Ichthyofaunal list of the continental slope of the southern Gulf of Mexico

José Martín Ramírez¹, Ana Rosa Vázquez-Bader², Adolfo Gracia³

¹ Postgraduate in Marine Sciences and Limnology, Universidad Nacional Autónoma de México ² Postdoc. Unidad Académica de Ecología y Biodiversidad Acuática, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México ³ Unidad Académica de Ecología y Biodiversidad Acuática, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, A.P. 70-305, Ciudad de México, 04510, México

Corresponding author: José Martín Ramírez (montevivo100@gmail.com)

Academic editor: M. Elina Bichuette | Received 26 November 2018 | Accepted 3 January 2019 | Published 16 May 2019

Abstract

Four oceanographic cruises were carried out between April 2011 and May 2013 on the continental slope of the southern Gulf of Mexico (GoM) in a depth range of 290 to 1200 m on board the R/V JUSTO SIERRA. A total of 91 trawls covered a total swept area of 170.49 hectares. We recorded 177 fish species belonging to 80 families. Fifteen species extended their distribution into the south of the gulf and 37 increased their depth ranges. Five species could have commercial importance: Aphanopus carbo Lowe, 1839; Hydrolagus mirabilis (Collett, 1904); Helicolenus dactylopterus (Dela-roche, 1809); Lophius gastrophysus Miranda Ribeiro, 1915, and Merluccius albidus (Mitchill, 1818). The most abundant species were Polymixia lowei Günther, 1859; Paracauda truculenta (Goode & Bean, 1896); M. albidus, Chlorophthalmus agassizi Bonaparte, 1840; Dibranchus atlanticus Peters, 1876; Nezumia aequalis (Günther, 1878); Yarrella blackfordi Goode & Bean, 1896; and Laemonema barbatulum Goode & Bean, 1883. High values of fish species richness, diversity, and evenness were registered throughout the study area. A high percentage of the fish species (97%) collected during this project are distributed in the entire GoM. Most of the species showed a wide depth distribution; however, a vertical zonation of species can be observed.

Keywords

Deep water, fishes, new records, species richness
Introduction

The Gulf of Mexico (GoM) is one of the most productive and economically important ecosystems in the world (Cato 2009, Tunnell 2009), and its large biodiversity makes it one of the most diverse seawater bodies (Felder et al. 2009). Due to its ecological and economic importance, ichthyofauna studies initially focused on commercial species. Research on fish biodiversity in the GoM, which began in 1850 (Darnell and Defenbaugh 1990), became more systematic and extensive since 1950. A total of 1541 species has been reported in the GoM in the different types of habitats that exist in this large ecosystem (McEachran 2009). Nevertheless, more emphasis has been placed on coastal regions because they are more accessible and economical to survey compared to deeper areas and the open sea.

Few investigations about fish biodiversity have been conducted on the continental slope, and most have focused on different ecological aspects of demersal fish communities in the northern part of the GoM (Pequegnat et al. 1990, Powell et al. 2003). More than 126 mesopelagic fish species were found in this region by Ross et al. (2010), who compared the composition of mesopelagic fishes in three different habitats located at depths between surface and 1000 m. Sulak et al. (2007) documented 53 benthic fishes associated with deep water coral habitats in the north-central gulf. McEachran and Fechhelm (1998) produced one of the most complete ichthyological inventories for the GoM and for the Caribbean Sea’s continental slope. In addition, Anderson et al. (1985), Saavedra-Díaz et al. (2004) and Paramo et al. (2015) issued complementary reports of 44 species in this region. Others studies of the deep-water fishes in the Caribbean, but concerning to deep reef fishes have been conducted by Colin (1974); Thresher and Colin (1986); Baldwin and Robertson (2014); Baldwin et al. (2016) and Quattrini et al. (2017).

Since there were not studies of fish communities in the southern deep-water of the GoM, the ichthyological inventory of this ecosystem is not yet completed. The Mexican portion of the GoM deep water has recently become an area of interest because of its oil extraction potential (PEMEX 2016) and its potential fishing resources, where at least three important shrimp species have recently been discovered (Gracia et al. 2010). In a potential scenario of exploitation of both living and non-living resources of deep waters of the GoM, it is crucial to acquire more knowledge about this ecosystem. Biodiversity inventories need to be developed to understand, manage, and conserve these resources.

In this study we present information of the fish biodiversity of the scarce explored continental slope of the southern GoM. Our study is the first one that systematically analyzes the deep-water fish fauna in this region.

Materials and methods

The GoM is in a subtropical region that measures 1600 km from east-to-west and 1300 km from north-to-south. It is influenced by the Caribbean Sea due to the transport of water masses via the Loop Current flowing into the gulf through the Yucatan
Channel and out of the gulf through the Straits of Florida. Winds, especially in winter also impact gulf circulation (Monreal-Gómez et al. 2004) (Fig. 1).

This research forms part of the project “Biodiversity and Potential Fishing Resources in Deep waters of the Gulf of Mexico,” through which oceanographic cruises (Benthic communities and potential fishing resources in the Gulf of Mexico deep waters, COBERPES) were conducted on the Mexican continental slope of the GoM on board the R/V JUSTO SIERRA of the Universidad Nacional Autónoma de México.

Four oceanographic cruises were carried out from April 2011 to May 2013: COBERPES 2 and COBERPES 3 on the Yucatan Slope; COBERPES 4, off the coast of Tamaulipas and COBERPES 5 on the Campeche Bank (Table 1). The benthic megafauna of soft bottom substrates was sampled in a depth range of 290–1200 m, using

Figure 1. Locations of the oceanographic cruises: COBERPES 2; COBERPES 3; COBERPES 4; and COBERPES 5. Abbreviations: ne: north-east; nw: north-west; se: south-east; sw: south-west; Al: Alabama; Atl: Atlantic; Bl: Belize; Cp: Campeche; La: Louisiana; Ms: Mississippi; Mx: Mexico; Pac: Pacific; QR: Quintana Roo; Tb: Tabasco; Tm: Tamaulipas; Tx: Texas; US: United States; Vz: Veracruz; Yc: Yucatan. Gulf of Mexico division taken from Felder et al. (2009).
a semi-commercial shrimp trawling net with an 18m mouth, a 4.5cm mesh and a 1.5cm cod-end opening. Since information about sea bottom was lacking, sea bed was previously explored using a Multihaz EM 300 echo sounder and a Topas PS-18 sub-bottom profiler. After finding adequate substrate, 30-minute trawls were performed at an average velocity of 77.16 m/min. The distance of each tow was determined by GPS readings. Fauna samples were sorted by taxonomic groups, weighed, and preserved in 10% formalin on board.

In the laboratory, fishes were identified to species level. The names, authorities, and years of the descriptions were cross-referenced against the Eschmeyer database (2017), as well as the geographic and bathymetric distribution of the species was consulted in different web sites: Ocean Biogeographic Information System (OBIS 2018); Smithsonian National Museum of Natural History; Biodiversity of the Gulf of Mexico Database (Moretzsohn et al. 2017); Texas A & M University Corpus Christi, Harte Research Institute for Gulf of Mexico Studies (2017); FishNet 2 (2013); World Register of Marine Species (WoRMS 2017) and FishBase (Froese and Pauly 2017). Each individual was measured, weighed, preserved in 70% alcohol, and retained in the Reference Collection of the Laboratorio de Ecología Pesquera de Crustáceos del Instituto de Ciencias del Mar y Limnología, UNAM. Number of fish species vs. sampling effort was analyzed to determine sample size using the Clench model (Jiménez-Valverde and Hortal 2003) and the freeware Stimates v8 (Colwell 2006). With the biological data was examined the abundance (individuals/ha), richness (number of species), diversity (Shannon and Wiener 1963), and evenness (Pielou 1977) of the fish communities in different sampling areas. The bathymetric distribution of the species was recorded considering the average depth of each trawl.

Results

Ninety-one trawls covering a 290–1200 m depth range were done in the different regions of the southern GoM during the four oceanographic cruises. The numbers of successful trawls at each depth stratum were 300 m: 17; 400 m: 11; 500 m: 16; 600 m: 8; 700 m:
Ichthyofaunal list of the continental slope of the southern Gulf of Mexico.

Figure 2. Plot for fish species accumulation for the total sample. Key: circles, random curve; continuous line, fit curve of Clench function ($Sn = (10.79*n)/(1+(0.0520*n))$. Each sample unit consisted of 30 minutes trawl at an average speed of 77.16 m/min (2.5 knots).

11; 800 m: 1; 900 m: 6; and 1000 m: 4, corresponding to 170 hectares total swept area. Seven trawls failed (Table 1). A total of 9781 fishes was caught, belonging to 80 families and 177 species (Table 2). The species accumulation curve related to the number of samples did not reach a clear asymptote; however, data adjusted with a Clench model suggests that 91% species richness of the southern GoM continental slope was recorded (Fig. 2).

The most abundant species were *P. lowei* (1206 individuals), *P. truculenta*, *M. albidus*, *C. agassizi*, *D. atlanticus*, *N. aequalis*, *Y. blackfordi*, and *L. barbatulum*. Among these, *P. lowei* and *C. agassizi* are outstanding, with a relative abundance greater than 10%, and *D. atlanticus*, and *M. albidus* with a relative frequency of more than 50% (Fig. 3).

The lowest richness was found in the Yucatan slope area near the Caribbean Sea (COBERPES 2), with a total of 27 species and a mean of 11.81 ± 5.71 (SD) species per trawl, whereas, the highest one was registered in the Campeche Bay (COBERPES 5) with 39 species (17.26 ± 9.06 species per trawl), however, a high fish species richness (>30 species) was recorded at different sites throughout the GoM (Fig. 4a). The highest fish abundance was registered in the Yucatan continental slope, close to the Caribbean Sea (COERPES 2), with 412.46 individuals/ha recorded and a sample mean of 76.83 ± 19.18 individuals/ha (Fig. 4b). High fish diversity (Fig. 4c) and evenness (Fig. 4d) were recorded in several locations along the entire gulf, except in the area close to the Caribbean Sea (COBERPES 2).

Fifteen species extended their distribution into the continental slope of the southern GoM: *Eptatretus caribbeaus* Fernholm, 1982; *Ventrisfossa mucrocephalus* Marshall, 1973; *L. barbatulum*; *Brotulotaenia nigra* Parr, 1933; *Lophiodes beroe* Caruso, 1981;
Figure 3. Abundance and frequency of the fish species: a Abundance (%) and b Frequency (%).

Table 2. List of the fish community. Presence and depth distribution ranges of fish species in the different cruises and literature reported (McEachran 2009, Ocean Biogeographic Information System (OBIS), Eschmeyer 2017, Moretzsohn et al. 2017, FishNet 2 2013, World Register of Marine Species 2017, and Froese and Pauly 2017). Key: * species which extended their distribution into the south of the Gulf of Mexico; ne: north-east; nw: north-west; se: south-east; sw: south-west; Al: Alabama; At: Atlantic; Bh: Bahamas; Bl: Belize; Cp: Campeche; Cb: Caribbean; Cu: Cuba; La: Louisiana; Ms: Mississippi; Mx: Mexico; QR: Quintana Roo; Tb: Tabasco; Tx: Texas; Tm: Tamaulipas; US: United States; Vz: Veracruz; Yc: Yucatan. ** Species which extended their depth ranges.

| Specie | COBERPES cruises | Reported distribution and depth range (m) |
|--------|------------------|-----------------------------------------|
| Antigonia capros Lowe, 1843 | X | 296 | entire/50–200 |
| Antigonia combatia Berry & Rathjen, 1959 | X | 308 | Fl, Al, Bl/68–585 |
| Aphanopus carbo Lowe, 1839 | X | 823 | Atl, Vz/200–2300 |
| Apristurus laurussonii (Saemundsson, 1922) | X | 562–937 | Ms, Al, Tx, Fl, Mx/500–1000 |
| Argentina georgei Cohen & Atsaides, 1969** | X X X X | 300–825 | entire/220–457 |
| Argyrelopus aculeatus Valenciennes, 1850 | X X | 436–825 | entire/100–2056 |
| Aristotomias tittmanni Welsh, 1923 | X | 974 | entire/100–2000 |
| Astronesthes similis Parr, 1927 | X | 611 | entire/0–800 |
| Astronesthes phryx Robins & Robins, 1970** | X X | 534–600 | Cb, Fl, Cu, Vz/385–425 |
| Balisteirinae aureorubena (Longley, 1935) | X X | 300–611 | Mx/91–610 |
| Baldininae viviana (Jordan & Swain, 1885) | X X X | 300 | Mx/20–610 |
| Barathronus bicolor Goode & Bean, 1886 | | 846 | entire/366–1561 |
| Barbatius carrifrons (Roule & Angel, 1931) | X | 953 | ne, nw, Fl/0–4500 |
| Bathyceratos argentea Goode & Bean, 1896** | X X X | 300–677 | entire/366–677 |
| Bathycerosus dubius (Breder, 1927) | X | 327 | entire/120–886 |
| Bathycerosus vicinialis (Garman, 1899) | X | 477 | Mx, US, Cb/101–503 |
| Bathypidius favosus Goode & Bean, 1886 | X X | 904–1068 | entire/770–2745 |
| Bathypidius macrosp Goode & Bean, 1885** | X X X X | 494–1068 | entire/200–777 |
| Bathypidius melanocephalus Vaillant, 1888 | X X X X | 602–1071 | entire/400–2600 |
| Bathypion tigilae Mead, 1958 | X X | 534–780 | entire/377–986 |
| Bathypidius guillaum (Goode & Bean, 1886) | X | 953 | entire/878–4720 |
| Bathypidius quadrifilis Günther, 1878 | X | 865 | entire/462–1408 |
| Specie | COBERPES cruises | Reported distribution and depth range (m) |
|-------|------------------|------------------------------------------|
| **Ichthyofaunal list of the continental slope of the southern Gulf of Mexico.** |
| Bathypтерeis viridensis (Roule, 1916) | X | 593–904 | entire/476–1477 |
| Bathymenognathus vicinus (Vaillant, 1888) | X | 477 | ne, nw, Tm100–1000 |
| Bembrose anatirostris Ginsburg, 1955** | X | 300–611 | entire/82–538 |
| Bembrose gobioideus (Goode, 1880)** | X | 300–825 | entire/82–740 |
| Benbodesmus simonyi (Steindachner, 1891)* | X | 436–500 | ne/200–900 |
| Benbodesmus tensi (Günther, 1877) | X | 300–825 | nw, ne, Mx200–850 |
| Bolinichthys supralateralis (Parr, 1928) | X | 599–677 | entire/40–850 |
| Bregmaceros atalanticus Goode & Bean, 1886 | X | 300–462 | entire/50–2000 |
| Bregmaceros cantori Milliken & Houde, 1984*** | X | 812 | ne/0–475 |
| Bregmaceros houdii Saksena & Richards, 1986*** | X | 346–611 | ne/50 |
| Brotonotus nigro Parr, 1933*** | X | 800–953 | Adl1000–1100 |
| Caesilotus cyanops Poey, 1866 | X | 300–500 | entire/45–459 |
| Chacanoperca lugubris Alcock, 1894 | X | 358–426 | entire/60–3210 |
| Chauliodus sloani Bloch & Schneider, 1801 | X | 300–593 | entire/0–470 |
| Chaunax pictus Lowe, 1846 | X | 321–865 | ne, nw, Tb200–978 |
| Chiromedo sp. | X | 780 | ne, Tb, QR |
| Chlorophthalmus agassizi Bonaparte, 1840 | X | 300–825 | entire/50–3000 |
| Citharichthys dinoceros Goode & Bean, 1886 | X | 363–426 | ne, QR, BL, Cu180–2000 |
| Coccorella atlantica (Parr, 1928) | X | 995 | entire/50–1000 |
| Coelorinchus caribbeatus (Goode & Bean, 1885)** | X | 300–825 | entire/200–700 |
| Coelorinchus caelorhincus (Risso, 1810) | X | 436–800 | entire/90–1485 |
| Coelorinchus occa (Goode & Bean, 1885) | X | 321–820 | entire/400–2220 |
| Coelorinchus sentrzymał Marshall & Iwamoto, 1973 | X | 300–534 | se, sw/300–500 |
| Colococa moesi Kanazawa, 1957 | X | 494–846 | Tm, Vz, ne, nw366–925 |
| Conocepa macropteron (Vaillant, 1888)** | X | 354–1071 | Mx800–2200 |
| Coryphaenoides alt��alis Marsahill & Iwamoto, 1973 | X | 904 | Mx/1035–1116 |
| Coryphaenoides mexicanus (Parr, 1946) | X | 534–937 | Mx110–1600 |
| Coryphaenoides xaniiophorus (Vaillant, 1888) | X | 677–1065 | entire/400–2775 |
| Crurina rugosa Bigelow & Schroeder, 1958 | X | 321–825 | Mx366–1007 |
| Cytopsis roca (Lowe, 1843) | X | 300–825 | Mx100–1000 |
| Dactylobatus clarkii (Bigelow & Schroeder, 1958) | X | 626 | Mx366–1000 |
| Diaphus dumerilii (Bleeker, 1856) | X | 423–823 | entire/0–850 |
| Diaphus fragilis (Tănă, 1928) | X | 823 | entire/15–1313 |
| Dibranchus atlanticus Peters, 1876 | X | 300–1071 | entire/22–1300 |
| Dicorele inorniger Goode & Bean, 1883 | X | 321–1071 | entire/200–1785 |
| Dipizantruma brevicauda Günther, 1887 | X | 494–766 | entire/439–1670 |
| Dipizantruma oregoni (Bigelow & Schroeder, 1958) | X | 611 | Mx369–1079 |
| Dipizantruma tervani (Bigelow & Schroeder, 1951) | X | 540–800 | Cp311–940 |
| Direntmnoides puzcridatua (Woods, 1973)** | X | 321–800 | entire/0–600 |
| Epigonus denticulatus Dieuzeide, 1950 | X | 354–800 | Mx130–830 |
| Epigonus macrosp (Brauer, 1906) | X | 766–823 | entire/550–1300 |
| Epigonus occidentalis Goode & Bean, 1896 | X | 573–700 | Vz, Tm360–737 |
| Epigonus oligolepis Mayer, 1974 | X | 540–619 | Mx380–660 |
| Epigonus pandionis (Goode & Bean, 1881) | X | 419–494 | Cp200–600 |
| Epigonus peciifer Mayer, 1974 | X | 346–677 | Mx100–1200 |
| Epapterurus caribbeanus Fernholm, 1982*** | X | 597 | Cb300–400 |
| Espringeria foliosus Bigelow & Schroeder, 1951 | X | 354–800 | ne, nw, sc, sw50–1052 |
| Etmopterus schultzi Bigelow, Schroeder & Springer, 1953 | X | 300–852 | entire/200–1000 |
| Etmopterus xenis Bigelow, Schroeder & Springer, 1953 | X | 392–800 | Mx100–1000 |
| Gaidella imberbis (Vaillant, 1888) | X | 300–974 | Mx, Cb, Cu70–900 |
| Gaidomus arcuatus (Goode & Bean, 1886)** | X | 321–1068 | entire/610–1370 |
| Gaidomus dispar (Vaillant, 1888) | X | 611–677 | Tm548–1105 |
| Gaidomus longifilis (Goode & Bean, 1885)** | X | 321–1071 | entire/630–2168 |
| Species                        | COBERPES cruises | Reported distribution and depth range (m) |
|-------------------------------|------------------|------------------------------------------|
| Galeus arae (Nichols, 1927)   | X X              | Mx/250–750                                 |
| Gibberichthys paumii Parr, 1933 | X                | entire/300–1100                           |
| Gigantha cheni Brauer, 1901   | X                | entire/0–1830                             |
| Gymnotorax kolpoi Böhlke & Böhlke, 1980 | X               | entiere/30–300                           |
| Halieutichthys aceleatus (Mitchell, 1818) | X            | X/8–820                                   |
| Halosaurus ovenii Johnson, 1864 | X X X X         | X/300–2000                                |
| Holocentrus dactylopterus (Dela Roche, 1809) | X         | X/50–1100                                 |
| Hemantias leptus (Ginsburg, 1952) | X              | entire/35–640                             |
| Heptanchias perlo (Bonnetterre, 1788) | X            | entire/0–1000                              |
| Hollandia hollardi Poy, 1861   | X X X X          | X/230–915                                 |
| Hoplostethus mediterraneus Cuvier, 1829* | X X X X         | X/100–1750                                |
| Hoplunnis tenuis Ginsburg, 1951** | X X X           | X/30>400                                  |
| Hydrolagus alberti Bigelow & Schroeder, 1951 | X X X X        | X/348–1470                                |
| Hydrolagus mirabilis (Collett, 1904) | X X X           | X/450–1933                                |
| Hygophum reinhardtii Lütken, 1892 | X            | entire/0–1100                              |
| Ijimaia antillarum Howell Rivero, 1935** | X X X X       | X/439>700                                 |
| Laemonema barbatulum Goode & Bean, 1883* | X X X          | X/50–1620                                 |
| Leptoderma macrops Vaillant, 1886 | X X X X         | X/500–2000                                |
| Leucoraja garmani (Whitley, 1939) | X X X X        | X/37–530                                  |
| Leucoraja lentiginosa (Bigelow & Schroedcr, 1951)** | X X X X       | X/53–538                                  |
| Lophiodon barbatulum Caruso, 1981* | X X X X        | X/347–860                                 |
| Lophiodon monodi (Le Danois, 1871)** | X X X          | ne, se/366–549                            |
| Lophiodon reticulatus Caruso & Suttkus, 1979 | X                | entire/64–820                             |
| Lophius gastrophysus Miranda Ribeiro, 1915 | X                | entire/40–700                             |
| Luciobrotula corethromycter Cohen, 1964 | X              | X/220–1830                                |
| Macroramphosus scolopax (Linnaeus, 1758)* | X           | ne, nw, Cu/25–600                         |
| Malacoderus laevis (Lowe, 1843) | X X X X        | X/200–1000                                |
| Malacoderus occidentalis Goode & Bean, 1885 | X X X X       | X/140–1495                                |
| Merluccius albicilla (Mitchell, 1818) | X X X X        | X/80–1170                                 |
| Monolene sessilicauda Goode, 1880 | X X X           | X/366–549                                 |
| Monomitopus agassizii Goode & Bean, 1896 | X X X X       | X/48–1125                                 |
| Myctophum nitidulum Garman, 1899 | X X X           | X/0–1537                                  |
| Nemichthys scolopax Richardson, 1848 | X              | X/100–4337                                |
| Neopinna americana (Grey, 1953) | X X X X         | X/0–600                                   |
| Neoscopelus macroptidus Johnson, 1863* | X X X X       | X/300–370                                 |
| Neoscopelus microchir Matsubara, 1943* | X X X          | X/300–814                                 |
| Nettastoma melanurus Rafinesque, 1810 | X X X X        | X/300–852                                 |
| Nezamia aequilis Günther, 1878) | X X X X         | X/321–973                                 |
| Nezamia clynet Marshall & Iwamoto, 1973** | X X X X       | X/420–1071                                |
| Nezamia suilla Marshall & Iwamoto, 1973 | X X X X        | X/400–1324                                |
| Oxinotus caribbaeus Cervignón, 1961** | X              | X/860–1500                                |
| Parasus lenci Goode & Bean, 1896 | X X X X         | X/0–1000                                  |
| Patanez pacificus Kamohara, 1935 | X              | cp, Cu/145–512                            |
| Peristedion ecuadorense Teague, 1961* | X X            | ne, nw, Cu, Tb/300–1180                   |
| Peristedion grevei Miller, 1967** | X X X X         | X/324–910                                 |
| Peristedion longispina Goode & Bean, 1886 | X X X          | X/60–914                                  |
| Peristedion miniatum Goode, 1880 | X X X           | X/64–910                                  |
| Peristedion thompsoni Fowler, 1952* | X              | X/115–475                                 |
| Specie                                                                 | Reported distribution and depth range (m) | COBERPES cruises |
|----------------------------------------------------------------------|------------------------------------------|------------------|
| Peristethion truncatum (Günther, 1880)                                | Vz, Yc/155–910                           | X X X X 336–852  |
| Photostomus guentheri Collett, 1889                                   | Zal, Cb/772                              | X 540–772 X      |
| Poecilopsetta beanii (Goode, 1881)                                    | entire/155–1636                          | X X X 300–825    |
| Polypterus asistemoidei Schultz, 1938*                                | ne, nw/0–1000                           | X X 300–820 X    |
| Polypterus thaeocoryn Parin & Borudulina, 1990                        | entire/165–1400                          | X X X 300–953    |
| Polyxina lucii Günther, 1859                                          | entire/0–2000                            | X X X 300–825    |
| Pontinus longipinis Goode & Bean, 1896**                              | entire/50–440                            | X X X 300–611    |
| Prioleutes atticus Goode & Bean, 1883**                               | Yc/35–457                                | X 611            |
| Prioleutes stearnsi Jordan & Swain, 1885                              | entire/11–549                            | X X X 308–346    |
| Prionotus macrophasalus (Müller & Jels, 1848)**                       | ne, nw, Cp/110–550                       | X 611            |
| Pseudomyrophis frio (Jordan & Davis, 1891)**                          | Yc/412–576                               | X 534–580 X      |
| Pseudonaja fischeri Bigelow & Schroeder, 1954                         | sw, Atl, Yc/0–180                        | X 494            |
| Rinoces nanus (Kofoed, 1927)                                          | entire/0–1000                            | X 1068           |
| Rondinina madereensis Maul, 1948                                       | ne, Cu/595–1450                         | X X X 852–1068   |
| Saurida caribbea Breder, 1927                                         | entire/4–460                             | X X 308–422 X    |
| Saurida normani Longley, 1935                                         | entire/25–550                            | X X X 300–611    |
| Scopelosaurus smithii Bean, 1925                                       | ne, Yz/50–3000                           | X X X 953        |
| Scorpaena dispar Longley & Hildebrand, 1940**                         | entire/0–500                             | X X X X 300–812  |
| Scylorhinus retifer (Garman, 1881)                                    | entire/36–750                            | X X X 300–812    |
| Setarchus guentheri Johnson, 1862                                     | ne, nw, Yc, QR/150–780                   | X X X 392        |
| Signong longonata (Günther, 1878)                                     | entire/25–1463                           | X X X X 494–1068 |
| Sphagmacrinus grumedicus (Parr, 1946)**                               | entire/1000–1960                         | X X X 820–1071   |
| Squalegadus mccuttis Gilbert & Huubs, 1916                            | Squalegadus gilberti Goode & Bean, 1886  | X X X 865–995    |
| Squalegadus gilberti Goode & Bean, 1886                               | entire/50–1740                           | X X X X 354–370  |
| Squalegadus gilberti Goode & Bean, 1886                               | entire/350–550                           | X X 300–370      |
| Squalegadus gilberti Goode & Bean, 1886                               | entire/0–1375                            | X X X 500–1375   |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X 628–953    |
| Squalegadus gilberti Goode & Bean, 1886                               | advent/945–4777                         | X X X 577–1065   |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X 628–953    |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X 611–772    |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X 327        |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X 300–974    |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 300–825  |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
| Squalegadus gilberti Goode & Bean, 1886                               | Squalegadus gilberti Goode & Bean, 1886  | X X X X 820      |
Figure 4. Community parameters for each cruise (COBERPES): a Species richness (number of species); b Abundance (individuals/ha); c Diversity (Shannon-Wiener); d Evenness (Pielou).

Hoplostethus mediterraneus Cuvier, 1829; Benthodesmus simonyi (Steindachner, 1891); Macroramphosus scolopax (Linnaeus, 1758); Bregmaceros cantori Milliken & Houde, 1984; Bregmaceros houdei Saksena & Richards, 1986; Peristedion ecuadorensis Teague, 196; Peristedion thompsoni Fowler, 1952; Polyipnus asteroides Schultz, 1938; Neoscopelus microchir Johnson, 1863, and Neoscopelus macrolepidotus Matsubara, 1943 (Table 2).

Thirty seven species increased its depth range distribution (Table 2). Three of the most abundant species recorded an average depth lower than 400 m (Fig. 3): Prionotus stearnsi Jordan & Swain, 1885 (318 ± 24.57 m); Xenolepidichthys dalgleishi Gilchrist, 1922 (379 ± 33.05 m) and Pontinus longispinis Goode & Bean, 1896 (376 ± 114.03 m). Many of the species showed a wide depth range distribution (400>800); however, only two of them presented the highest average depth: Monomitopus agassizti (Goode & Bean, 1896) and Y. blackfordi (743 ± 223.92 m and 749 ± 172.95 m, respectively) (Fig. 5).

Discussion

The species accumulation curve suggests that we registered most of the fish species found on soft bottoms of the continental slope of the southern GoM. Nevertheless, since the species accumulation curve continued to increase, the inventory still appears to be inconclusive. This situation is congruent with the fact that the sampling effort in the GoM deep waters has been low, particularly in the south. We identified 177 species which represent 12% of the total fish species (1541) reported for all habitats in continental shelf and deep waters including demersal and pelagic fishes of the GoM
The only previous systematic study using a similar sampling gear was conducted in the northern GoM by Powell et al. (2003) who recorded 93 demersal fish species for the upper (315–785 m) and mid slope (686–1369 m).

Based on the fish list elaborated by McEachran (2009) we counted 335 benthic and demersal fishes for the continental slope of the GoM. This number is 30 % higher than the 235 summed from this paper and Powell et al. (2003) study. It must be noted that McEachran list includes fishes collected with other gears and also in other habitats, like hard bottoms. Nonetheless, three fish species can be added to McEachran list: *Kali indica* Lloyd, 1909, following Powell et al. (2003) and two species found in this research *E. caribbeaus* and *B. nigra*. In this way, a total compilation of 338 species of benthic and demersal
fishes can be listed for this ecosystem. Additionally, 15 species extended their distribution into the south of the GoM (Table 2). It must also be noted that 37 species extended their depth ranges, nine of them were recorded in deeper ranges and 28 species in shallower depths than previously reported in literature. Most of the species showed a wide distribution depth range which is consistent with the distribution pattern of deep water fishes.

The highest species richness recorded in the continental slope of the Campeche Bay (COBERPES 5), is probably influenced by the high freshwater discharge of the largest hydrological system in the southern GoM: Grijalva-Usumacinta during summer, which inputs 62% of the total freshwater to the Mexican GoM (Day et al. 2004), similar to what Powell et al. (2003) found in the northern GoM, near the mouth of the Mississippi River. Likewise, the upwelling produced by cyclonic gyres in the Campeche Bank (De la Lanza-Espino and Gómez-Rojas 2004, Durán-Campos et al. 2017), could be playing an important ecological role. These factors together incorporate large concentrations of nutrients which may trigger local productivity, and subsequently the diversity of demersal fishes on the continental slope in this region. Fish richness and diversity difference between COBERPES 3 and COBERPES 5 could also be influenced by seasonal productivity variations due to current pattern change in the area.

Five species captured in this survey are of commercial importance in other parts of the world. M. albidus was one of the second most frequent species (50%) which accounted greatly to total biomass (72.296 kg) and presented relatively large sizes (total length = 103–555 mm). This species could have a fishing potential in the GoM, as it was an important fishing resource in the US Atlantic in the early 1990s, but its production decreased significantly over a 10-year period of exploitation (Traver et al. 2012). Other taxa of commercial interest in the Atlantic such as H. mirabilis, H. dactylopterus and particularly A. carbo (one individual), are important fishing resources in the central and northern regions of the eastern Atlantic Ocean (Bensch et al. 2009, Pajuelo et al. 2010). Another species registered in the present study was L. gastrophysus, which was a significant deep water fishing resource in Brazil from 2000 to 2007 (Álvarez et al. 2009). However, the fishing potential of these species in the GoM is still to be defined with further studies.

Compiling data of fish species of this study as well as from the literature (McEachran and Fechhelm 1998, Powell et al. 2003 and McEachran 2009), we found that the north and south parts of the GoM share 97% of the species recorded on soft bottoms of the continental slope of the whole gulf. On the other hand, more than 63% of the species (n = 44) recorded for the Caribbean Sea (n = 69) (Anderson et al. 1985, Saavedra-Díaz et al. 2004, Paramo et al. 2015) also occur in the GoM. McEachran (2009) pointed out that this fish similarity is influenced by fauna from the central Atlantic (the region between North Carolina and the Great and Lesser Antilles, including The Bahamas, Bermuda islands, and South America) due to the Loop Current effect that connects the Yucatan and Florida currents (Monreal-Gómez et al. 2004, NOAA 2016).

This result is consistent with the distribution of deep water fishes inhabiting large bathymetric areas due to more stable environmental conditions in these habitats (Clark et al. 2010). A similar distribution pattern has been recorded in several studies done in the world, for example in the Mediterranean Sea (Moranta et al.1998), in the Atlantic (Menezes et al. 2006, 2015; Magnussen 2002; Bergstad et al. 2012; Koslow 1993;
Our results suggest that a high number of species dwelling on the continental slope are shared between the north and south of the GoM. We recorded an extension in distribution into the south of the GoM and also bathymetrically of several fish species. New records are highly likely to be increased if sampling effort continues both geographically and bathymetrically, since the species cumulative curve did not reach an asymptote. This research contributes to the knowledge of the deep water fish community of the GoM, never studied before in the southern region. However, information needs to be enhanced since deep water natural resources of the southern GoM could be subject to increasing human pressures in the near future.

Acknowledgements

Our acknowledgements are due to Programa de Apoyo a Proyectos de Investigación e Innovación Tecnológica (PAPIIT), Proyecto IN223109-3 of the Universidad Nacional Autónoma de México (UNAM) and to the crew of the R/V Justo Sierra for their support in conducting the cruises. The Consejo Nacional de Ciencia y Tecnología (CONACyT) is greatly appreciated for the PhD scholarship. Particularly, we extended thanks to our colleagues of the laboratory of Ecología Pesquera de Crustáceos, ICML, UNAM: Rosa María Hernández Díaz, Diana Torres Galíndez, Magaly Galván Palmerín, Linda Trejo Torres, Sandra Antonio Bueno, Andrea Yazmín López Chávez, León Felipe González Morales, and Iván Martínez Romero. Thanks also to the staff of the Department of Hidrobiología of the Universidad Autónoma Metropolitana-Iztapalapa (UAM-I): Verónica Escobar Morales, Araceli Soto Ávila, Obeth Ayala Medina, Luis Arturo Ponza Ramos, and David Herrera Olayo.

References

Álvarez JAP, Pezzuto PR, Wahrlich R, Souza ALS (2009) Deep-water fisheries: History, status and perspectives. Latin American Journal of Aquatic Research 37(3): 513–541. https://doi.org/10.3856/vol37-issue3-fulltext-18

Anderson ME, Crabtree RE, Carter HJ, Sulak KJ, Richardson MD (1985) Distribution of demersal fishes of the Caribbean Sea found below 2,000 meters. Bulletin of Marine Science 37: 749–807.

Baldwin CC, Robertson DR (2014) A new Liopropoma sea bass (Serranidae, Epinephelinae, Liopropomini) from deep reefs off Curaçao, southern Caribbean, with comments on depth distribution of western Atlantic liopropomins. ZooKeys 409: 71–92. https://doi: 10.3897/zookeys.409.7249

Baldwin CC, Robertson DR, Nonaka A, Tornabene (2016) Two new deep-reef basslets (Teleostei, Grammatidae, Lipogramma), with comments on the ecoevolutionary relationship of the genus. Zookeys 638: 45–82. https://doi.org/10.3897/zookeys.638.10455
Bensch A, Gianni M, Gréboval D, Sanders JS, Hjort A (2009) Worldwide review of bottom fisheries in the high seas. FAO Fisheries and Aquaculture Technical Paper No. 522, Rev. 1, Roma, 145 pp.

Bergstad OD, Menezes GMM, Høines ÅS, Gordon JDM, Galbraith JK (2012) Patterns of distribution of deepwater demersal fishes of the North Atlantic mid-ocean ridge, continental slopes, islands and seamounts. Deep-Sea Research I 61: 74–83. https://doi.org/10.1016/j.dsr.2011.12.002

Cato JC (2009) Gulf of Mexico Origin, Waters and Biota: Ocean and Coastal Economy (Vol. 2). Texas A & M University Press, College Station, 136 pp.

Clark MR, Althaus F, Williams A, Niklitsheck E, Menezes G, et al. (2010) Are deep-sea fish assemblages globally homogeneous? Insights from seamounts. Marine Ecology 31(Suppl. 1): 39–51. https://doi.org/10.1111/j.1439-0485.2010.00384.x

Colin PL (1974) Observation and collection of deep-reef fishes off the coast of Jamaica and British Honduras (Belize). Marine Biology 24(1): 29–38.

Colwell RK (2006) Statistical estimation of species richness and shared species from samples. Version 8. http://purl.oclc.org/estimates

Darnell MR, Defenbaugh ER (1990) Gulf of Mexico: Environmental overview and history of environmental research. American Zoologist 30: 3–6. https://doi.org/10.1093/icb/30.1.3

Day WJ, Díaz de León A, González-Sansón G, Moreno-Casasola P, Yáñez-Arancibia A (2004) Diagnóstico Ambiental del Golfo de México. Resumen ejecutivo. In: Caso M, Pisanty I, Ezcurre E (Eds) Diagnóstico Ambiental del Golfo de México. SEMARNAT, Ciudad de México, 15–46.

De la Lanza-Espinog G, Gómez-Rojas JE (2004) Características físicas del Golfo de México. In: Caso M, Pisanty I, Ezcurre E (Eds) Diagnóstico Ambiental del Golfo de México. SEMARNAT, Ciudad de México, 103–132.

Durán-Campos E, Salas de León DA, Monreal-Gómez MA, Coria-Monter E (2017) Patterns of chlorophyll-a distribution linked to mesoscale structure in two contrasting areas Campeche Canyon and Bank, Southern Gulf of Mexico. Journal of Sea Research 123: 30–38. https://doi.org/10.1016/j.seares.2017.03.013

Eschmeyer WN (2017) Catalog of fishes. Catalog databases of CAS. https://www.calacademy.org/scientists/projects/catalog-of-fishes [accessed April 2017]

Felder DL, Camp D, Tunnell Jr JW (2009) An Introduction to Gulf of Mexico Biodiversity Assessment. In: Felder DL, Camp DK (Eds) Gulf of Mexico: Origin, Waters, and Biota. Texas A & M University Press, 1–13.

Fishnet 2 (2013) Fishnet 2. http://www.fishnet2.net/search.aspx [accessed April 2017]

Froese R, Pauly D (2017) FishBase. http://www.fishbase.org [accessed August 2018]

Gracia A, Vázquez-Bader AR, Lozano-Álvarez E, Biones-Fourzán P (2010) Deep water shrimp (Crustacea: Penaeoidea) off the Yucatan Peninsula (southern Gulf of Mexico) a potential fishing resource? Journal of Shellfish Research 29(1): 37–43. https://doi.org/10.2983/035.029.0124

Jiménez-Valverde A, Hortal J (2003) Las curvas de acumulación de especies y la necesidad de evaluar la calidad de los inventarios biológicos. Revista Ibérica de Aracnología 31(8): 151–161.
Koslow JA (1993) Community structure in the North Atlantic deep-sea fishes. Progress in Oceanography 31: 321–338. https://doi.org/10.1016/0079-6611(93)90005-X
Magnussen E (2002) Demersal fish assemblages of Faroe Bank: species composition, distribution, biomass spectrum and diversity. Marine Ecology Progress Series 238: 211–225. https://doi.org/10.3354/meps238211
McEachran JD (2009) Fishes (Vertebrata: Pisces) of the Gulf of Mexico. In: Felder DL, Camp DK (Eds) Gulf of Mexico: Origin, Waters, and Biota. Texas A & M University Press, USA, 1223–1316.
McEachran JD, Fechhelm JD (1998) Fishes of the Gulf of Mexico. (Vol. 1) Myxiniformes to Asteroideiformes. University of Texas Press, USA, 1004 pp.
Menezes GM, Sigler M, Silva HM, Pinho MR (2006) Structure and zonation of demersal fish assemblages off the Azores Archipelago (Mid-Atlantic). Marine Ecology Progress Series 324: 241–260. https://doi.org/10.3354/meps324241
Menezes GM, Tariche O, Pinho MR, Sigler MF, Silva HM (2015) Structure and zonation of demersal fish assemblages off the Cabo Verde archipelago, (northeast-Atlantic) as sampled by baited longlines. Deep-Sea Research I 102: 118–134. https://doi.org/10.1016/j.dsr.2015.04.013
Monreal-Gómez MA, Salas de León DA, Velasco-Mendoza H (2004) La hidrodinámica del Golfo de México. In: Caso M, Pisany I, Ezcurra E (Eds) Diagnóstico Ambiental del Golfo de México. SEMARNAT, Ciudad de México, 47–68.
Moretzsohn F, Brenner J, Michaud P, Tunnell Jr JW, Shirley T (2017) Biodiversity of the Gulf of Mexico Database (BioGoMx). Version 1.0. Harte Research Institute for Gulf of Mexico Studies (HRI), Texas A & M University-Corpus Christi (TAMUCC), Corpus Christi, Texas. http://www.e-gulf.org [accessed May 2017]
Moranta J, Stefanescus C, Massuti E, Morales-Nin B, Lloris D (1998) Fish community structure and depth related trends on the continental slope of the Balearic Islands (Algerian Basin, western Mediterranean). Marine Ecology Progress Series 171: 247–259. https://doi.org/10.3354/meps171247
NOAA (2016) Gulf of Mexico Regional Action Plan. https://www.cakex.org/documents/gulf-mexico-regional-action-plan [accessed 13 June 2018]
OBIS [Ocean Biogeographic Information System] (2018) Ocean Biogeographic Information System. http://www.iobis.org [accessed August 2018]
Pajuelo JG, González JA, Santana JI (2010) Bycatch and incidental catch of the black scabbardfish (Aphanopus spp.) fishery off the Canary Islands. Fisheries Research 106: 448-453. https://doi.org/10.1016/j.fishres.2010.09.019
Paramo J, Pérez D, Acero A (2015) Estructura y distribución de los condrictios de aguas profundas en el Caribe colombiano. Latin American Journal of Aquatic Research 43(4): 691–699. https://doi.org/10.3856/vol43-issue4-fulltext-8
PEMEX (2016) Reporte de resultados de PEMEX al 31 de diciembre de 2015. http://www.pemex.com/ri/finanzas/Reporte%20de%20Resultados%20no%20Dictaminados/Reporte_4T15.pdf [accessed 28 June 2018]
Pequegnat WE, Gallaway BJ, Pequegnat LH (1990) Aspects of the ecology of the deep-water fauna of the Gulf of Mexico. American Zoologist 30: 45–64. https://doi.org/10.1093/icb/30.1.45
Pielou EC (1977) Mathematical Ecology. Wiley, New York, 385 pp.

Powell MS, Haedrich RL, McEachran JD (2003) The deep-sea demersal fish fauna of the northern Gulf of Mexico. Journal of Northwest Atlantic Fisheries Science 31: 19–33. https://doi.org/10.2960/J.v31.a2

Quattrini AM, Nizinsky MS, Chaytor JD, Demopoulos AW, Roak EB, France SC, Moore JA, Heyl T, Auster PJ, Kinlan B, Ruppel C, Elliott KJ, Kennedy BRC, Lobecker E, Skarke A, Shank TM (2015) Exploration of the canyon-incised continental margin of the northeastern United States reveals dynamics habitats and diverse community. PLoS ONE 10(10): e0139904. https://doi.org/10.1371/journal.pone.0139904

Quattrini AM, Demopoulos AEJ, Randal S, Roa-Varón A, Chaytor JD (2017) Demersal fish assemblages on seamounts and other features in the northeastern Caribbean. Deep-Sea Research I 123: 90–104. https://doi.org/10.1016/j.dsr2.2017.03.009

Ross WS, Quattrini MA, Roa-Varón A, Mc Clain PJ (2010) Species composition and distribution of mesopelagic fishes over the slope of the north-central Gulf of Mexico. Deep Sea Research II 57: 1926–1956. https://doi.org/10.1016/j.dsr2.2010.05.008

Saavedra-Díaz LM, Roa-Varón A, Acero PA, Mejía LS (2004) Nuevos Registros ícticos en el talud superior del Caribe Colombiano (Órdenes: Albuliformes, Anguilliformes, Osmeriformes, Stomiiformes, Aulopiformes y Pleuronectiformes). Boletín de Investigaciones Marinas y Costeras 33: 181–207.

Shannon CE, Wiener W (1963) The mathematical theory of communication. University of Illinois, Urbana, 117 pp.

Smithsonian National Museum of Natural History (2017) Search the Division of Fishes Collection. http://collections.nmnh.si.edu/search/fishes/ [accessed August 2018]

Sulak KJ, Brooks RA, Luke KE, Norem AD, Randall M, Quaid AJ, Yeargin GE, Miller JM, Harden WM, Caruso JH, Ross SW (2007) Demersal fishes associated with Lophelia pertusa coral and hard-substrate biotopes on the continental slope, northern Gulf of Mexico. In: George RY, Cairns SD (Eds) Conservation and adaptive management of seamount and deep-sea coral ecosystems. University of Miami, 65–92.

Texas A & M University Corpus Christi, Harte Research Institute for Gulf of Mexico Studies (2017) Biodiversity of the Gulf of Mexico Database. http://www.e-gulf [accessed April 2017]

Traver ML, Alade L, Sosebee KA (2012) Population biology of a data poor species, offshore hake (Merluccius albidsus) in the northwest Atlantic, United States. Fisheries Research 114: 42–51. https://doi.org/10.1016/j.fishres.2011.08.004

Thresher RE, Colin PL (1986) Trophic structure, diversity and abundance of fishes of the deep reef (30–300 m) at Enewetak, Marshall Island. Bulletin of Marine Science 38(1): 253–272.

Tunnell Jr JW (2009) Gulf of Mexico. In: Earle SA, Glover LK (Eds) Ocean: An Illustrated Atlas. National Geographic Society, Washington DC, 136–137.

WoRMS Editorial Board (2017) World Register of Marine Species. http://www.marinespecies. org [accessed April 2017]