Chapter 9
Deep-Water Penaeoid Shrimp of the Southern Gulf of Mexico Upper Slope: Distribution, Abundance, and Fishery Potential

A. Gracia and A. R. Vázquez-Bader

Abstract A systematic study to investigate the epibenthic megafauna biodiversity and potential fishing resources in the upper slope (290–1200 m depth) was carried along the Mexican Gulf of Mexico (off Tamaulipas-Yucatán). Samples were collected with a commercial shrimp trawl net (18 m mouth aperture, 4.5 cm stretched mesh, 1.5 cm stretched mesh cod-end). Fourteen species of the Aristaeidae, Penaeidae, Solenoceridae, and Benthesicymidae families were caught: *Aristaeomorpha foliacea*, *Aristaeopsis edwardsiana*, *Aristeus antillensis*, *Hepomadus tener*, *Parapenaeus americanus*, *Penaeopsis serrata*, *Parapenaeus politus*, *Funchalia villosa*, *Pleoticus robustus*, *Hymenopenaeus debilis*, *Solenocera vioscai*, *S. necopina*, *S. atlantidis*, and *Benthoecetes bartletti*. Two species were first records and two species extended its distribution to the southern Gulf of Mexico. Depth range of ten species was extended in its deeper limit. Shrimp of the Aristaeidae family were the most abundant with 6173 individuals (41%) followed by Penaeidae with 4772 organisms (31%), Solenoceridae 2914 with individuals (19%), and Benthesicymidae with 1352 specimens (9%). Seven species represented 99% of the total penaeoid catch in numbers and biomass (*A. foliacea*, *P. serrata*, *P. robustus*, *A. antillensis*, *P. americanus*, *B. bartletti*, and *A. edwardsiana*). Largest sizes were recorded in *A. foliacea*, *A. edwardsiana*, and *P. robustus* deep-water shrimp (45.57–48.09 mm mean CL). Maximum CL were also registered in these species (86.4–97.85 mm CL). Estimated penaeoid deep-water catch per unit effort (kg/h) varied from zero to18.62 kg/h. High mean CPUE values (>1.0 kg/h) were estimated at the 300–799 m depth range. Four areas of high deep-water shrimp abundance were identified in an area estimated of 60,000 km^2 in the upper slope at 300–1000 m depth. The penaeoid fishery potential and possible utilization is discussed.

Keywords Penaeoid · Deep-water shrimp · Distribution · Gulf of Mexico Potential fishery resources · CPUE · Fishing grounds

A. Gracia (✉) · A. R. Vázquez-Bader
Instituto de Ciencias del Mar y Limnología, Unidad Académica de Biodiversidad y Ecología Marina, Universidad Nacional Autónoma de México, CDMX, México
e-mail: gracia@unam.mx

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9.1 Introduction

The Gulf of Mexico is a semi-enclosed sea bordered by three nations (Mexico, USA, and Cuba). It is the ninth largest body of the world that has an extension of 1,540,000 km^2 (Ward and Tunnell 2017) and has been classified as one of the Large Marine Ecosystems of the planet (Kumpf et al. 1999). Several ecosystems are found around the Gulf, like salt marshes, oyster reefs, mangrove swamps, and seagrasses. About 55% of its surface area (0.9 million km^2) belongs to Mexico Economic Exclusive Zone. The Gulf of Mexico basin has an average depth of 1485 m with a maximum depth near to 4000 m in the central area and the Sigsbee Canyon (Darnell 2015). According to Ward and Tunnell (2017) approximately 32% of the Gulf of Mexico is continental shelf (up to 200 m), 41% is continental slope (200–3000 m), and 24% is abyssal plain (>3000 m). Continental shelves have different sediment types; western shelves in the North and South are mainly composed of fine-grained mud and clay sediments of terrigenous origin, whereas the broad shelves adjacent to Florida and Yucatán Peninsulas are sandy carbonated areas.

General circulation pattern is influenced by the Loop Current that originates from the Caribbean Sea and enters to the Gulf between the Yucatán Peninsula and Cuba and leaves through Florida Straits (Monreal-Gómez et al. 2004). The current generates a net current West-North-East movement around the Gulf from Campeche Bank to Florida with the presence of several cyclonic-anticyclonic gyres of different scales due to wind direction and pressure effects (Monreal-Gómez and Salas de León 1997). Occasionally, large eddies spin off the Loop Current and move westward across the Gulf to Tamaulipas coasts (Sturges and Lugo Fernández 2005). The Gulf of Mexico receives freshwater load of several rivers being the most important the Mississippi River in the north and the Grijalva-Usumacinta River system in the South.

The Gulf of Mexico also supports largely the fishery production of the three bordering countries. Fisheries landings are based on an array of fishes and shellfishes exploited in the diverse ecosystems around the Gulf of Mexico (Gracia et al. 2020). Fisheries rely on several species inhabiting inshore, coastal, benthic, demersal, and oceanic-pelagic realms. Although many fish species like snappers, groupers, croakers, menhaden, mackerel, dolphinfish, billfish, and tunas are important, crustaceans represent the most valuable resource in the Gulf of Mexico. Among crustaceans shallow-water shrimp of the superfamily Penaeoidea are the most important fishing resource (Gracia et al. 2010). According to Vázquez-Bader and Gracia (1994) and Gracia and Hernández-Aguilera (2005), at least 15 species of this Superfamily occur in shallow waters of the continental shelf of the Mexican Gulf of Mexico; however, mainly six species (brown, pink, white, spotted pink, rock, and seabob shrimps) support the bulk of shrimp fishery due to its abundance and commercial size. Brown, pink, and white shrimp have been extensively exploited along the Mexican Gulf of Mexico since the early 1950s through artisanal and industrial fisheries which conducted the stocks to fully and overexploited states (Gracia 1995, 1996, 2004; Gracia and Vázquez-Bader 1998, 1999). Also due to the intense fishery activities in the continental platform of the Gulf of Mexico, it is not possible that shrimp production could increase based on the traditional fishing grounds. One alternative is to find potential fishery resources in deeper waters to fulfill the increasing demand of food. This demand has caused that fisheries activities have gone deeper around the world. In Latin America, there are 17 species of commercial interest that support deep-water shrimp fisheries mainly in Chile, Colombia, Brazil, and some activities in Costa Rica and Guyana (Arana et al. 2009; Dallagnolo et al. 2009; Wehrtmann et al. 2012; Pérez et al. 2019).

In the Gulf of Mexico, 1007 decapod crustacean species have been reported in the planktonic pelagic and benthic environments of coastal, inshore, and oceanic realms (Felder et al. 2009a). According to Wicksten and Packard (2005), 130 decapod species occur on the continental slope to the abyssal plain (200–3840 m). Felder et al. (2009a), based mainly on data of the northern Gulf of Mexico, compiled 56 shrimplike species of the Aristeidae, Benthesicymidae, Penaeidae, Sicyoniidae, and Solenoceridae families and stand out the scarce knowledge for the southern Gulf. Of these species, only Royal Red Shrimp *Pleoticus robustus* is subjected to commercial exploitation by a small-scale fishery in the northern Gulf of Mexico. In the southern Gulf of Mexico, there are no deep-water fisheries except the one carried on pelagic fish species like yellowfin tuna and other tuna, marlin, billfish, as well as incidental caught species. Deep-water benthic potential fishing resources and megafauna biodiversity have been poorly studied in the southern Gulf of Mexico. Recently, the National Autonomous University of Mexico (UNAM) through the Institute of Marine Sciences and Limnology has conducted a systematic survey to investigate the epibenthic megafauna biodiversity and to identify potential fishing resources in the upper slope of the Mexican Gulf of Mexico.

Several contributions have increased remarkably the knowledge about the species composition and abundance of crustaceans (Lozano-Álvarez et al. 2007; Briones-Fourzán et al. 2010; Vázquez-Bader and Gracia 2013, 2016; Vázquez-Bader et al. 2014; Lemaitre et al. 2014), echinoderms (Vázquez-Bader et al. 2008; Solís-Marín et al. 2014), and fishes (Ramírez et al. 2019), including the presence of deep-water shrimp of potential fisheries interest (Gracia et al. 2010) in the upper slope of Mexican Gulf. The knowledge of deep-water biodiversity and living resources of the Gulf of Mexico also is important because the Gulf of Mexico has been subjected to different stressors from diverse sources derived from land and marine environments including industrial, agriculture, urban activities, oil industry activities, and two mega oil spills in the southern (Ixtoc 1, 1979–1980) and northern Gulf (deep-water horizon, 2010). The impact of oil spills on living resources and in general on the Gulf ecosystem is of outstanding concern and recently deserved great scientific research effort (Murawski et al. 2020a). The increasing trend of oil exploration and production in ultra-deep-water fields of the Gulf of Mexico with potential possibility of another accident (Murawski et al. 2020b) stand out the need for having a better knowledge of ecological communities of the Gulf of Mexico deep waters.

9.2 Material and Methods

9.2.1 Sampling Procedure

The study developed by the National Autonomous University of Mexico (UNAM) to investigate the epibenthic megafauna biodiversity and to identify potential fishing resources in the upper slope of the Mexican Gulf of Mexico started in 1999 and then was resumed in 2007 with a yearly basis up to now. It was supported partly with funds of the project "Biodiversity and potential fishing resources in deep waters of Gulf of Mexico" (PAPIIT IN223109, DGAPA-UNAM) and then through the Institute of Marine Sciences and Limnology and ship time provided by Scientific Research Coordination of UNAM.

This unique exploration by its coverage, scope, and frequency was conducted onboard the R/V Justo Sierra of UNAM in the upper slope of the Mexican Gulf of Mexico in a depth range of 290–1200 m. Surveys were done along the entire Mexican Gulf from the Mexican-USA border (offshore Tamaulipas state) to the Yucatan Channel in the Mexican Caribbean Sea (Fig. 9.1). This study encompass 17 cruises: BATO (May 1999), BIOREPES (August 2005), BIOREPES 2 (May–June 2007), BIOREPES 3 (November 2008), COBERPES (August 2009), COBERPES 2011 (April 2011), COBERPES 3 (November 2011), COBERPES 4 (August 2012), COBERPES 5 (May 2012), COBERPES 6 (August 2014), COBERPES 7 (April 2016), COBERPES 8 (October 2016), COBERPES 9 (July–August 2017), SOGOM 1 (June 2015), SOGOM 2 (September 2016), SOGOM 3 (May 2017), and SOGOM 4 (September 2018).

Samples were obtained with a commercial shrimp trawl net (18 m mouth aperture, 4.5 cm stretched mesh, 1.5 cm stretched mesh cod-end). Since there was not enough data about sea bottom characteristics, a seabed exploration was carried with a multibeam echosounder EM 300 and a sub-bottom profiler Topas PS 18 before casting the trawl net. Procedure consisted in detecting soft bottoms large enough for operating safely the trawl net. This required a distance that could allow launching, recovering, and a 30 min trawling operation. Total distance varied because time for launching and recovering increased with depth. This means that in deeper locations (>900 m) a linear distance up to 4 miles was required for safe trawling operation. Due to ship time availability, bottom surveys were limited to 2 h and then moved to other potential areas if exploration was not successful.

Once a suitable soft bottom was found, a 30-min trawl was performed at a speed of 2.5–3 knots along the explored area. The initial and final position of each tow were registered during each cast. The trawl operation was constantly surveilled with the EM 300 echosounder and the ship GPS system whose high precision (1.2 m) practically allows to follow back the same path explored.

The catch from each haul was sorted by species, quantified, weighed, and preserved in ethanol 70%. Organisms were deposited in the Crustacean Reference Collection of the Laboratorio de Ecología Pesquera de Crustáceos (LEPC-ICML-UNAM). Shrimp were measured to the nearest mm 0.01 mm with vernier calipers

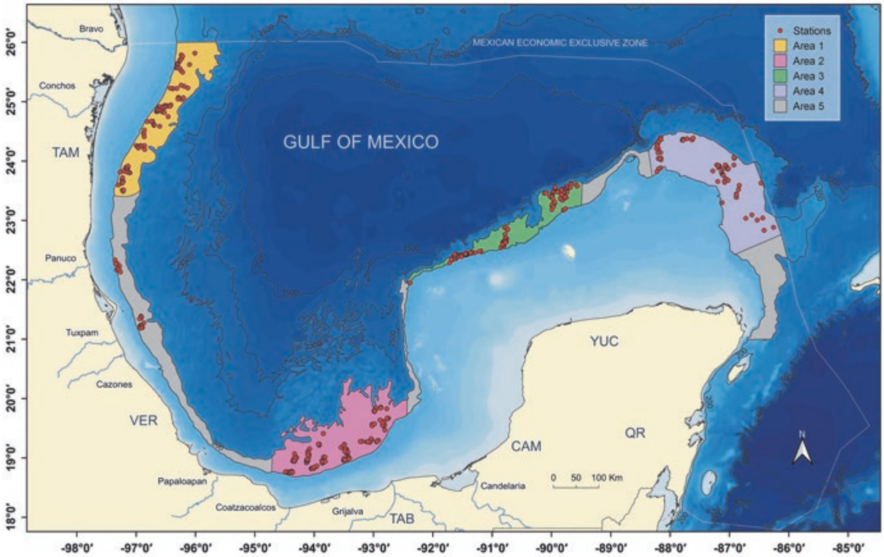

Fig. 9.1 Sampling locations in the upper slope of the Mexican Gulf of Mexico. Main river and its names are shown. Coastal states names are abbreviated. *TAM* Tamaulipas, *VER* Veracruz, *TAB* Tabasco, *CAM* Campeche, *YUC* Yucatán, *QR* Quintana Roo

from the posterior orbital margin to posterolateral margin of the carapace length (CL). Catch per unit effort (CPUE) was standardized in kilograms per hour per single net. Mean CPUE data was estimated in a 100-m-depth strata basis.

9.2.2 Sampling Locations

During the 17 cruises, 460 hauls were done along the Mexican Gulf. Sampling strategy tried to cover the whole gulf; however, bottom surveys did not show suitable bottoms for trawling in all the area. Trawlable bottoms (Fig. 9.1) were found mainly off Tamaulipas State (Area 1), off Tabasco and Campeche (Area 2), in the east Yucatán upper slope (Area 3) and northwest of Yucatán Peninsula near to the Mexican Caribbean Sea (Area 4). In the area denominated 5 (Fig. 9.1) trawlable bottoms were not frequently found so trawls done were a few. Bottom in this area was mainly steep, rugged, or rocky, unsuitable for trawl sampling. Soft bottoms when found in Area 5 were scattered among irregular topography and/or did not have enough distance for safe sampling. However, it is important to stand out that these soft bottoms with a patchy distribution could represent a habitat for penaeoid shrimp.

The research cruises conducted in Area 1 were BIOREPES 3, COBERPES 4, and COBERPES 9. Cruises developed in the Area 2 were comparatively more numerous: COBERPES, COBERPES 3, COBERPES 5, SOGOM 1, COBERPES, SOGOM 2, SOGOM 3, COBERPES 8, and SOGOM 4. The area 3 was sampled with cruises BATO, BIOREPES 1, BIOREPES 2, COBERPES 2011, COBERPES 3, and COBERPES 6. Cruises that covered Area 4 were BIOREPES 1, BIOREPES 2, COBERPES 2011, and COBERPES 6. Area 5 was surveyed during all cruises, but sampling locations were detected in cruise COBERPES.

9.3 Results

9.3.1 Penaeoid Species Composition

A total of 15,221 penaeoid shrimp belonging to four families (Aristaeidae, Penaeidae, Solenoceridae, and Benthesicymidae) and 14 species were caught. Four species of aristeid shrimp were collected: *Aristaeomorpha foliacea* (Risso, 1827), *Aristaeopsis edwardsiana* (Johnson, 1868), *Aristeus antillensis* A. Milne-Edwards & Bouvier, 1909, and *Hepomadus tener* Smith, 1884. Penaeoid shrimp found were *Parapenaeus americanus* Rathbun, 1901, *Penaeopsis serrata* Bate, 1881, *Parapenaeus politus* (Smith, 1881), and *Funchalia villosa* (Bouvier, 1905); the family Solenoceridae was represented by five species: *Pleoticus robustus* (Smith, 1885), *Hymenopenaeus debilis* Smith, 1882, *Solenocera vioscai* Burkenroad, 1934, *S. necopina* Burkenroad, 1939, and *S. atlantidis* Burkenroad, 1939. In the family Benthesicymidae only one species was collected: *Benthoecetes bartletti* Smith, 1882.

Shrimp of the Aristaeidae family were the most abundant with 6173 individuals (41%) followed by Penaeidae family with 4772 (31%), Solenoceridae 2914 individuals (19%), and Benthesicymidae with 1352 organisms (9%) (Fig. 9.2). In the Aristeidae family (Fig. 9.3), *A. foliacea* was the most abundant species with 3584 (58%) specimens, followed by *A. antillensis* with 1317 (21%) organisms, *A. edwardsiana* with 1255 (20%), and a low presence of *H. tener* (<1%). *Aristaeopsis edwardsiana* and *A. antillensis* were found along the whole Mexican Gulf of Mexico in a depth range of 300–1011 and 300–1011 m, respectively (Table 9.1). *Aristaeomorpha foliacea* was registered in almost all the study area except near the Caribbean Sea in the eastern-southeast sector of the Gulf following Felder et al. (2009b) division (see Briones-Fourzán et al., this volume). *A foliacea* distributed in a depth range of 226–1144 m. *H. tener* was collected only in the southwestern Gulf of Mexico in a narrow depth range (863–1144 m) (Table 9.1).

Penaeoid shrimp amounted a total catch of 4771 organisms (Fig. 9.4). Within the Penaeidae family, *P. serrata* was largely the most representative with 3400 (71%) shrimp caught followed by *P. americanus* with 1311 (28%) individuals, *P. politus* 59 (1%) organisms, and *F. villosa* with a scarce occurrence of two organisms (<1%). *Parapenaeus americanus*, *P. politus*, and *P. serrata* were collected along the entire southern Gulf of Mexico. Bathymetric distribution of *P. americanus* was registered in a shallow range of the upper slope from 244 to 462 and 206–385 m depth,

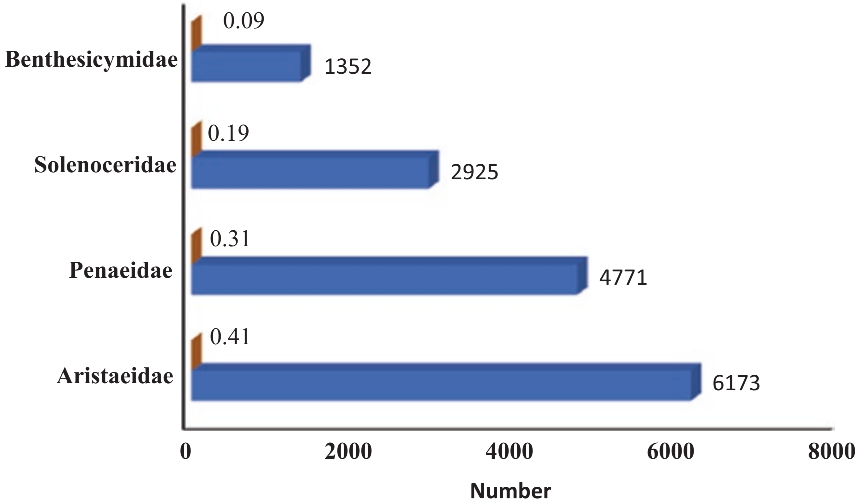

Fig. 9.2 Comparative abundance of the four deep-water penaeoid shrimp families registered in the upper slope of the Mexican Gulf of Mexico

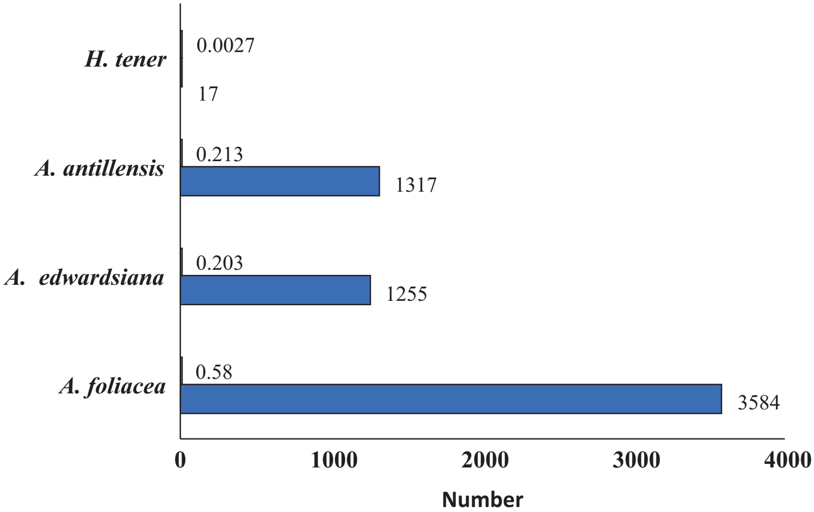

Fig. 9.3 Abundance and percentage of deep-water shrimp of the Aristaeidae family

respectively, whereas *P. politus* was found in almost all the depth range studied (309–904 m) (Table 9.1).

The Solenoceridae family was represented by five species with a total of 2925 shrimp caught (Fig. 9.5). *Pleoticus robustus* was the most abundant with 2772 individuals representing 95% of the solenocerid shrimp total catch. *Hymenopenaeus debilis* (104 organisms, 4%), *S. necopina* (36 specimens, 1.2%), *S. vioscai* (12

Table 9.1 Bathymetric distribution of penaeoid deep-water shrimp in the Mexican Gulf of Mexico

Species	Depth range (m)
A. foliacea	226–1144
A. edwardsiana	300–1011
A. antillensis	300–1108
H. tener	863–1147
P. americanus	244–462
P. serrata	309–904
P. politus	200–385
F. villosa	560.00
H. debilis	251–1104
P. robustus	296–735
S. vioscai	257–433
S. necopina	306–791
S. atlantidis	298.00
B. bartletti	546–1044

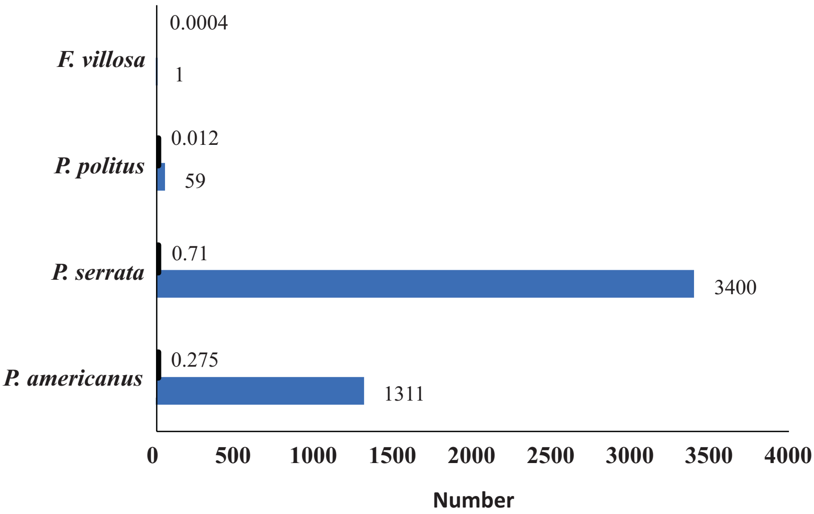

Fig. 9.4 Abundance and percentage of deep-water shrimp of the Penaeidae family

shrimp, <1%), and a unique presence of *S. atlantidis* (≪1%) constituted the rest of shrimps of this family. *Pleoticus robustus*, *H. debilis*, and *S. vioscai* were registered along the whole upper slope of the Mexican Gulf. Bathymetric distribution of *P. robustus* was recorded in a depth range of 296–735 m. *H. debilis* presented an extended depth range (251–1104 m) along the upper slope, whereas *S. vioscai* bathymetric distribution was limited to shallow upper slope depths (257–433 m). *S. necopina* was found in almost all the study area except in the northwest part of

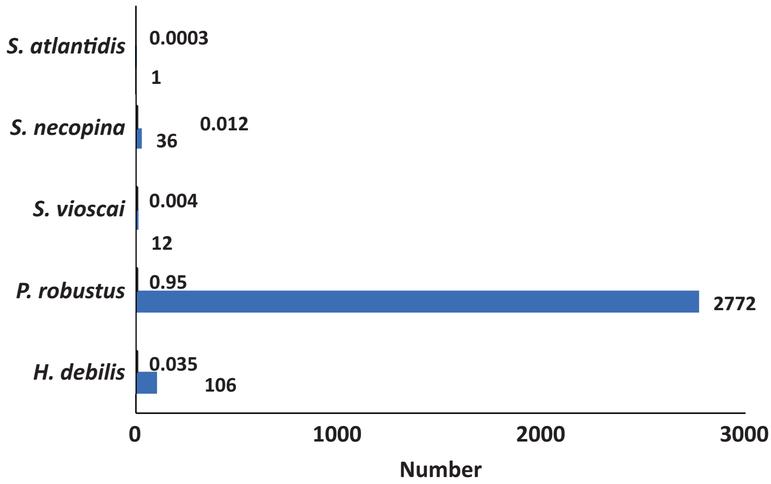

Fig. 9.5 Abundance and percentage of Deep-water shrimp of the Solenoceridae family

the Mexican waters of the Gulf of Mexico. This shrimp was registered in a depth range of 206–798 m. The only individual of *S. atlantidis* was found in the southwestern Gulf of Mexico at 298 m depth (Table 9.1).

In this study the Benthesicymidae family was only represented by *B. bartletti* with 1352 organisms. It was present in all the upper slope of the southern Gulf of Mexico. Its bathymetric distribution was registered in a 546–1094 m depth (Table 9.1).

9.3.2 Biomass and Catch per Unit Effort (CPUE)

The overall comparison of penaeoid shrimp catch shows that (99%) of the catch in numbers was composed mainly by seven species: *A. foliacea* (24%), *P. Serrata* (22%), *P. robustus* (18%), *A. antillensis* (9%), *P. americanus* (9%), *B. bartletti* (9%), and *A. edwardsiana* (8%). The other eight species only represented 1% of the total penaeoid shrimp catch varying from 0.007 to 0.68%. In terms of biomass these species represented more than 99% of total penaeoid shrimp weight (293 kg). *A. edwardsiana* registered the highest total biomass with 97.2 kg which represented 33% of the seven species total weight (290 kg). *P. robustus* was the second one with a total biomass of 72.7 kg (25%), followed by *A. foliacea* with 62.4 kg (21%). *P. serrata*, *A. antillensis*, and *P. americanus* presented lower biomass values with 26 kg (9%), 16.1 (6%), and 11.1 (4%), respectively. The biomass of the tiny shrimp *B. bartletti* amounted 4.9 kg and only represented 2% of the total biomass, so it was not considered for further analysis (Fig. 9.6).

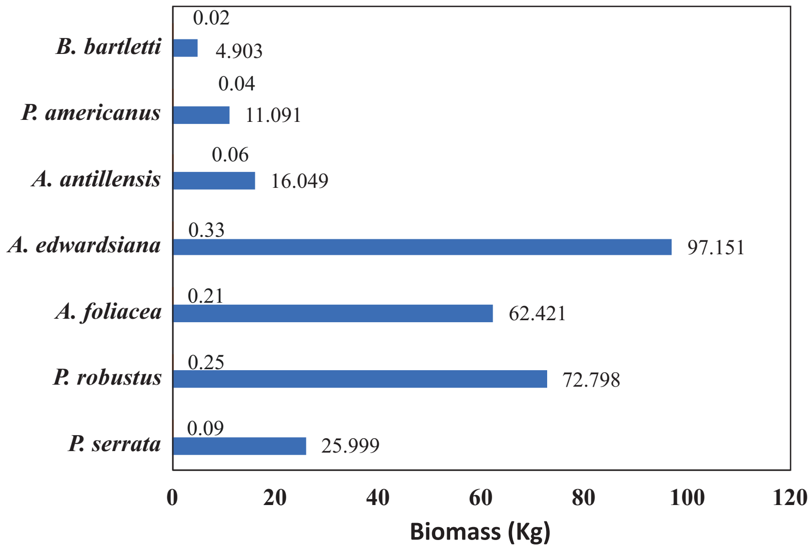

Fig. 9.6 Biomass of the seven penaeoid deep-water shrimp species amounting 99% of the total catch

Table 9.2 Size range, average size, and standard deviation (Carapace Length, mm) of the six most abundant penaeoid deep-water shrimp in the southern Gulf of Mexico

Species	Minimum size	Average ± SD	Maximum size
A. edwardsiana	18.79	48.09 ± 15.01	88.25
A. foliacea	31.56	49.80 ± 7.00	86.4
P. robustus	18.04	45.57 ± 16.73	97.85
A. antillensis	18.32	28.31 ± 7.25	76.63
P. serrata	11.37	23.00 ± 3.49	46.31
P. americanus	10.51	21.5 ± 4.0	30.4

The penaeoid shrimp that constituted the 98% of the catch biomass showed sizes that ranged from small to large ones and can be divided in two groups. The first one comprised *A. foliacea*, *A. edwardsiana*, and *P. robustus* which presented the largest sizes with mean cephalothoracic length (CL) varying from 45.57 to 48.09 mm. Maximum CL were also registered in these species from 86.40 to 97.85 mm CL. The second group was composed of *A. antillensis*, *P. serrata*, and *P. americanus* with a CL mean size range of 21.50–28.31 mm. *P. americanus* was the smallest one with a mean size of 21.5 mm CL and minimum CL of 10.51 mm (Table 9.2).

The total catch per unit effort (kg/h) of the six penaeoid species registered values that ranged from 0 to18.62 kg/h. Average CPUE ordered by 100 m strata showed higher values at shallows depths with a maximum in the 400–499 m stratum (3.1 kg/h). CPUE record of this stratum was 50 and 60% higher than the adjacent depth strata. After the maximum value, the CPUE presented a decreasing trend with

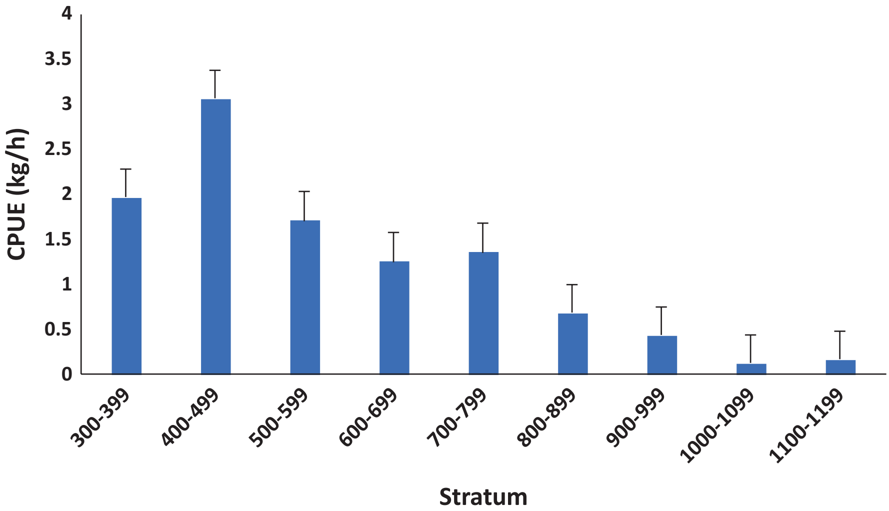

Fig. 9.7 Catch per unit effort (kg/h) of deep-water penaeoid shrimp per100 m stratum in the upper slope of the Mexican Gulf of Mexico

a slight increase in the 700–799-m-depth stratum. High mean CPUE values (> 1.0 kg/h) were estimated at the 300–799 m depth range (Fig. 9.7).

9.4 Discussion

9.4.1 Distribution and Depth Range

Most of the 14 penaeoid shrimp were widely distributed along the southern Gulf of Mexico. The aristeid *A. foliacea* and *A. edwardsiana* have a cosmopolitan distribution including the Gulf of Mexico (Pérez-Farfante and Kensley 1997; Tavares 2002; Gracia et al. 2010; Wehrtmann et al. 2012). Felder et al. (2009a) reported a narrower depth range distribution for *A. foliacea* and *A. edwardsiana* in the Gulf of Mexico of 400–800 and 680–990, respectively. In this study, the bathymetric distribution of these two species is extended in the shallow and deep limits which is according to the reported general bathymetric distribution for *A. foliacea* (250–1300 m) and *A. edwardsiana* (274–1850 m) (Tavares 2002). *A. antillensis* distribution is restricted to the Western Atlantic from Florida to Brazil (Holthuis 1980; Pérez-Farfante and Kensley 1997; Tavares 2002). Previous reports in the Gulf of Mexico were limited to the northeast (Roberts and Pequegnat 1970; Pérez-Farfante and Kensley 1997). In this study, and also according to Gracia et al. (2010) and Wehrtmann et al. (2012), *A. antillensis* occurred along the whole Mexican Gulf of Mexico, so its distribution range is extended. Depth range distribution is also extended in the deeper limit to 1108 m. *H. tener* geographical distribution was reported for the western Atlantic including the Gulf of Mexico (Felder et al. 2009a). Inside the Gulf, it was only reported for the northern area in a deeper range of 1386–3780 m (Roberts and Pequegnat 1970; Pérez-Farfante and Kensley 1997), but in this study its bathymetric range is extended to lower depths (Table 9.1).

The penaeoid shrimp have a broad distribution in the Atlantic. *Parapenaeus americanus* is distributed from New Jersey, the Caribbean Sea to Uruguay (Pérez-Farfante 1977; Pérez-Farfante & Kensley 1997). It was previously reported for the northern (Felder et al. 2009a) and southern (Gracia et al. 2010) Gulf of Mexico. This shrimp was frequently found in the catches during this study with a wide distribution along the Gulf. Its bathymetric range was limited to the shallow upper slope (241–462). This depth distribution is almost like the reported depth range (190–412) for this species (Felder et al. 2009a), but extending 50 m deeper. *P. serrata* was the most abundant of the penaeoid family distributing along the whole study area. It has an amphi-Atlantic distribution and was also reported for the northern (Roberts and Pequegnat 1970; Pérez-Farfante and Kensley 1997) and southern Gulf of Mexico (Gracia et al. 2010). The bathymetric range is extended to 904 m compared with the reported deeper limit (Pérez-Farfante and Kensley 1997; Felder et al. 2009a). *Parapenaeus politus* has a wide distribution from Massachusetts to the Caribbean Sea including the entire Gulf of Mexico (Roberts and Pequegnat 1970; Williams 1984; Pérez-Farfante and Kensley 1997; Gracia and Hernández-Aguilera 2005). Although it was not very abundant in the catches, it occurred along the whole study area. Depth data records allowed to extend *P. politus* distribution in its deeper limit to 385 m compared with the 330 m previous register (Felder et al., 2009a). The only specimen of *F. villosa* was found in the south-southwestern sector of the Gulf of Mexico. This species is a pelagic-benthopelagic shrimp that has a worldwide distribution in the North and South Atlantic, Mediterranean Sea, and South Pacific (Crosnier and Forest 1973; Abele and Kim 1986; Hopkins et al. 1994). Felder et al. (2009a) reported the distribution of *F. villosa* for the northeastern Gulf of Mexico in a depth range of 50–1430 m. The presence of *F. villosa* in the southwestern Gulf of Mexico is the first record for this area which is within the reported depth range of this species.

Four of the solenocerid shrimp registered were found along the whole study area. *Pleoticus robustus* was the most abundant one representing 95% of total shrimp catch. *Pleoticus robustus* distribution range is restricted to the western Atlantic from Massachusetts and the Caribbean Sea to French Guiana (Pérez-Farfante 1977; Holthuis 1980; Pérez-Farfante and Kensley 1997; Tavares 2002). According to Felder et al. (2009a), it is found in the entire Gulf of Mexico in a depth range of 200–1000 m. In this study, *P. robustus* was collected along the whole Mexican Gulf, but the deeper register was limited to 735 m depth. *H. debilis* geographical range was reported for the Atlantic from New Jersey to Guyana, Azores, and the eastern Atlantic (Roberts and Pequegnat 1970; Pérez-Farfante 1977; Pérez-Farfante and Kensley 1997). Inside the Gulf of Mexico, its presence has been registered mainly in northern Gulf of Mexico (Felder et al. 2009a). *Hymenopenaeus debilis* specimens represent the first records in the southern Gulf of Mexico. Although this species was not very abundant, it had a constant presence along the area, confirming that its distribution comprises the entire Gulf. The depth range observed in the southern Gulf fits within the larger bathymetric distribution (300–2163 m) reported for *F. villosa* (Felder et al. 2009a). *S. vioscai* distribution was reported from North Carolina to the Gulf of Mexico (Roberts and Pequegnat 1970; Pérez-Farfante and Kensley 1997; Williams 1984; Gracia and Hernández-Aguilera 2005; Vázquez-Bader and Gracia 1994). *Solenocera vioscai* was found along all the study area, but in a small number. According to Vázquez-Bader and Gracia (1994), this solenocerid species was the most abundant in the continental platform of the southern Gulf of Mexico compared with *S. necopina* and *S. atlantidis*. The low occurrence of *S. vioscai* in the upper slope can be understood because its main distribution is in shallow waters of the continental shelf. However, it should stand out that the depth range recorded (257–433 m) extends largely the *S. vioscai* bathymetric distribution compared with the reported one (37–239 m, Felder et al. 2009a). *Solenocera necopina* and *S. atlantidis* have been reported to distribute in the entire Gulf of Mexico. Besides, its geographical range is almost similar, from North Carolina to Uruguay and Brazil, respectively (Roberts and Pequegnat 1970; Williams 1984; Pérez-Farfante and Kensley 1997), but the reported bathymetric distribution range is larger for *S. necopina*. Depth ranges of both species were extended in its deeper limit with data registered in the Mexican Gulf of Mexico. The only specimen of *S. atlantidis* was found at 298 m depth higher than the maximum reported depth of 232 m (Felder et al., 2009a, b), whereas *S. necopina* extended to 791 m compared with the previous 550 m report (Roberts and Pequegnat 1970; Williams 1984; Pérez-Farfante and Kensley 1997; Gracia and Hernández-Aguilera 2005).

Benthoecetes bartletti was the only species caught of the Benthesicymidae family in spite that 11 species are reported for the Gulf of Mexico, mainly in the north area (Felder et al. 2009a). *Benthoecetes bartletti* has a cosmopolitan distribution in a depth range of 509–5777 m depth, including the entire Gulf of Mexico (Roberts and Pequegnat 1970; Pérez-Farfante and Kensley 1997). The depth range recorded in the southern Gulf of Mexico fall within this wide bathymetric distribution.

9.4.2 Potential Fishery Resource

The six most abundant penaeoid that represented 98% of the biomass and 90% of shrimp catch number (*A. foliacea*, *A. edwardsiana*, *P. robustus*, *A. antillensi*s, and *P. americanus*) were reported by Gracia et al. (2010) as a potentially important deep-water shrimp fishery resource in the Gulf of Mexico. Most of these species have a worldwide distribution or along the Atlantic and many of them are the target of important economic fisheries in some world deep-water oceans. *Aristaeomorpha foliacea* (giant red shrimp) sustains a valuable deep-water shrimp fishery in the Mediterranean Sea and the eastern Atlantic off Portugal that is one of the most important fishery resources in the area (D'Onghia et al. 1998; Figueiredo et al. 2001; Ragonese et al. 2001; Belcari et al. 2003). In Latin America the giant red shrimp fishery was initiated in Brazil since 2003 (Pezutto et al. 2006; Dallagnolo et al. 2009; Wehrtmann 2012). *Aristaeopsis edwardsiana* (Scarlet shrimp) is commercially exploited in the eastern Atlantic from Africa to Portugal and Spain (Holthuis 1980). In Latin America, it was caught in French Guiana (Guéguen 2001) and constituted an important fishery in Brazil deep waters (Pezutto et al. 2006; Dallagnolo et al. 2009; Wehrtmann et al. 2012). *Aristeus antillensis* (purple shrimp) was also fished in Brazil with the giant red and scarlet shrimp and seasonally in French Guiana (Guéguen 1998, 2001; Pezutto et al. 2006). *Pleoticus robustus* (royal red shrimp) had been exploited in the northern Gulf for a long time since 1960. Royal red shrimp is the target of a small shrimp trawl fleet fitted to fish in deep-waters off Alabama and Florida States. Average annual royal red shrimp catch is comparatively lower than the shallow water penaeoid shrimp catch (Jones et al. 1994; Stiles et al. 2007; Wehrtmann et al. 2012). *Penaeopsis serrata* (Speckled Shrimp) and *P. americanus* (Rose Shrimp) are not directly subjected to a fishery exploitation elsewhere probably due to its small size, but they are frequently present in deep-water shrimp catch.

Gracia et al. (2010) and Wehrtmann et al. (2012) reported that *A. foliacea*, *A. edwardsiana*, and *P. robustus* were the most important deep-water shrimp in terms of biomass representing 90% of the total weight catch. The results obtained in this study, with more sampling effort, show that these three species amount 79% of total catch, which still represent the largest part of the total deep-water shrimp catch. As stated above, these three species presented larger sizes than *A. antillensis*, *P. serrata*, and *P. americanus* which only amounted for 21% of the total biomass. Large sizes of giant red, scarlet, and red royal shrimp make them commercially more attractive than the purple, speckled, and rose shrimp.

The general penaeoid CPUE pattern (kg/h) with respect to depth is consistent with data reported by Gracia et al. (2010) and Wehrtmann et al. (2012) who coincided that high CPUE values are mainly found in the 300–700 depth range, although in this study a high mean value was also registered in the 700–799 m depth stratum. On the other hand, Gracia et al. (2010) registered higher CPUE values in the 600–699 m stratum in the Yucatán upper slope (Area 3), whereas Wehrtmann et al. (2012) reported higher values in the 500–699 m depth range. These variations could be expected because cruises were carried on different years, seasons, and geographical areas and also can be influenced by the typical patchy distribution of penaeoid shrimp (D'Onghia et al. 1998; Belcari et al. 2003; Gracia et al. 2010). Nonetheless, the mean deep-water shrimp CPUE pattern estimated in this study could be robust to describe the penaeoid shrimp abundance related to depth as it encompasses many of these variability sources.

According to Gracia et al. (2010) the mean CPUE values estimated in the Gulf of Mexico could be comparable with CPUE registered in deep-water shrimp fisheries of the world. The mean values are in the range reported for several deep-water shrimp fisheries; however they seem to be lower. For example, mean annual CPUE records for *A. edwardsiana* in Brazil fisheries were in a 4.7–14 kg/h range, whereas *A. foliacea* and *A. antillensis* were about 0.76–6.3 and 0.005–2.4 kg/h, respectively (Dallagnolo et al. 2009). CPUE values recorded for *A. foliacea* and *A. antennatus* in the Mediterranean Sea and Eastern Atlantic off Portugal (0–12 kg/h) (D'Onghia et al. 1998; Figueiredo et al. 2001; Carbonell and Azevedo 2003; Can and Atkas 2005) are in a range similar to the one registered in the Mexican Gulf of Mexico. It must be pointed out that CPUE registers for the Gulf of Mexico were estimated from an exploratory scientific survey which may not be as accurate as the ones derived of a commercial fleet specialized on deep-water trawl fishing. However, it may serve as an index of the deep-water shrimp abundance in the Gulf of Mexico (Gracia et al. 2010; Wehrtmann et al. 2012).

Penaeoid deep-water shrimp have a potential distribution along the Gulf of Mexico in an area estimated of 60,000 km^2 of the upper slope between 300 and 1000 m depth (Fig. 9.8). This area has a complex topography with submarine canyons, escarpments, rugged bottoms, and basins. Al least four potential fishing grounds were located in this study (Fig. 9.8) with plain soft bottoms suitable for trawling. CPUE values were very variable, but some registers were up to 18.62 kg/h. The highest mean CPUE estimated in this area is like the average CPUE estimated (~2–2.4 kg/h by net) in the shallow water penaeoid overexploited white (*L. setiferus*) and pink shrimp (*F. duorarum*) fisheries in the southwestern Gulf of Mexico (Gracia et al. 2010; Wehrtmann 2012; INAPESCA 2014). This is not the case for the *F. aztecus* (brown shrimp) fishery whose stock is in good condition and currently sustains most of the Mexican shrimp fishery in the Gulf of Mexico (Gracia 2004). Estimated shallow water brown shrimp CPUE based on data reported by INAPESCA (2010) varied between 20 and 65 kg/h by net. This CPUE value is remarkably higher than the one recorded for deep-water shrimp in this scientific survey, but usually deep-water shrimp yield is lower that the shallow one. Annual shrimp deep-water

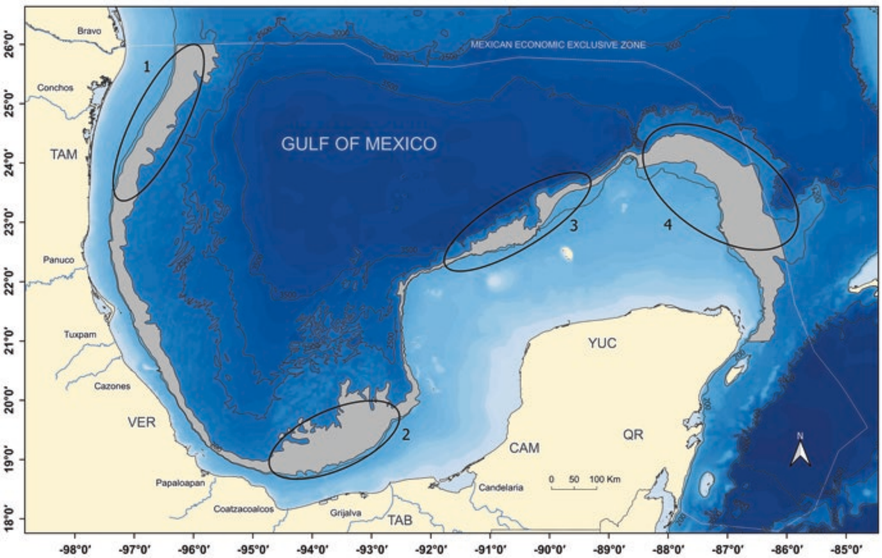

Fig. 9.8 Deep-water penaeoid shrimp distribution area and potential fishing grounds in the southern Gulf of Mexico

fishery registers vary between 100 and 200 metric tons (Stiles et al. 2007; Dallagnolo et al. 2009), although some like *A. foliacea* in the Mediterranean Sea can reach around 1000 metric tons. According to Gracia and Vázquez-Bader (2014), a moderate annual yield could be expected for a potential deep-water fishery in the southern Gulf of Mexico, although it could be important due to deep-water shrimp commercial value. However, it is still necessary to carry on further studies to assess the deep-water shrimp stocks potential.

9.5 Conclusions

The increasing demand for seafood propitiated that fishing activities moved farther and deeper around the world. In the Gulf of Mexico, most of the fishing resources reached its maximum sustainable level or are in an overexploited stage (DOF 2018), particularly shallow penaeoid shrimp (Gracia 2004). Finding and assessing potential fishery resources is contemplated in the Mexican National Plan of Scientific and Technological Research for Fisheries and Aquaculture to increase fishery production. deep-water penaeoid shrimp represent a valuable potential fishery resource as well as other species found in the catch like lobsters (see Briones-Fourzán et al. this volume), fishes (Ramírez et al. 2019), and other crustaceans that could be caught as by-catch. Utilization of deep-water penaeoid shrimp would require adapting ships for operating deeper, but more important is to assess its potential and to evaluate possible strategies for its utilization and conservation of the deep-water ecosystem.

Deep-water ecosystems and fishery resources are very vulnerable to overexploitation. Deep-water fishery resources could be depleted quickly, and population rebuilding could be slow (Koslow et al. 2000; Large et al., 2002). For example, the rapid fishing effort growth in the *A. edwardsiana* fishery in Brazil reduced substantially the deep-water shrimp stock (Dallagnolo et al. 2009). Another case was reported in the deep-water shrimp fishery in Costa Rica where the catch reduced strongly (Wehrtmann and Nielsen Muñoz 2009). At the international arena, there are opinions suggesting a total protection of deep-water ecosystems and its resources; however, the constant protein demand poses a pressure in these ecosystems.

Gracia and Vázquez-Bader (2014) pointed out that an eventual utilization of deep-water fishery resources would require a strategy based on the knowledge of the stock potential and actions that could allow its integral utilization as well as the conservation of the fragile deep-water ecosystem. This should include (1) assessment of the stock sizes, knowledge of deep-water shrimp biology and ecology, delimitation of fishery grounds, and sustainable exploitation levels, (2) adopting strategies of precautionary fishing based on the shrimp deep-water population renewal potential, (3) optimal utilization of deep-water catch, and (4) minimizing the impact on deep-water ecosystem, especially on cold water coral reefs.

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