the eastern Pacific. One of the cetaceans of the Biosphere Reserve is the vaquita (*Phocoena sinus*), the world's smallest and most endangered marine cetacean (Vidal et al. 1999; Rojas-Bracho and Taylor 1999; chapter 14). This rare porpoise is endemic to the uppermost part of the Northern Gulf, where its critical habitat appears to straddle the southern boundary of the Biosphere Reserve in the small area west of Rocas Consag (Gallo-Reynoso 1998). Only 2 species of marine mammals are endemic to the Gulf, the vaquita and the fishing bat. Although the latter occurs in scattered colonies throughout the Gulf, especially in the Midriff Islands area, it is rare north of there and has not been recorded from the Biosphere Reserve.

The 7 marine reptiles of the Gulf comprise now-small populations of 5 sea turtles, 1 sea snake (*Pelamis platurus*), and 1 crocodile (*Crocodylus acutus*). Four of the turtles (all of which are threatened or endangered) are recorded from the Biosphere Reserve, although their numbers are few throughout the Northern Gulf due to historical

Table 9.3. Nonfish vertebrate diversity (aquatic birds, reptiles, mammals) in the Gulf of California.

	Total for Gulf	Present in SGC	Present in CGC	Present in NGC	Present in BR
Reptiles (sea turtles, sea snake, crocodile)	7 (0)	7	6	7	5
Aves (birds)	181 (1)[a]	165	135	146	131
Mammals (cetaceans, pinnipeds, fishing bat)	36 (2)	32	29	24 (1)	13
Totals	224 (3)	204	170	177 (1)	149

Numbers of endemic species per region in parentheses. NGC = Northern Gulf of California; CGC = Central Gulf of California; SGC = Southern Gulf of California; BR = Upper Gulf/Delta Biosphere Reserve subregion of Northern Gulf.
[a]Essentially endemic.

fishing pressure and modern incidental take in gillnets and shrimp trawls. The crocodile is now present only in a few estuaries of the mainland side of the Southern Gulf (Navarro-Serment 2002). The yellowbelly sea snake (a tropical Indo-Pacific species) occurs infrequently in the Central and Northern Gulf, but is increasingly common southward all the way to Ecuador.

Invertebrate diversity is highest in the Central Gulf (3293 taxa), and lowest in the Northern Gulf (2258 taxa; table 9.4). The Biosphere Reserve is home to 1050 invertebrate taxa, or 22% of all invertebrates known from the Gulf. For benthic invertebrates, highest species diversity occurs in shallow coastal regions, particularly in the Northern Gulf and along the coasts of Sinaloa and Nayarit (fig. 9.2). For pelagic invertebrates, highest diversity occurs along the Gulf coast of Baja California Sur, from Bahía Concepción southward to La Paz; lowest species diversity occurs in the Northern Gulf, along the coast of Sonora, and in the extreme Southern Gulf (fig. 9.3).

Among the invertebrates, the highest diversity occurs with the Mollusca (2193 taxa) and Arthropoda (1051 taxa; table 9.4). Within the Mollusca, the gastropods and bivalves stand out with 1530 and 565 taxa, respectively. More than 20% (460 taxa) of the molluscs known from the Gulf are endemic to that region, including 396 gastropods (of which 39 are opisthobranchs [sea slugs] and 3 are marine pulmonates), 44 bivalves, 15 chitons, 4 cephalopods (3 octopuses; 1 squid, *Loliolopsis chiroctes*), and a scaphopod (tables 9.4 and 9.5). Among the Arthropoda, the brachyuran crabs (Decapoda) and amphipods (Peracarida) are most diverse, with 301 and 232 taxa, respectively (table 9.4).

Overall invertebrate endemicity in the Gulf is 16% (766 taxa). At the phylum level, the highest levels of endemism occur in the Brachiopoda (80%), Ctenophora (50%), Platyhelminthes (41%), Echiura (25%), and Mollusca (21%). At lower taxonomic levels, highest endemism occurs among Anthozoa (34%), Polyplacophora (26%), Gastropoda (26%), and Cumacea (25%). However, several of these figures should be viewed with caution because some taxa are very poorly studied in the Gulf and tropical eastern Pacific in general (e.g., Brachiopoda, Cnidaria, Ctenophora, Platyhelminthes, Echiura, Cumacea, Tanaidacea, micromolluscs, Urochordata, Hemichordata). Only 1 hemichordate (*Ptychodera flava*) and 1 cephalochordate (the lancelet, *Branchiostoma californiense*) are recorded from the Gulf.

Among the 128 invertebrates endemic to the Northern Gulf are the unique carpet anemone (*Palythoa ignota*) and the giant aphroditid polychaetes (*Aphrodita mexicana, A. sonorae*), all of which appear to be greatly reduced in numbers and threatened due to excessive bottom trawling. In addition, 7 species of pea crabs (Pinnotheridae) are endemic to the northern Gulf, as are 2 goneplacid crabs (*Glyptoplax consagae, Speocarcinus spinicarpus*), 11 species of sea slugs, the cone snail *Conus angulatus* (previously considered a synonym of *C. regularis*), and the scallop *Leptopecten palmeri*.

Threats to Biodiversity in the Gulf of California

There are many threats to biodiversity in the Gulf. Not all are being driven from within Mexico, and most are influenced by economic or environmental pressure from the United States. One of the greatest threats comes from the disruption of rivers that once flowed into the Gulf. Although virtually all of the rivers that once reached the Gulf have been altered or destroyed by overdraft and diversion (e.g., Ríos Fuerte, Mayo, Yaqui, Sonora, and Concepción), the most significant is the Colorado River which, before construction of Hoover (Boulder) Dam, provided most of the fresh water supply to the Northern Gulf (Brusca et al. 2001; Brusca and Bryner 2003; Brusca 2004). Historically, an average of 16.7 million acre-feet (maf) of water reached the Colorado Delta annually from the river. A hundred years ago, riverboats steamed from the Gulf of California up the Lower Colorado/Gila River system into Arizona. Until completion of Hoover Dam in 1935 (creating Lake Mead), fresh water from the Colorado River flowed into the Northern Gulf throughout the year, with great seasonal floods resulting from spring snowpack melt in the Rocky Mountains. By the time Glen Canyon Dam was completed in 1962, input of Colorado River water to the Delta and Northern Gulf had completely ceased. For 20 years after completion of Glen Canyon Dam, as Lake Powell filled, virtually no water from the river reached the sea. In 1968, flow readings at the southernmost measuring station on the river were discontinued, since there was nothing left to measure. Today, 20 dams (58 dams if tributaries are included) and thousands of kilometers of canals, levies, and dikes have converted the Colorado River

Table 9.4. Species diversity of major invertebrate taxa in the Gulf of California.

Major Taxa	Totals for Gulf	SGC	CGC	NGC	BR	END	PEL	BEN
Porifera	86	36	42	46	19	16	0	86
Cnidaria	253	112	146	114	33	47	20	209
Hydrozoa	146	55	74	69	11	12	15	113
Anthozoa	102	53	72	44	21	35	0	96
Scyphozoa	5	4	0	1	1	0	5	0
Ctenophora	4	2	3	1	1	2	4	0
Platyhelminthes	22	5	16	12	10	9	0	22
Nemertea	17	5	8	6	2	2	0	17
Annelida	717	442	436	287	117	79	21	675
Oligochaeta	1	0	0	1	1	0	0	0
Polychaeta	716	442	436	286	116	79	21	675
Sipuncula	11	8	10	5	5	0	0	11
Echiura	4	2	2	2	0	1	0	4
Pogonophora	1	0	1	0	0	0	0	1
Arthropoda	1051	785	713	508	248	118	154	861
Pycnogonida	15	4	9	10	9	0	0	15
Cirripedia	43	30	22	14	5	9	4	37
Stomatopoda	28	22	17	8	2	3	0	28
Peracarida	328	223	224	174	59	30	116	189
Mysida	6	5	3	0	0	1	5	0
Amphipoda	232	163	155	126	30	17	109	113
Isopoda	80	53	62	41	27	10	2	67
Tanaidacea	2	2	2	1	0	0	0	2
Cumacea	8	0	2	6	2	2	0	7
Euphausiacea	14	14	8	4	1	0	14	0
Decapoda	623	492	433	298	172	76	20	592
Dendrobranchiata	32	31	24	16	10	1	8	24
Stenopodidea	2	2	2	0	0	0	0	2
Caridea	132	80	95	40	17	14	10	120
Astacidea	1	1	0	0	0	0	0	1
Thalassinidea	19	14	8	8	5	3	0	17
Palinura	8	8	4	2	1	0	0	8
Anomura	128	106	87	65	41	18	0	127
Brachyura	301	250	213	167	98	40	2	293
Mollusca	2193	1386	1560	1000	542	460	11	1965
Monoplacophora	1	1	0	0	0	0	0	1
Polyplacophora	57	25	44	38	20	15	0	55
Gastropoda	1530	938	1073	656	360	396	3	1317
Bivalvia	565	392	415	285	150	44	0	561
Scaphopoda	20	14	14	15	8	1	0	19
Cephalopoda	20	16	14	6	4	4	8	12
Bryozoa (Ectoprocta)	169	96	147	119	10	10	0	165
Brachiopoda	5	3	0	2	2	4	0	5
Echinodermata	262	207	180	138	56	16	0	262
Chaetognatha	20	17	14	7	1	0	20	0
Hemichordata	1	0	1	1	1	0	0	1
Chordata	38	6	13	10	3	3	21	14
Ascidia	16	5	12	9	2	3	0	13
Appendicularia	21	0	0	0	0	0	21	0
Cephalochordata	1	1	1	1	1	0	0	1
Totals	4854	3113	3293	2258	1050	766	251	4299

NGC = Northern Gulf of California; CGC = Central Gulf of California; SGC = Southern Gulf of California; BR = Upper Gulf/ Delta Biosphere Reserve subregion of Northern Gulf; END = endemic to the Gulf; PEL = pelagic species only; BEN = benthic species only.

into a highly controlled plumbing system in which every drop of water is carefully managed, and only about 4 maf/year reaches the Delta (and then, only during wet years). In addition, most of the Delta's wetlands have been converted into farmland or urban sprawl. What was once 2 million acres of wetlands has been reduced to less than 60,000 acres of freshwater wetlands (much of this in the "recreated" 30,000 acre Ciénega de Santa Clara) and 130,000 acres of coastal salt marsh. Due to the greatly reduced freshwater flow, the powerful tides of this region now overwhelm the river channel. During spring tides, seawater creates an estuarine basin for 50–60 km up-river, averaging 2–8 km in width and 16 km wide at the mouth. This marine intrusion has killed most of the freshwater flora and fauna that used to live along the lowermost river corridor (Brusca et al. 2001; Brusca and Bryner 2003; Brusca 2004).

Before construction of Hoover Dam, the annual sediment discharge from the Colorado River into the Gulf was enormous, estimated to range from 45 to 455 million metric tons/year. Indeed, the entire Northern Gulf is considered the "Colorado River Sedimentary Province." The name of the river itself, Colorado, is Spanish for a red or ruddy color, and the first name given to the Gulf of California was the Vermilion Sea (by Francisco de Ulloa, the first Spanish navigator to sail there under orders from the conquistador Hernán Cortés). The reduction of freshwater input and sediment discharge since 1935 has modified the hydrography of the Colorado River Delta/Northern Gulf system, initiating a regime of deltaic erosion. Deltaic deposition no longer takes place, and the entire Delta is now exposed to destructive hydrodynamic forces of tides and storms, promoting resuspension, erosion of ancient river sediments, and the gradual export of sediments to the southwest and eventually out of the Northern Gulf. These changes are altering the littoral wetlands and biological equilibrium of the region (Brusca et al. 2001; Brusca and Bryner 2003; Brusca 2004).

The single most serious threat to the integrity of the Delta's natural communities is from Colorado River water management decisions made in the United States. A 1944 water treaty guarantees Mexico 1.5 maf/year from the river (plus an additional 200,000 acre-feet when surpluses are declared), and a 1973 amendment to the treaty guarantees Mexico relatively pure water. However, virtually all of the Colorado River water crossing the border is diverted for urban and agriculture use in the Mexicali Valley, where a half-million acres are under irrigation. During most years, no Colorado River water reaches the Sea of Cortez, nor does the Delta have any explicit ecological water entitlement. Water that has reached its riparian corridor in recent years has done so solely because infrequent U.S. flood releases have exceeded the use and diversion capacity of upstream users (Brusca et al. 2001; Glenn et al. 2001).

It is likely that the reduction of freshwater input into the Northern Gulf, in combination with other anthropogenic factors, has driven some species to (or nearly to) extinction. However, we have so few historical or baseline data for marine organisms of this region that extinctions (or local extirpations) would go unnoticed for commercially unimportant or otherwise little-known species. There has never been a comprehensive, dedicated survey of the marine fauna of the Northern Gulf and Colorado River Delta ecosystem.

The delta clam, *Mulinia coloradoensis*, used to be one of the most abundant animals of the northernmost Gulf. Windrows of its shells line the beaches of the Delta and northwestern shores of the Northern Gulf. This species was thought to be extinct until its recent rediscovery in small numbers near the mouth of the river (Kowalewski et al. 2000; Rodríguez et al. 2001). The near demise of this species has been suggested to be the result of decreased benthic productivity resulting from upstream diversion of the Colorado River's flow (Kowalewski et al. 2000; Rodríguez et al. 2001). However, there is no indication that nutrient levels (and hence productivity) have decreased significantly in the Northern Gulf, and nutrients that have been lost by depletion of riverine sediment input may have been regained in the form of agricultural runoff and deltaic erosion (releasing ancient trapped nutrients). Hence, the near extinction of this clam may be linked to another, as yet unknown factor related to reduction of freshwater input to the Delta.

The recent return in large numbers of the once "commercially extinct" gulf corvina (*corvina golfina*, *Cynoscion othonopterus*) to the northernmost Gulf may be tied to increased Colorado River flows during wet years since the 1980s (Román-Rodríguez et al. 1998; Rowell et al. in press). Freshwater input from the Colorado River is also important to the life history of commercial shrimps of the region. Commercial shrimp catches have been falling since the 1960s, due to a combination of overfishing and loss of habitat for young (reviewed in Brusca et al. 2001). It has been estimated that an influx of just 250,000 acre-feet/year of Colorado River water

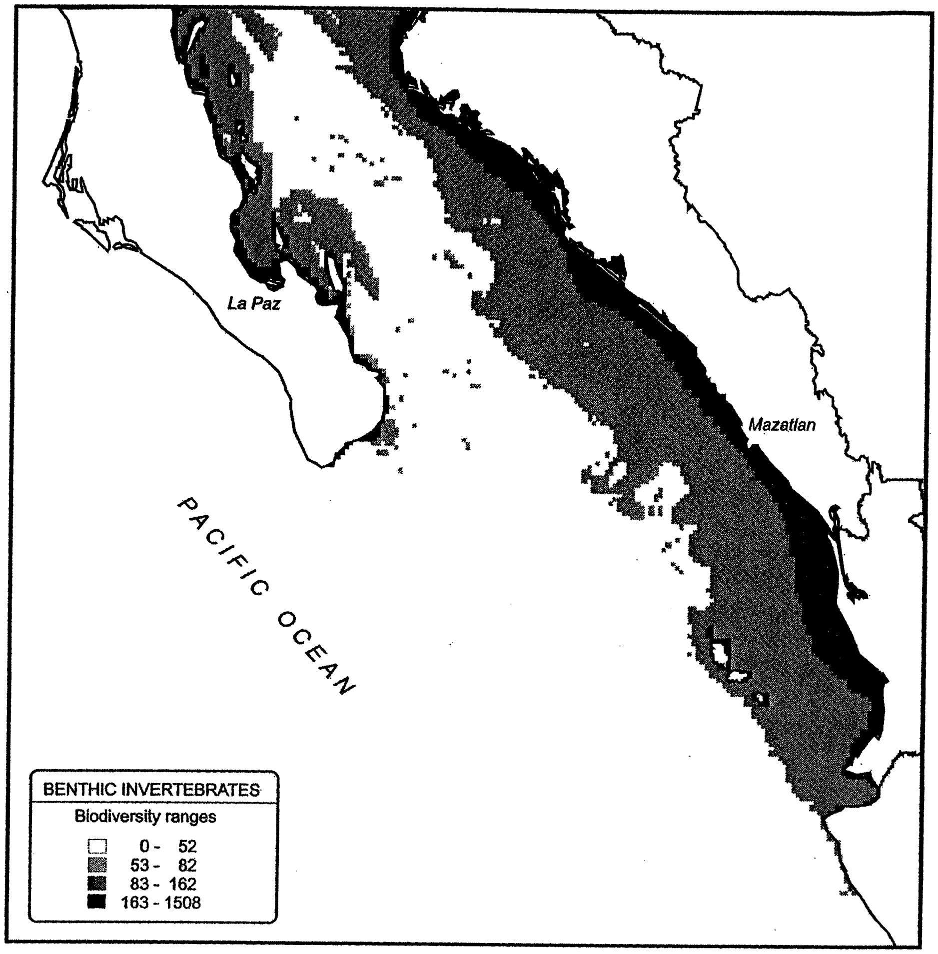

Figure 9.2a. Species diversity of benthic invertebrates in the Gulf of California.

would double shrimp production in the Northern Gulf (Galindo-Bect et al. 2000). The young of these shrimps use the shallow wetlands and *esteros* of the region, including the tidelands of the delta, as a nursery, migrating into these areas subsequent to their offshore planktonic larval phase. When the shrimp reach juvenile or subadult stage, they migrate offshore once again.

Reduction of the brackish estuarine habitat likely also has, in combination with historical overfishing and continuing capture of juveniles in shrimp nets, driven the large, corvinalike totoaba to near extinction (Hastings and Findley, in press). Continued absence of freshwater input could drive the endemic Palmer's saltgrass (*Distichlis palmeri*), which apparently needs periodic freshwater flooding to germinate, to extinction (see Felger 2000, for a summary of the biology of this species). The same may be true of the endemic delta silverside fish (*pejerrey delta, Colpichthys hubbsi*). Aquatic birds also rely heavily on the Gulf's coastal lagoons and wetlands, all of which are on the western flyway for migratory waterfowl.

Today, every fishery in the Gulf is probably overfished (Greenberg and Vélez-Ibáñez 1993; Musick et al 2000; Brusca et al. 2001; Greenberg, in press). The American Fisheries Society (AFS) official list of North American Marine Fishes at Risk of Extinction reports (an underestimated) 11 at-risk species in the Gulf of California. Five of these are large serranids (groupers, *meros, cabrillas*) and sciaenids (corvinas, *berrugatas, chanos*), some of which are endemic or nearly endemic to the Gulf. These species are sensitive to overharvesting because of their

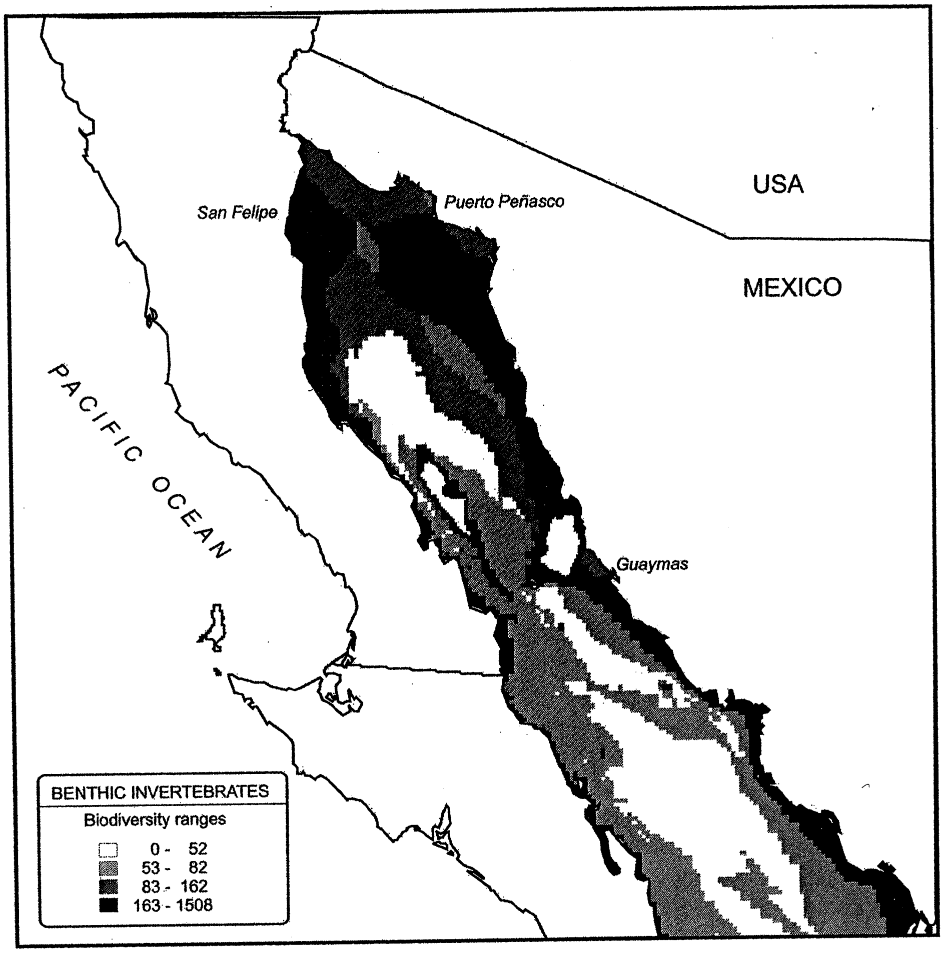

Figure 9.2b. Species diversity of benthic invertebrates in the Gulf of California.

late maturity and formation of localized spawning aggregations. In addition, most (if not all) of the serranids are protogynous, and the sciaenids require estuarine habitats once provided by the rapidly diminishing Colorado River Delta for spawning and nursery grounds. The AFS also lists the Gulf, especially its northern part, as 1 of 5 geographic hotspots in North America where numerous fish species are at risk; certainly, the same could be said for the invertebrates of this region.

The vaquita is a small, endemic porpoise that lives only in the northernmost Gulf. With the most recent estimate of vaquita abundance at only 567 individuals, and bycatch mortality at an estimated 39–84 deaths per year, this porpoise is the most endangered marine cetacean in the world (Vidal 1995; Jaramillo-Legorreta et al. 1999; Rojas-Bracho and Taylor 1999; Vidal et al. 1999; D'Agrosa et al. 2000; chapter 14). The primary cause of vaquita mortality is incidental capture in gillnets, and unless this type of fishing gear is banned in the Biosphere Reserve and in its critical habitat to the south (Gallo-Reynoso 1998), the vaquita will almost certainly be extinct in a few years.

Many once abundant but less visible species, such as the threatened giant brown sea cucumber (*Parastichopus fuscus*), are now practically gone from the Gulf. Sea cucumbers have vanished at the hands of Mexican and Japanese fishers who collect them for Asian food markets. Even though this sea cucumber is now protected by Mexican law, it continues to be harvested from the offshore islands in the Gulf, the last remaining refugium for this and many other species that were once abundant along

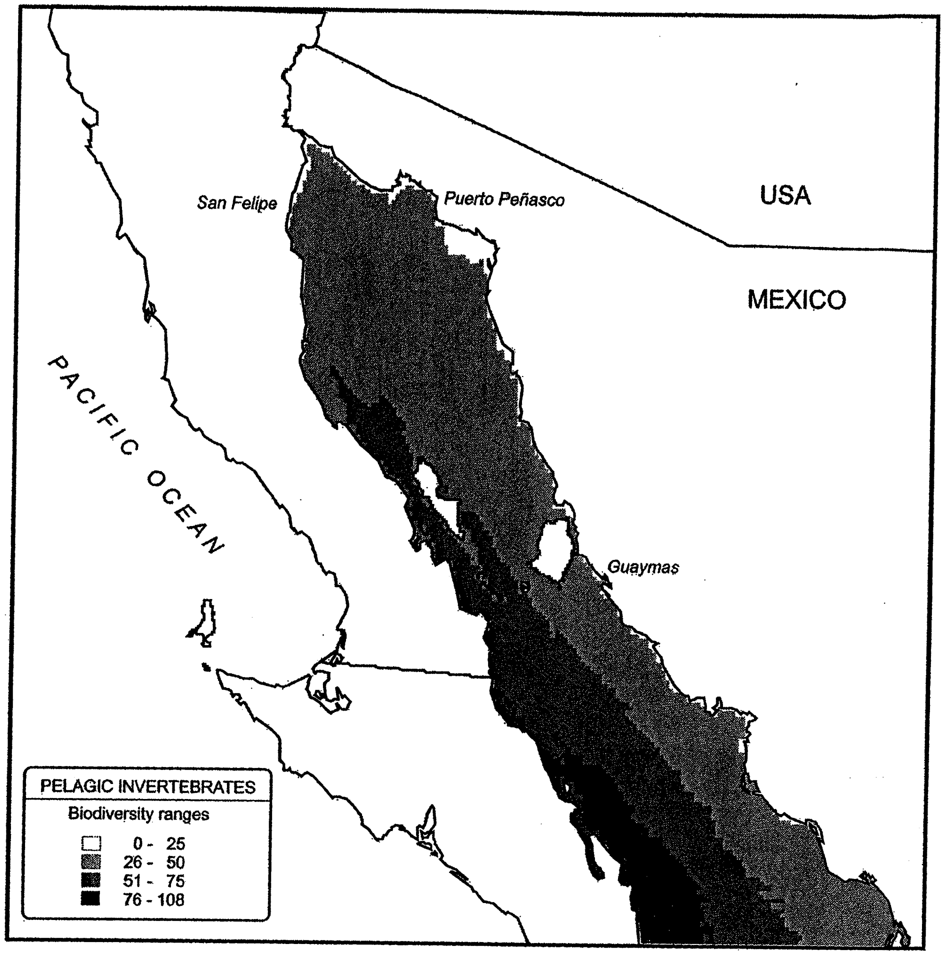

Figure 9.3a. Species diversity of pelagic invertebrates in the Gulf of California.

the mainland and peninsular coasts. In areas of heavy and increasing tourism, such as Puerto Peñasco, San Felipe, Guaymas/San Carlos, Mazatlán, Loreto, La Paz, and Los Cabos, littoral biodiversity is but a shadow of what it was just 20 years ago. Part of the tourism-driven loss is hand collecting of animals by visitors (and perhaps the trampling underfoot of fragile habitats exposed at low tide), but equally important is the collection of large molluscs and echinoderms by residents for sale to tourists as curios or to local restaurants where they are served in seafood cocktails (e.g., large bivalve and gastropod molluscs, octopuses). In the Southern Gulf (and to the south) many large molluscs are disappearing due to subsistence (artisanal) fishing. For example, the large fasciolarid snail *Pleuroploca princeps*, the large chiton *Chiton articulatus*, and giant limpet *Patella mexicana* (the largest living limpet; to 15 cm) have disappeared from accessible shores, and today they are found almost exclusively on island refugia or highly inaccessible stretches of the mainland coast.

Industrial and artisanal shrimp fishing also exacts a harsh toll on the Gulf's marine environment, as more than a 1000 large shrimp trawlers annually rake an area of sea floor equivalent to twice the total size of the Gulf (Brusca et al. 2001). This high rate of bottom trawling damages fragile benthic habitats, and during the mid-1960s to late 1970s trawlers generally captured an average of 10 kg of fish and invertebrate bycatch for every kilogram of commercial shrimp, with a range of about 1.2–35 kg of bycatch (per kilogram shrimp) in 95% of trawl hauls analyzed (Pérez-Mellado and Findley 1985; van der Heiden 1985). Today, bottom trawlers aver-

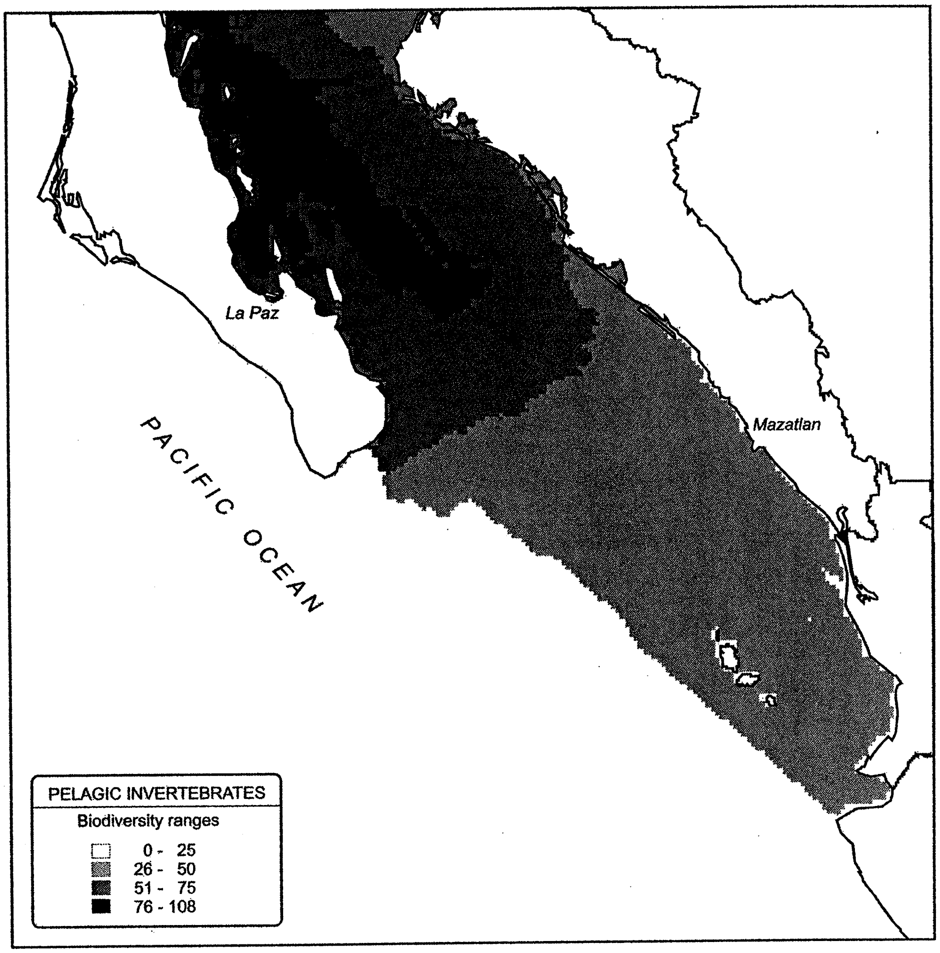

Figure 9.3b. Species diversity of pelagic invertebrates in the Gulf of California.

age 10–30 kg bycatch per kilogram shrimp (depending on the time of year) in the Northern Gulf (R. Brusca, interviews with Puerto Peñasco shrimp fishers). The number of commercial shrimp trawlers in the Gulf grew from 700 in 1970 to a high of 1400 in 1983, then decreased to 1144 in 1997, then increased again to 1470 in 2000 (García-Caudillo and Gómez-Palafox, in press), despite warnings as early as the 1970s of a possible crisis resulting from overexploitation (e.g., Snyder-Conn and Brusca 1977). Catch-per-unit-effort has been declining for decades, while government subsidies artificially sustain the overcapacity of the industrial fishing fleet. Without these government subsidies, the current level of commercial trawling would not be economically feasible. Limited scientific and anecdotal information suggests that sweeping changes in benthic/demersal community structure have taken place over the past 50 years as a result of this disturbance (van der Heiden 1985; Nava and Findley 1994; Nava-Romo 1994), including an apparent accelerating decrease in the diversity and biomass of the bycatch, possibly heralding an early stage in regional benthic/demersal ecosystem collapse.

Increasing loss of coastal habitats due to development, including poorly designed marinas and aquaculture installations lacking environmental controls, has reduced the rich *esteros*, estuaries, and mangrove communities of the Gulf that serve as critical spawning and nursery grounds for shrimp and other invertebrate and fish species. Ninety percent of Mexico's cultivated shrimp production is in southern Sonora, Sinaloa, and Nayarit, all of which have rapidly growing, semi-intensive, and spatially

Table 9.5. Endemicity of major invertebrate taxa in the Gulf of California.

Major taxa	END	SGC	CGC	NGC	ND
Porifera	16	5	3	6	0
Cnidaria	47	4	16	12	0
Hydrozoa	12	1	3	5	0
Anthozoa	35	3	13	7	0
Scyphozoa	0	0	0	0	0
Ctenophora	2	0	1	0	0
Platyhelminthes	9	1	1	4	0
Nemertea	2	0	2	0	0
Annelida	79	9	34	20	2
Oligochaeta	0	0	0	0	0
Polychaeta	79	9	34	20	2
Sipuncula	0	0	0	0	0
Echiura	1	0	0	0	0
Pogonophora	0	0	0	0	0
Arthropoda	118	11	15	31	3
Pycnogonida	0	0	0	0	0
Cirripedia	9	2	1	0	1
Stomatopoda	3	0	2	0	0
Peracarida	30	1	4	14	0
Mysida	1	0	0	0	0
Amphipoda	17	0	0	10	0
Isopoda	10	1	3	3	0
Tanaidacea	0	0	0	0	0
Cumacea	2	0	1	1	0
Euphasiacea	0	0	0	0	0
Decapoda	76	8	8	17	2
Dendrobranchiata	1	0	0	0	0
Stenopodidea	0	0	0	0	0
Caridea	14	3	6	1	0
Astacidea	0	0	0	0	0
Thalassinidea	3	1	0	1	0
Palinura	0	0	0	0	0
Anomura	18	2	0	1	2
Brachyura	40	2	2	14	0
Mollusca	460	111	70	51	22
Monoplacophora	0	0	0	0	0
Polyplacophora	15	0	0	4	0
Gastropoda	396	101	62	42	21
Bivalvia	44	10	7	5	1
Scaphopoda	1	0	0	0	0
Cephalopoda	4	0	1	0	0
Bryozoa (Ectoprocta)	10	0	3	1	0
Brachiopoda	4	2	0	2	0
Echinodermata	16	12	2	0	0
Chaetognatha	0	0	0	0	0
Hemichordata	0	0	0	0	0
Chordata	3	0	0	1	0
Ascidiacea	3	0	0	1	0
Appendicularia	0	0	0	0	0
Cephalochordata	0	0	0	0	0
Totals	766	155	147	128	27

NGC = Northern Gulf of California; CGC = Central Gulf of California; SGC = Southern Gulf of California; END = total number of Gulf endemics; ND = specific locality data lacking.

expansive coastal pond infrastructure. Loss of these wetlands also reduces important stopover sites for migratory birds (see chapter 15). Mexico's Ministry of Tourism's planned "Nautical Ladder" (*Escalera Náutica*) proposes 23 marinas to be in place by 2006 around both sides of the Baja California peninsula and southward on the mainland all the way to Teacapán (Sinaloa). The marinas likely will cause permanent loss of wetlands, and constructing the infrastructure required to connect them with roads and services could also be damaging. Areas that have experienced rapid growth of tourism and "vacation home" development (mainly for visitors from the United States) such as Puerto Peñasco and San Carlos in Sonora, and the coastal strip from San Felipe to Puertecitos (Baja California), have been hard hit ecologically by human perturbation. The intertidal zones of these areas have lost almost all of their larger-bodied fauna (especially echinoderms and molluscs) and now harbor only small remnants of their past biological diversity.

The coral reef at Cabo Pulmo is an area of extreme concern. Although the reef is included in the 7111-ha Cabo Pulmo National Marine Park, created in 1995, it has never had proper protection. The reefs are in shallow water, which means they are quickly affected by increased sea-surface temperatures associated with global warming and from sediment and wastewater runoff from coastal development. Charter sport fishing boats and small-scale Mexican fishers exploit the reef, taking fish and causing anchor damage. Tropical fishes are also removed from the reef habitat by the commercial aquarium trade. The maritime boundaries of the park are not marked. The reef is also easily (and heavily) accessed by sport divers, and as commercial sport diving operations in the area grow, damage to the reefs is inevitable unless strict regulations and educational programs are put in place. The growth of vacation homes along the shoreline of Cabo Pulmo could also result in nutrient enrichment by way of sewage runoff (above ground or below ground), resulting in overgrowth of the reef by algae and eventual eutrophication. Despite regional concern by universities, nongovernmental organizations, and local residents, local politics and lack of protection present major threats to the survival of this rare ecosystem—the Gulf of California's only coral reef.

Commercial fishing boats using large gillnets and long-lines with many hooks overexploit offshore waters, and small boat (*panga*) fishers often take shrimp and finfish from shallower coastal waters, estuaries, and other coastal lagoons before they have reached reproductive maturity. Foster et al. (1997) described the overexploitation of the scallop population (*Argopectin circularis*) around Isla El Requéson (in Bahía Concepcón, Baja California Sur), where the commercial take fell from 1.5 million kg in 1991 to just 1080 kg in 1994.

Narcotraffickers using the Gulf of California as a corridor to transport illegal drugs from Mexico to the United States present a new and growing threat to biodiversity. They often camp on islands, damaging coastal environments, and after a run abandon (or trade) their *pangas* (skiffs) in the upper Gulf in such high numbers that the local fishers have greatly increased their boat presence, and ecological impact, in the region. Many islands of the Gulf are also threatened by introduction of exotic/domestic animals (e.g., rats, cats, ants, cockroaches) and plants (e.g., buffelgrass) that impact native plant, reptile and bird populations (Bahre 1983).

Living rhodolith beds occur at several shallow-water localities along the southeastern coast of Baja California Sur and infrequently from Puerto Lobos (Cabo Tepoca, Sonora) to at least Bahía Banderas (Jalisco). These are unique living habitats composed of unattached spherical nodules (to 10 cm) of free-living calcareous red algae (Corallinales, Rhodophyta) that can cover large areas of the shallow sea bed (Riosmena-Rodriguez et al. 1999; Foster 2001). Rhodolith beds in the Gulf harbor a diverse associated fauna, although a full survey of their associated animal communities has yet to be undertaken (see Cintra-Buenrostro et al. 2002, for molluscs; Reyes-Bonilla et al. 1997, for corals; and Clark 2000, for chitons). Because the beds are sites of high scallop abundance, disturbance and damage associated with scallop fishing (hookah hoses and anchors dragging the bottom) are a threat to these unique communities, and Foster et al. (1997) recorded considerable damage from scallop fishers in rhodolith beds around Isla El Requéson. And, of course, offshore rhodolith beds can be greatly damaged by shrimp trawlers (video footage of this is seen in the Howard Hall production "Shadows in a Desert Sea"; Hall 1992). Because of their strong three-dimensionality and conversion of soft-bottom habitats to hard-bottom ecosystems, rhodolith beds are probably important sites for larval recruitment, including commercial species. The extensive near-shore Pliocene and Pleistocene carbonate deposits of the southeastern Baja California peninsula indicate that rhodolith communities have been an important part of the shallow marine environment of this region for millions of years.

In summary, biodiversity in the Gulf of California is threatened by reduction of freshwater inflow, chemical pollution from agriculture, runoff, and sewage from urban areas, coastal habitat destruction, inadequate fisheries regulation and historical overfishing, lack of reliable scientific data upon which to base management decisions, uncontrolled tourism, narcotrafficking, and introduction of exotic species. In combination, these factors have resulted in the near extinction of such highly visible or charismatic endemic species as the totoaba and vaquita, near extirpation of 5 species of sea turtles, destruction of biodiversity in littoral and offshore benthic habitats, and decimation of benthic/demersal ecosystems due to commercial bottom trawling for shrimp and finfish (including substantial reductions in the Gulf's important commercial shrimp populations). However, despite these threats, in the Gulf of California one still can find a number of coastal refugia, areas not easily accessible by road or large fishing boats, which serve as important shelters for species extirpated elsewhere in the Gulf. Current discussions on a biodiversity action and sustainable management plan for the Gulf, spearheaded by regional nongovernmental conservation organizations as well as several government agencies, are focusing on protection of these refugia, as well as the islands, estuaries, and other coastal lagoons of this tremendously diverse region. Two recently enacted laws in Mexico prohibit the use of gillnets with mesh sizes greater than 6 inches and prohibit the use of bottom trawling in federally protected areas, such as the Upper Gulf/Delta Biosphere Reserve. These new laws (*normas*) are major steps toward a meaningful conservation effort in the Gulf of California.

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Appendix 9.1: Primary Institutions Conducting Zoological Research in the Gulf of California Since 1965

1. Arizona-Sonora Desert Museum (ASDM), Tucson, Arizona
2. California State University at Long Beach (CSULB), Long Beach, California
3. Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Baja California
4. Centro de Investigación en Alimentación y Desarrollo (CIAD), Guaymas (Sonora) and Mazatlán (Sinaloa)
5. Centro de Investigaciones Biológicas del Noroeste (CIBNOR), La Paz (Baja California Sur) and Guaymas (Sonora)
6. Centro Interdisciplinario de Ciencias Marinas del Instituto Politécnico Nacional (CICIMAR-IPN), La Paz, Baja California Sur
7. Instituto del Medio Ambiente y Desarrollo Sustentable del Estado de Sonora (IMADES; formerly CIDESON), Hermosillo and El Golfo de Santa Clara, Sonora
8. Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)-Campus Guaymas, Sonora
9. Scripps Institution of Oceanography (SIO), University of California at San Diego, La Jolla, California
10. Universidad Autónoma de Baja California (UABC), Ensenada, Baja California
11. Universidad Autónoma de Baja California Sur (UABCS), La Paz, Baja California Sur
12. Universidad de Sonora (UNISON), Hermosillo, Sonora
13. Universidad Nacional Autónoma de México (UNAM): Facultad de Ciencias, Instituto de Ciencias del Mar y Limnología's (ICML-UNAM) Mazatlán field station, and Instituto de Biología (IB-UNAM)
14. University of Arizona (UAZ), Tucson
15. University of California at Los Angeles (UCLA)
16. University of California at Santa Barbara (USB), Marine Science Institute
17. University of California at Santa Cruz (UCSC)

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