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Reproduction and community structure of fish from winter shrimp bycatch from the Southeast Gulf of California

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Shrimp fishery is one of the most important fisheries of the world. However, the low selectivity from trawl nets leads the capture of a large number of non-target species. Shrimp bycatch include a large number of fish and invertebrate species; of which fish species are the most abundant. The present study aims to determine the community structure as well as the average sizes at first maturity of the fish species from shrimp bycatch caught from industrial fisheries at the southeast of the Gulf of California from Sinaloa to Guerrero, Mexico; from January to March 2015. A total of 37 species of finfish were found; of which five were considered rare. The fish species with the highest Importance Value Index (IVI) were *Pseudupeneus grandisquamis*, *Paralichthys woolmani*, *Lutjanus peru* y *Diapterus peruvianus*. The average size at first maturity of 12 fish species was determined; nine of which have not been previously reported. Of the analyzed organisms 90% were in juvenile stage; including species with riverine and artisanal fisheries. The present study demonstrates the risk in marine populations of different non-target species due to the low selectivity of shrimp trawls.

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Abstract

Shrimp fishery is one of the most important fisheries of the world. However, the low selectivity from trawl nets leads the capture of a large number of non-target species. Shrimp bycatch include a large number of fish and invertebrate species; of which fish species are the most abundant. The present study aims to determine the community structure as well as the average sizes at first maturity of the fish species from shrimp bycatch caught from industrial fisheries at the southeast of the Gulf of California from Sinaloa to Guerrero, Mexico; from January to March 2015. A total of 37 species of finfish were found; of which five were considered rare. The fish species with the highest Importance Value Index (IVI) were *Pseudupeneus grandisquamis*, *Paralichthys woolmani*, *Lutjanus peru* y *Diapterus peruvianus*. The average size at first maturity of 12 fish species was determined; nine of which have not been previously reported. Of the analyzed organisms 90% were in juvenile stage; including species with riverine and artisanal fisheries. The present study demonstrates the risk in marine populations of different non-target species due to the low selectivity of shrimp trawls.

Key words. Community structure, Length of maturity, Finfish, Shrimp bycatch.

Introduction

Shrimp are among the most globally traded fishery products. The shrimp fishery generates important economic benefits. Nevertheless, there has been a constant emphasis on the impact of this activity on shrimp bycatch fauna; FAO considers this fishery the main source of discards (Kumar and Deepthi, 2006; FAO, 2017). At global level constant proposals and innovations have been made for the design of trawls (Boopendranath et al, 2013), making a great progress in the protection of sea turtles and sea mammals (Morzaria-Luna et al, 2013). However, species considered as minor importance died during the trawling, and these organisms are returned to the sea; leads to environmental contamination (Ramírez-Ramírez et al, 2008).

In tropical countries shrimp bycatch corresponds to more than 90% of the catch; some of these organisms with a greater marketing potential. Nevertheless, biological aspects from shrimp bycatch fish are scarce (Ramos-Santiago et al, 2006; Herrera-Valdivia, López-Martínez and Morales-Azpeitia, 2016). In addition to knowing the species of fish that comprise the bycatch, it is important to know their size structure and reproductive status, because a large part of shrimp bycatch organisms correspond to juveniles, or sub adults, which significantly affects recruitment for the following generations (Broadhurst et al, 2000). The lack of information about the size of first maturity, reproductive periods, as well as the minimum sizes of catch, lead an absence of a correct regulation of small fisheries (Morzaria-Luna et al, 2013).

Therefore, the aim of this work is to determine the population structure and relative abundance of the fish species present in the accompanying fauna of the shrimp, as well as their spatial variability and potential risk in the recruitment of species. Such information is the basis for determining the actual status of marine communities and the effect of human activity in each region.

Materials and methods

This study is based on analysis of bycatch obtained from trawling of a shrimp vessel operating on the continental shelf from Sinaloa to Guerrero; southeast of the Gulf of California. The work included the fauna obtained from seven catch sites (Fig. 1; Table 1). The catches were made from January 26 to March 20, 2015, using a trawl of 70' feet long (21.3 m) and 37 mm net mesh. Each trawl was submerged for two hours at a depth of 20 and 54 meters approximately.

After the target species (shrimp) was separated at the vessel, a random sample of 10 kg from bycatch fauna was taken, from which all finfishes species were separated and identified to species level (Allen and Robertson, 1994). The Total Length (TL) of each organism was measured and gonadal maturity and sex was analyzed by morph-colorimetric methods (Bucholtz, Tomkiewicz, and Dalskov, 2008; Sánchez et al, 2013).

Total abundance and abundance per station of each species was estimated. Besides, the Relative Density (RD), Relative Frequency and Importance Value Index (IVI; Smith and Smith, 2006) were calculated for each species; which indicates the degree of dominance of one or more species and their degree of constancy within the ecosystem.

$$RD = \frac{\text{Total number of individuals of a species}}{\text{Total number of individuals of all species}} \text{ X } 100$$

$$FA = \frac{\text{Frequency of one species}}{\text{Total frequency of all species}} \text{ X } 100$$

$$IVI = RD + FR$$

The 12 species with the highest IVI were selected for the evaluation of the size structure per station. The sizes of the organisms were analyzed to determine the normality and homoscedasticity of the sample. A one-way ANOVA at $p < 0.05$ was used to find significance between the data, and finally the differences among stations were sought by the Tukey-Kramer multiple comparison test, with a 95% confidence level with the support of the NCSS 2007 statistical program.

Length at maturity (TL_m)

In the literature, information on sexual maturity comes in various categories "concepts" (Froese and Pauly 2000), symbols and definitions (Ragonese and Bianchini 2014), closely related. The mean length at which fish of a given populations become sexually mature for the first time (L_m) is an important management parameter used to monitor whether enough juveniles in an exploited stock mature and spawn (Beverton and Holt, 1959; Ault, Bohnsack and Meester, 1998; Jennings, Reynolds and Mills, 1998). To facilitate estimation of L_m in absence of suitable data, an empirical relationship based on linking L_m with L_∞ was used and proposal by Froese and Binohlan (2000).

$$\log L_\infty = 0.044 + 0.9841 * \log(TL_{max})$$

$$logTL_m = 0.8979 * \log(L_\infty) - 0.0782$$

TL_{max} was obtained for each species in the sample of FishBase.org.

Results

Fish relative abundance and distribution

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From the seven stations, the highest specific richness was at station 7 with 17 species, while the lowest specific richness was presented at station 4 with 13 species (Fig. 2). The total abundance of the study was 1410 fish from 37 species, belonging to 28 families and 35 genera. Rare species were only found in one station and corresponded to 16% of fish species (table 2).

Of the 37 fish species, only 13 species had an IVI greater than 50. The most frequent species were the bigscale goatfish *Pseudupeneus grandisquamis,* speckled flounder *Paralichthys woolmani,* Pacific red snapper *Lutjanus peru* and the Peruvian mojarra *Diapterus peruvianus* (Table 2); the four presented the greatest abundances of the study with 398, 327, 213 y 126 individuals, respectively. Meanwhile the rare species were *Bagre pinnimaculatus, Bairdiella ronchus*, *Brotula clarkae*, *Ancylopsetta dendrítica* y *Sphyraena guachancho* with only one individual of each species throughout the study.

Community structure

From the 12 fish species with higher IVI, just *P. grandisquamis* (IVB= 128.15), *P. woolmani* (IVB= 122.63), *L. peru* (IVB= 115.06) and *D. peruvianus* (IVI= 108.91) were present at all stations (Table 3), with maximum abundances per station of 197, 96, 91, 49 individuals, respectively. The rest of the species were absent in at least one station, with an average abundance among 2 and 10 individuals per station.

In the majority of species, no significant differences were found in the TL size structure according to the latitudinal distribution; only *Synodus scituliceps* showed highly significant differences ($p < 0.01$) in station 1 relative to station 2 (Fig. 3). The average sizes from *D. peruvianus*, *L. peru*, *P. woolmani* and *P. grandisquamis* were 12 cm, 12.71 cm, 11.51 cm, 12.11 cm, respectively.

Fish sex proportion and sexual maturity.

The TL_m for the species with highest IVI was 18.5 cm for *P. grandisquamis* and *D. peruvianus*, 44 cm for *P. woolmani* and 51.2 cm for *L. peru* (Fig. 3). For all analyzed species, less than 10% of fish presented developed gonads (Fig. 4); only the species *Scorpaena sonorae* presented a 100% of mature individuals; although individuals from this species were only found at station 6. The absence of developed gonads did not allow the sex determination from 23 of the 37 fish species analyzed. From the remaining 14 species, 90% of the organisms were female and only males were found in three species: *Diplectrum macropoma*, *D. peruvianus* and *Larimus argenteus*; in the last one, the proportion of males was greater than females with 75% (Fig. 5).

Discussion.

The shrimp bycatch in Mexico, as in tropical countries, is composed of a great diversity of species of mollusks, echinoderms, crustaceans and fish. All fish species analyzed in this study belong to superclass Osteichthyes. Although a large number of rare and low frequent species were found at each station, however, great abundances were also founded as is the case of *P. grandisquamis* with 197 individuals in a 10 kg sample. The species of fish found within the accompanying fauna of the shrimp are typical of sandy substrates of lagoon-estuarine systems where shrimp fishery is carried out (Rábago-Quiroz et al, 2011), with the exception of species associated with rocky and coral environments like *Chaetodon humeralis* and *Balistes polylepis*, both were considered as rare species; where specifically *C. humeralis* was only found at station 7.

The most representative families of this study (Sciaenidae, Tetraodontidae, Haemulidae and Paralichthyidae, among others) are typical of captures of tropical regions (Gibinkumar et al., 2012). Although only 38% of the species were considered abundant and frequent, suggesting that most species were caught during the haul or lifting of the net. The great majority of analyzed species corresponded to benthopelagic species (*Caranx otrynter*, *Chloroscombrus orqueta*, *S. pachygaster*, *Isopisthus remifer*) and pelagic-neritic species (*Fistularia corneta, L. argenteus* and *Opisthonema libertate*), which coincides with previous reports of studies for the Gulf of California (López-Martínez et al, 2010; González-Sansón et al, 2014).

The dominant species of the study; with an IVI greater than 50, contribute with more than 92% of the total abundance, which is typical of catches in the Gulf of California (Rábago-Quiroz et al, 2011). It has even been reported that by-catch may have larger volumes than the target fishery (Barreto, Polo and Mancilla, 2001, Gibinkumar et al., 2012). On the other hand, the analyzed organisms presented a great variety of sizes classes; mostly below 20 cm TL and mainly juvenile organisms. These sizes agree with previous reports indicating that organisms in this size class are more likely to be stuck in hauls, because the effort to escape from the nets is too exhausting (Liggins and Kennelly, 1996).

From the above, it is necessary to seek strategies for the management and use of these species, since the vast majority of species have a high potential for commercialization, and even several of these species have their own fisheries (FAO, 2017). One of the three fisheries indicators is the percentage of mature fish in catch; especially to assess an eventual risk in fish stocks (Froese, 2004). In general for teleosts, the use of maximum length to predict the length at first maturity was probed (Froese and Binohlan, 2000); as in seahorses species, for example (Foster and Vincent, 2004), due the asymptotic length is highly correlated with maximum length.

The correlation among asymptotic length and first maturity length was of 85-91% across 265 fish species (Froese and Binohlan, 2000). However, for the most part of the species, there are no reports on many of its biological aspects; highlighting only studies of species *A. mazatlanus, L. peru, P. woolmani* and *P. grandisquamis* (Amezcua-Linares and Castillo-Rodriguez, 1992; Ramos-Santiago et al, 2006; Herrera-Valdivia, López-Martínez and Morales-Azpeitia, 2016; FishBase, 2017). In this sense, it is important to emphasize that both first maturity sizes and reproductive periods are not static, but are subject to environmental variations and the analysis methods (Rodríguez-Domínguez et al, 2015). Usually the size at first maturity is underestimated. For teleosts, the size at first maturity is estimated as the size at which 50% of the organisms have reached sexual maturity, the size at which ovaries appeared (Kanou and Kohno, 2001), the size of the smallest recorded female with hydrated eggs (Nguyen and Do, 1996), the size of the smallest recorded first bred, and the minimum size of the recorded female to release her eggs (Froese, 2004).

The present study is the first to analyze the sizes at first maturity of fish species present in shrimp bycatch, including inferring or direct methods; of which, more than 90% of the organisms are outside the limits of sustainable fisheries, that is, well below the size of first maturity (immature organisms). However, none of the species analyzed in this study presents a hazard status or are threatened according to conservation standards (NOM-ECOL-059-2010; COFEMER, 2017; CONABIO, 2017), this may be due to the scarcity of population and reproductive studies. Although, some species have well established fisheries (*L. peru* y *P. woolmani*) there is no official regulation on minimum catch sizes; only a minimum catch size has been proposed for *L. peru* at 31 cm TL (Ramos-Cruz, 2001; COMEFER, 2017). This study shows that many of the species present in shrimp bycatch have an imminent risk, due to their low sizes at catch and the large percentage of immature organisms within the catches, which not only affects the populations, but also damages to the whole trophic chain.

Conclusions

From the Southeast Gulf of California winter shrimp bycatch a total of 37 fish species were identified; of which, dominant species were *P. grandisquamis*, *P. woolmani*, *L. peru* y *D. peruvianus*. From analized organisms, 90% were in juvenile stage; meanwhile, from the group with developed gonad, 93% were female. This work highlights the necessity to improve the selectivity from the shrimp trawls and the imminent risk for the marine communities.

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Figure 1

Location of the seven shrimp catches stations in the Southeast of Gulf of California, México.

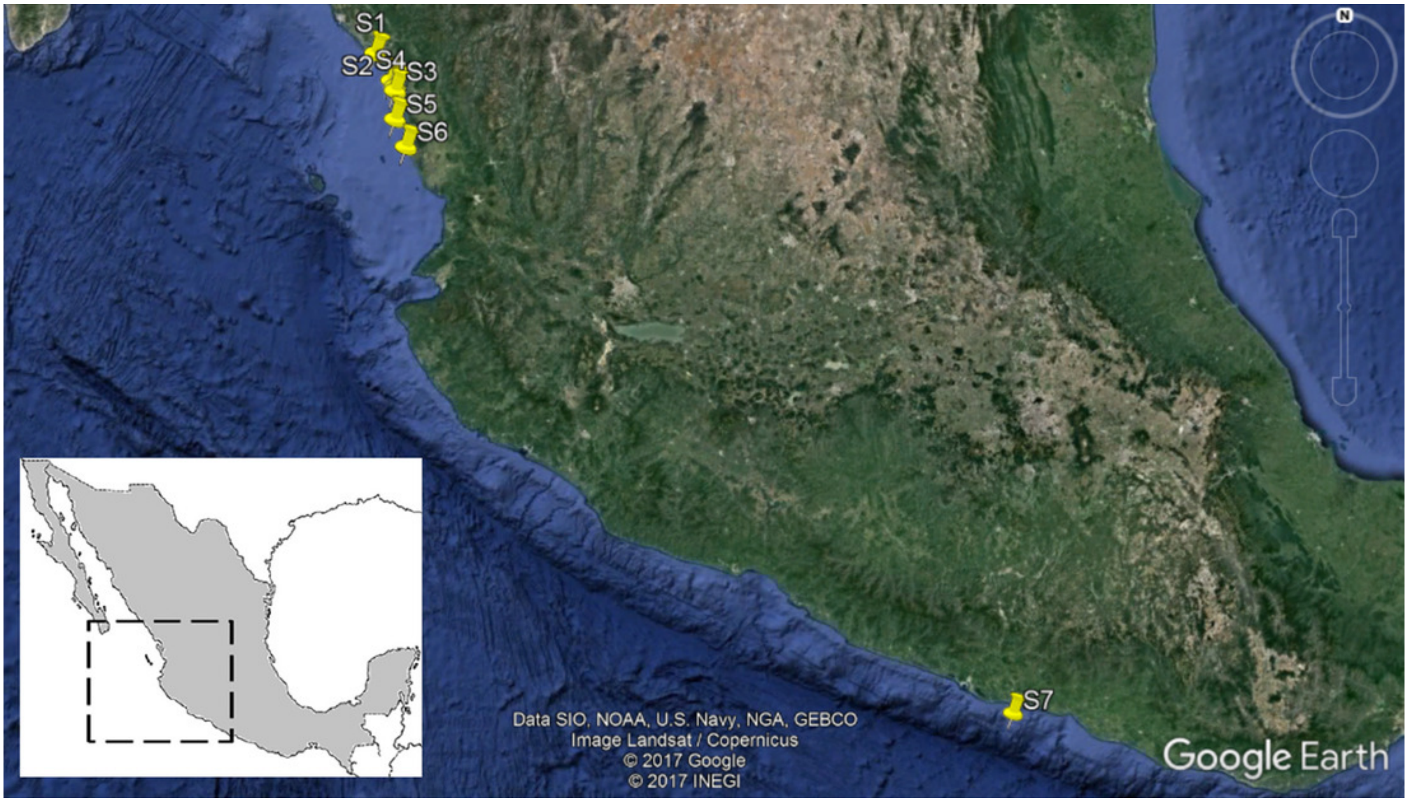

Figure 2

Species richness of fishes from shrimp bycatch per sampled station

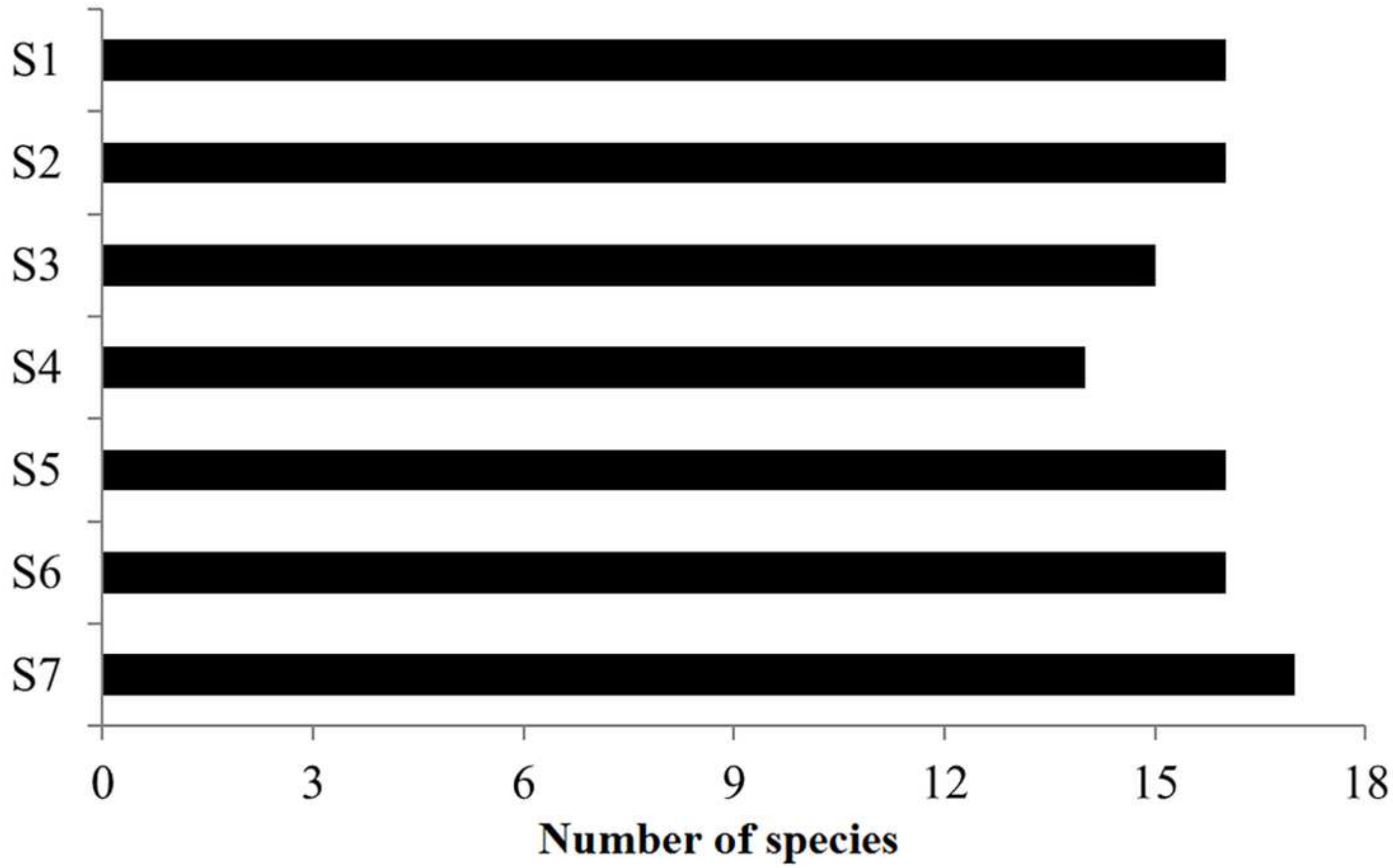

Figure 3

Fishes size structure at each sampling station

A) *A. mazatlanus*. B) *C. orqueta*. C) *D. peruvianus*. D) *D. macropoma*. E) *F. corneta*. F) *L. peru*. G) *P. woolmani*. H) *P. panamensis*. I) *P. horrens*. J) *P. grandisquamis*. K) *S. pachygaster*. L) *S. scituliceps*. The bars represent the average total length ± standard deviation. The dotted gray line indicates the size of first maturity reported in the literature. The continuous gray line indicates the average length of maturity obtained in this study. The dotted black line indicates the maximum size of immature organisms obtained during this study. * Represents significant differences in total length from each species among different sampled stations ($p<0.01$).

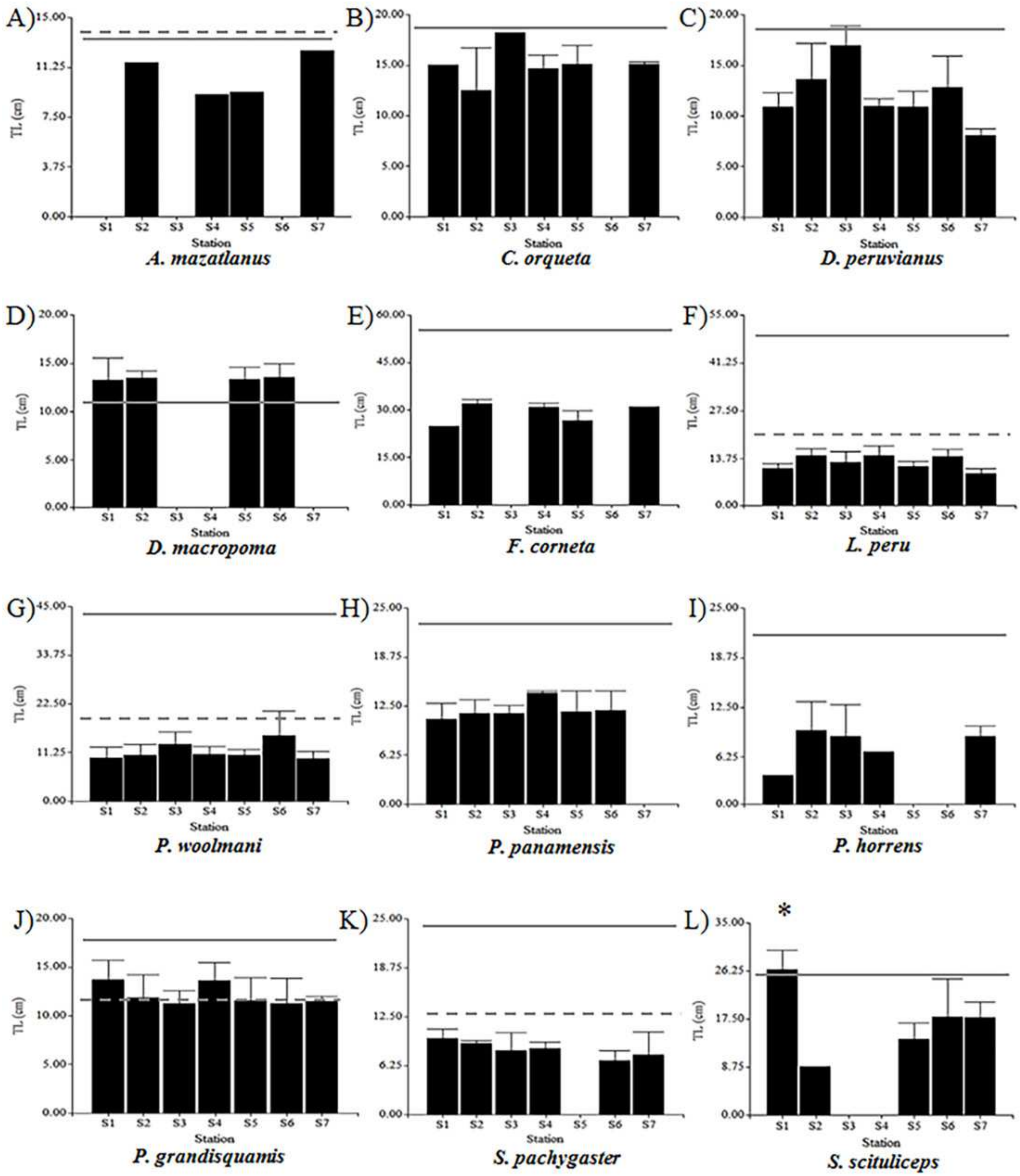
A)
15.00
11.25
7.50
3.75
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
A. mazatlanus
B)
20.00
15.00
10.00
5.00
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
C. orqueta
C)
20.00
15.00
10.00
5.00
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
D. peruvianus
D)
20.00
15.00
10.00
5.00
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
D. macropoma
E)
60.00
45.00
30.00
15.00
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
F. corneta
F)
55.00
41.25
27.50
13.75
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
L. peru
G)
45.00
33.75
22.50
11.25
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
P. woolmani
H)
25.00
18.75
12.50
6.25
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
P. panamensis
I)
25.00
18.75
12.50
6.25
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
P. horrens
J)
20.00
15.00
10.00
5.00
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
P. grandisquamis
K)
25.00
18.75
12.50
6.25
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
S. pachygaster
L)
*
35.00
26.25
17.50
8.75
0.00
TL (cm)
S1 S2 S3 S4 S5 S6 S7
Station
S. scituliceps

Figure 4

Juvenile and mature fish's proportion

Ma: mature (developed gonad). Im: immature (undeveloped gonad). Bars represent 100% of organisms. Gray bar: percentage of immature individuals. Black bar: percentage of mature individuals.

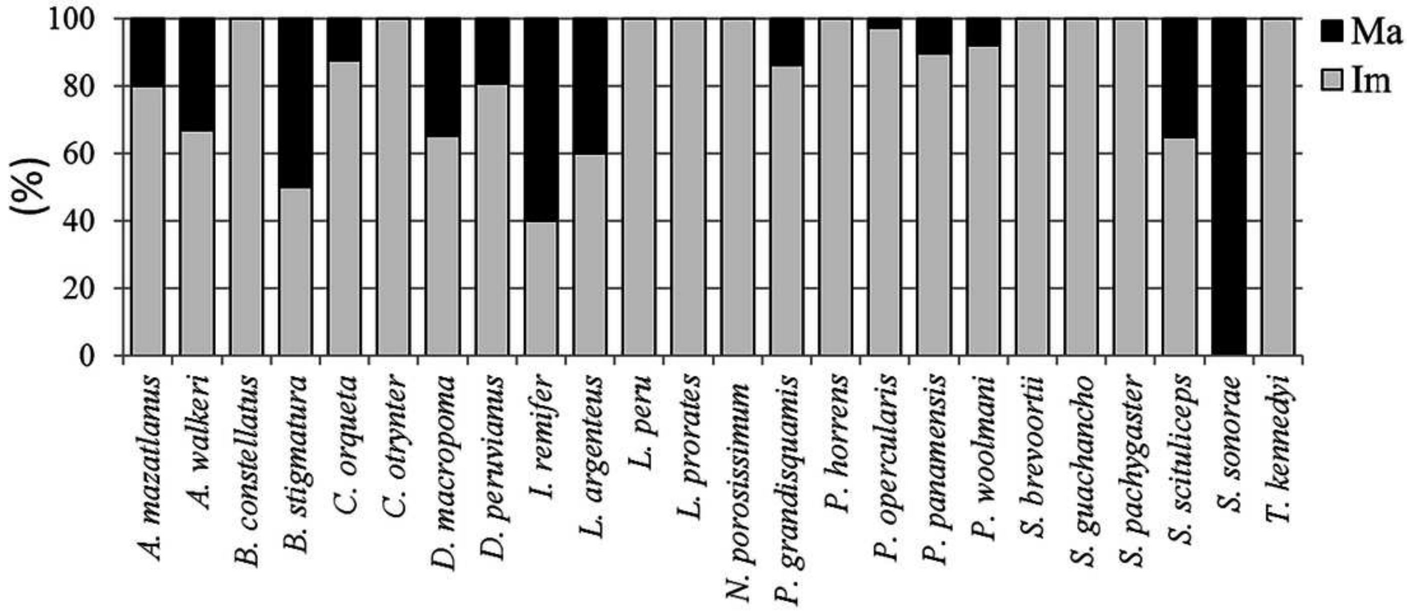

Figure 5

Sex proportion of fishes from shrimp bycatch

F: female. M: male. Bars represent 100% of organisms. Gray bar: percentage of females. Black bar: percentage of males.

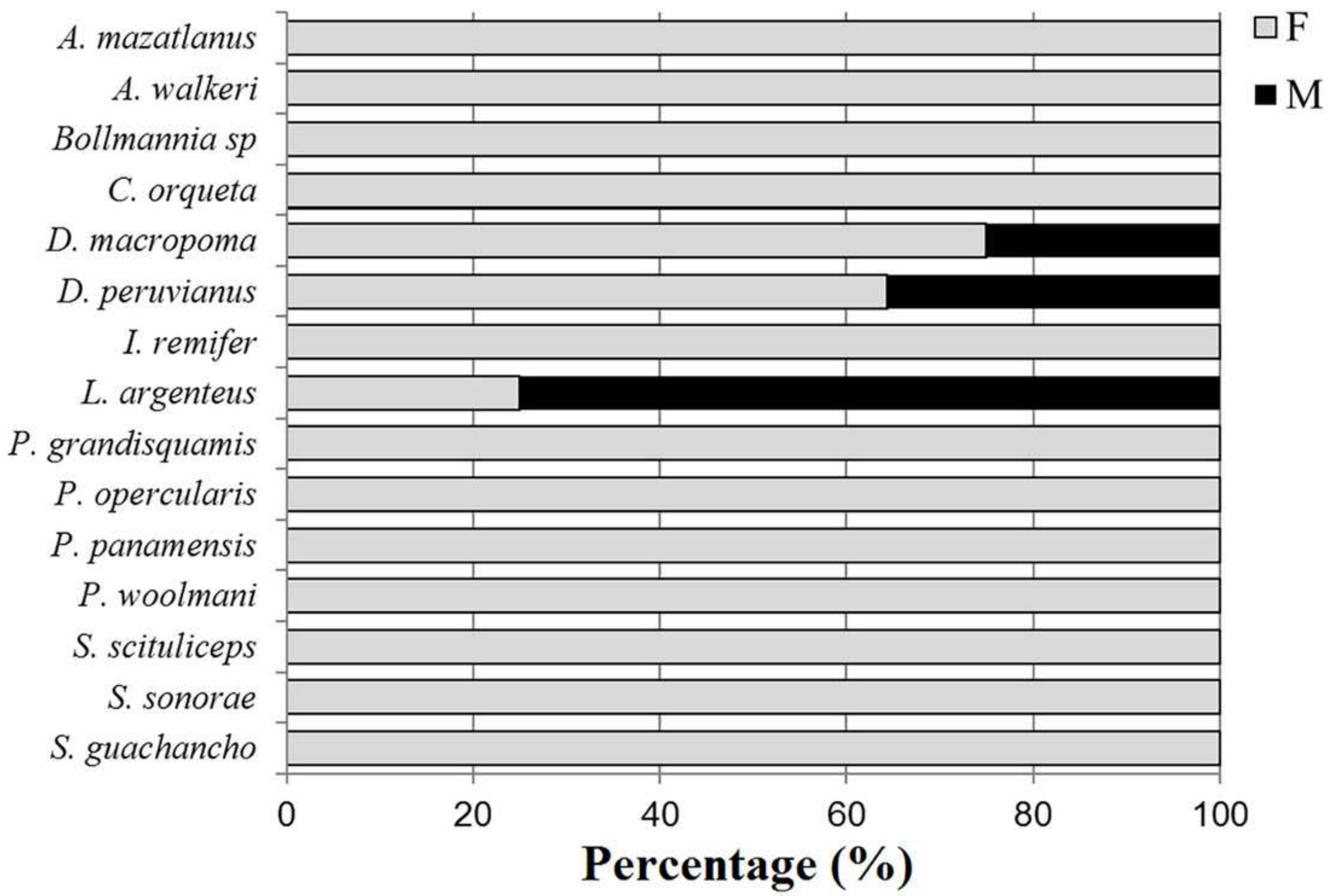

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Table 1(on next page)

Geographic location of each of the stations sampled at the SE of the Gulf of California.

Table 1. Geographic location of each of the stations sampled at the SE of the Gulf of California.

	Lat. North	**Long West**	**Depth (m)**	**Day sampling period**
S1	22.44390	-106.02915	30.6	Day
S2	22.27755	-106.55704	37.8	Night
S3	22.24762	-105.50341	37.8	Day
S4	22.21147	-105.50131	32.4	Day
S5	22.05882	-105.51375	34.2	Night
S6	21.48749	-105.42990	27	Day
S7	16.40722	-99.42970	19.8	Day

Table 2 (on next page)

Table 2. Fishes IVI from shrimp bycatch from the southeast of the Gulf of California.

RD: Relative Density, RF: Relative Frequency, IVI: Importance Value Index; from highest to lowest IVI. Freq: Frequency; R: Rare, LF: Low frequent, F: Frequent, HF: High Frequent. TL_{max}: Maximum length. TL_m: Length of maturity. SL: Standard length. FL: Fork length.

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Table 2. Fishes IVI from shrimp bycatch from the southeast of the Gulf of California.

RD: Relative Density, RF: Relative Frequency, IVI: Importance Value Index; from highest to lowest IVI. Freq: Frequency; R: Rare, LF: Low frequent, F: Frequent, HF: High Frequent. TL_{max}: Maximum length. TL_m: Length of maturity. SL: Standard length. FL: Fork length.

Family	Specie	Freq	RD	RF	IVI	TL_{max} (cm)	TL_m (cm)
Mullidae	*Pseudupeneus grandisquamis*	HF	28.15	100	128.15	30	18.5
Paralichthyidae	*Paralichthys woolmani*	HF	22.63	100	122.63	80	44
Lutjanidae	*Lutjanus peru*	HF	15.06	100	115.06	95	51.2
Gerreidae	*Diapterus peruvianus*	HF	8.91	100	108.91	30	18.5
Tetraodontidae	*Sphoeroides pachygaster*	HF	5.16	85.71	90.87	40.5 SL	24.1 SL
Haemulidae	*Pomadasys panamensis*	HF	4.81	85.71	90.52	39	23.3
Carangidae	*Chloroscombrus orqueta*	HF	1.13	85.7	86.83	30	18.5
Synodontidae	*Synodus scituliceps*	F	2.26	71.42	73.68	42	24.9
Triglidae	*Prionotus horrens*	F	0.85	71.42	72.27	35	21.2
Fistulariidae	*Fistularia corneta*	F	0.78	71.42	72.2	106	56.3
Serranidae	*Diplectrum macropoma*	F	2.83	57.14	59.97	18	11.7
Achiridae	*Achirus mazatlanus*	F	0.28	57.14	57.42	20	12.9
Batrachoididae	*Nautopaedium porosissimum*	F	0.24	57.14	57.42	32	19.5
Ophichthidae	*Ophichthus triserialis*	F	0.28	42.85	43.13	122	63.8
Balistidae	*Balistes polylepis*	LF	0.21	42.85	43.06	76	42
Sciaenidae	*Larimus argenteus*	LF	0.21	42.85	43.06	35	21.2
Carangidae	*Selene brevoortii*	LF	0.85	28.57	29.42	38 FL	22.8 FL
Ophidiidae	*Lepophidium prorates*	LF	0.42	28.57	28.99	29.5 SL	18.2 SL
Sciaenidae	*Isopisthus remifer*	LF	0.35	28.57	28.92	36	21.7
Clupeidae	*Opisthonema libertate*	LF	0.28	28.57	28.85	30	18.5
Carangidae	*Caranx otrynter*	LF	0.21	28.57	28.78	60	34.1
Bothidae	*Bothus constellatus*	LF	0.14	28.57	28.71	15.7	10.4
Cynoglossidae	*Symphurus prolatinaris*	LF	0.14	28.57	28.71	16.1 SL	10.6 SL
Carangidae	*Trachinotus kennedyi*	LF	0.14	28.57	28.71	90	48.8
Tetraodontidae	*Sphoeroides testudineus*	LF	1.27	14.28	15.55	38.8	23.2
Polynemidae	*Polydactylus opercularis*	LF	0.92	14.28	15.2	50	29
Scorpaenidae	*Scorpaena sonorae*	LF	0.42	14.28	14.7	15.8 SL	10.5 SL
Tetraodontidae	*Sphoeroides annulatus*	LF	0.21	14.28	14.49	44	25.9
Chaetodontidae	*Chaetodon humeralis*	LF	0.21	14.28	14.49	25.4	15.9
Engraulidae	*Anchoa walkeri*	LF	0.21	14.28	14.49	14.5	9.7
Gobiidae	*Bollmannia stigmatura*	LF	0.14	14.28	14.42	14 SL	9.4
Haemulidae	*Xenichthys xanti*	LF	0.14	14.28	14.42	24	15.2
Ariidae	*Bagre pinnimaculatus*	R	0.07	14.28	14.35	95	51.2
Sciaenidae	*Bairdiella armata*	R	0.07	14.28	14.35	30	18.5
Bythitidae	*Brotula clarkae*	R	0.07	14.28	14.35	115	60.6
Paralichthyidae	*Ancylopsetta dendritica*	R	0.07	14.28	14.35	35	21.2
Sphyraenidae	*Sphyraena guachancho*	R	0.07	14.28	14.35	200	98

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Table 3(on next page)

Abundance per station of fish species with highest IVI

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Table 3. Abundance per station of fish species with highest IVI.

Species	S1	S2	S3	S4	S5	S6	S7
C. orqueta	1	2	1	3	6		3
D. peruvianus	13	9	3	15	49	26	11
D. macropoma	8	6			3	23	
F. corneta	1	5		2	2		1
L. peru	21	61	11	91	8	7	14
P. woolmani	24	24	44	22	36	74	96
P. panamensis	7	9	3	2	13	34	
P. horrens	1	6	2	1			2
P. grandisquamis	67	31	19	36	12	36	197
S. pachygaster	6	5	36	6		17	3
S. scituliceps	2	2			6	17	5

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