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Population dynamics and spatial distribution of flatfish species in shrimp trawl bycatch in the Gulf of California

Dinámica poblacional y distribución espacial de los lenguados capturados incidentalmente en arrastres camaroneros en el Golfo de California

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ABSTRACT

By determining the specific composition, spatial distribution and population dynamics of flatfish species captured in shrimp trawls' bycatch in the Gulf of California, this study aims to contribute to the knowledge of bycatch fish population which has thus far been of little interest. Samplings were taken from shrimp trawls' in two fishing seasons (2002 and 2003) onboard shrimp fleets and also from two research cruises during closed shrimp season. The results showed 15 species of flatfish belonging to 5 families: Achiridae, Bothidae, Cynoglossidae, Pleuronectidae and Paralichthyidae. Paralichthyidae was the most abundant with 9 species. The range in sizes of these flatfish species varied in total length from 20 to 380 mm, with the most frequent sizes ranging from 60 to 180 mm and only a few species of the *Paralichthys* genera surpassing 250 mm in total length. The growth estimate parameter for the most abundant flatfish species varied according to the longevity of these species. More than 50 % of the organisms sampled were of small size, and the majority of these were captured before the sexual maturity which may have caused a potential effect on the population; however the consequences of this action on the population are unknown.

Key words: Bycatch, Gulf of California, flatfish, spatial distribution, population dynamics.

RESUMEN

Con la determinación de la composición específica, distribución espacial y dinámica poblacional de las especies de lenguados capturadas incidentalmente por embarcaciones camaroneras en el Golfo de California, este estudio pretende contribuir al conocimiento en un nivel poblacional de especies capturadas incidentalmente, las cuales han sido de poco interés en las investigaciones. Se efectuaron muestreos de fauna de acompañamiento del camarón en dos temporadas de pesca (2002 y 2003) a bordo de barcos camaroneros y en dos cruceros de investigación durante la época de veda del camarón. Los resultados mostraron 15 especies de lenguados pertenecientes a cinco familias, siendo la familia Paralichthyidae la que presentó el mayor número de especies (9). El intervalo de tallas obtenido fue de 20 a 380 mm de longitud total, siendo las más frecuentes de 60 a 180 mm y sólo las especies del género *Paralichthys* rebasaron los 250 mm. Los parámetros de crecimiento estimados estuvieron de acuerdo a la longevidad de estas especies. Más del 50 % de los organismos fueron de tallas pequeñas y la mayoría fueron capturadas antes de su talla de primera madurez sexual, pudiendo tener potenciales efectos en las poblaciones; sin embargo las consecuencias de este hecho en las poblaciones son desconocidas.

Palabras clave: Captura incidental, Golfo de California, lenguados, distribución espacial, dinámica poblacional.

INTRODUCTION

In the international forefront, a transcendental issue in the management and conservation of exploited marine ecosystems is the incidental capture of marine organisms by the main fisheries. According to recent estimates of the FAO, the annual discard rate of all the worlds' commercial fisheries is 8 %, which means a discard rate of 7.3 million tons per year with the highest rates being found in those fisheries operating in shallow waters near the coast (Kelleher, 2005). The shrimp trawl fisheries, tropical shrimp fisheries in particular, are the greatest source of discard, accounting for 27.3 percent (1.86 million ton) of the estimated total discard in the world (Kelleher, 2005), with unknown consequences to the ecosystem and with discarded species that could be utilized as food source.

To date, there have been several international studies pertaining to the shrimp trawl bycatch, which have focused on bycatch volumes (Alverson *et al.*, 1996; Kelleher, 2005), marine megafauna (Julian & Beeson, 1998; Diamond *et al.*, 2000), composition of species especially these of economic value (Pikitch *et al.*, 1998; Galloway & Cole, 1999) and of measures which would help to reduce the bycatch (Kenelly & Broadhurst, 1995; Macbeth *et al.,* 2004; Chokesanguan, 2005), however little has been studied about the overall bycatch population obtained through shrimp trawling.

The Gulf of California is one of the most mega-diverse regions in the world and it is the Mexican fishing region where most of the commercial captures are obtained (Lluch-Cota *et al.*, 2007), with a total fishery production of 700,000 tons; of which approximately 9% correspond to the shrimp fishery (Anónimo, 2005 and 2006). This fishery is one of the most important in the Gulf of California because it is a source of income and employment for communities along the Gulf of California's coast (López-Martínez *et al.*, 2001). Despite the economic importance of this fishery, it is one which contributes to the most bycatch, generating around 114,000 tons of discarded fish per year (Bojorquez, 1998), with a total biomass estimated at (90 ± 45) × 10^3 tons (Madrid-Vera *et al.,* 2007). Some researches on how to reduce this bycatch are currently underway (García-Caudillo *et al.*, 2000; Balmori *et al.*, 2003). The majority of the species in the shrimp trawl bycatch are species with little or no economic value (Van der Heiden, 1985; Pérez-Mellado & Finley, 1985); however, there are some species that are appreciated commercially, including some species of flatfish. No research has yet been made regarding species composition, distribution, relative abundance, or population dynamics of these flatfishes; they have only been mentioned in some researches about the shrimp trawl bycatch (Grande-Vidal & Díaz-López, 1981; Van der Heiden, 1985; Pérez-Mellado & Finley, 1985). For this reason, we investigated specific composition, spatial distribution, and population dynamics of flatfish species captured in shrimp trawl bycatch in the Gulf of California, contributing to the knowledge of bycatch studies at the population level of fish captured incidentally in the shrimp fisheries.

MATERIAL AND METHODS

We analyzed data on shrimp trawl bycatch from: a) samples obtained onboard two vessels of shrimp fleet from the Gulf of California (B/M "Maria Eugenia" and "Veronica" in March 2003, each covering different areas) (Fig. 1a); b) samples from two research cruises in the Gulf of California during the closed shrimp season onboard the vessels B/M "Delly IV" July-August 2002 and B/O "BIP XI" July-August 2003 (Fig. 1b). The capturing method for these samples was shrimp trawls which were conducted similarly to the commercial fishery system. The shrimp fleet operated mainly in specific areas known as "caladeros", hence samplings were done in these areas. Samplings from the research cruises were performed during the shrimp closed season according to series of stations (operated by the National Fisheries Institute of Mexico) for a specific trawling time (60 min approximately) with the objective of covering the total distribution area of the shrimp species.

In both cases the following observations were recorded during each shrimp trawl: depth and location of the trawling, trawl velocity, path distance and capture composition, the main species captured, and the latitude and longitude at the beginnings and end of each trawl. Once onboard the incidental capture or bycatch was separated from the target species (shrimps species), after which one sample of 20 kg approximately was obtained.

In the laboratory, the samples were separated into general groups (fishes, crustaceans and mollusks). Flatfishes obtained from the samples were separated from the rest of fish species. The flatfish species were identified using the Mexicans Marine Fishes Catalogue (INP, 1976), Eschmeyer & Herald (1983), Hensley (1995) and Robertson & Allen (2002).

To obtain the spatial distribution of each flatfish species captured, distribution maps were made using the capture depth, and the latitude and longitude from each trawl sampled.

The following measures from each organism were recorded: total length (LT), standard length, weigh, sex and sexual maturity (according to the Nikolski (1963) fish maturing scale). The length structures of the flatfish species were used to estimate annual growth parameters through the seasonal von Bertalanffy growth equation of Pauly (1987):

$$L_t = L_\infty \left[1 - e^{\left(-k(t-t_0)\right) - (C/2\pi)\cdot \sin(2\pi \cdot (t-ts))}\right]$$

Where L_t= length at age t, L_∞= asymptotic length, K= growth coefficient (year-1), t_0= length for the hypothetical age t=0. The symbol ts and C are parameters that control seasonal growth oscillations over a period of one year.

The estimates of the growth parameters L_∞ and *K* were obtained by using an electronic length frequency analysis ELEFAN I (Gayanilo *et al.,* 2005), using length-frequency data set of each species. The estimates of the third parameter, t_0, were obtained from the empiric equation proposed by Pauly *et al.* (1984), which has the following equation:

$$t_0 = 1 \cdot L_\infty^{\left[-0.3922 - (0.2752 \cdot \log L_\infty) - (1.038k \cdot \log K)\right]}$$

Recruitment patterns from each flatfish species were obtained using ELEFAN II (Gayanilo *et al.,* 2005). This method reconstructs the recruitment pulses from a time series of length-frequency data to determine the number of pulses per year and the relative strength of each pulse.

Due to the fact that the majority of organisms analyzed were small in size, there was insufficient information to determinate the sexual maturity of flatfish species; for this reasons a bibliographic search in different databases specialized (Fishbase, ITIS) in obtaining data for the sexual maturity of each species was carried out.

The longevity of each flatfish species was obtained using Pauly's equation (1984):

$$t_{max} = 3 / K$$

Where K= growth coefficient (year-1), and t_{max}= longevity.

RESULTS

Sixty one shrimp trawls were sampled, 14 during 2002 and 47 during 2003, within different areas of the Gulf of California as is shown in figure 1.

Species composition and spatial distribution. The more abundant groups found in the bycatch during this study were: fishes (78.6 to 97.4 %), crustaceans (1.7 to 10.9 %) and mollusks (0.02 to 10.3 %). The flatfishes represented 9.09 % (4.92 to 11.6 %) of the total bycatch (including fishes, crustaceans and mollusks).

One thousand one hundred and ten flatfishes were analyzed during this study. They belonged to five Families: Achiridae, Bothidae, Cynoglossidae, Pleuronectidae and Paralichthyidae. The Paralichthyidae family represented the majority of species. There were nine different Paralichthyidae species; two species each of Pleuronectidae and Cynoglossidae and one each of Achiridae and Bothidae (Table 1).

It was observed that the variation in abundance of different flatfish species captured was dependent of the sample area. *Paralichthys woolmani* (Jordan & Williams 1897), *Citharichthys fragilis* (Gilbert 1890), *Achirus mazatlanus* (Steindachner 1869),

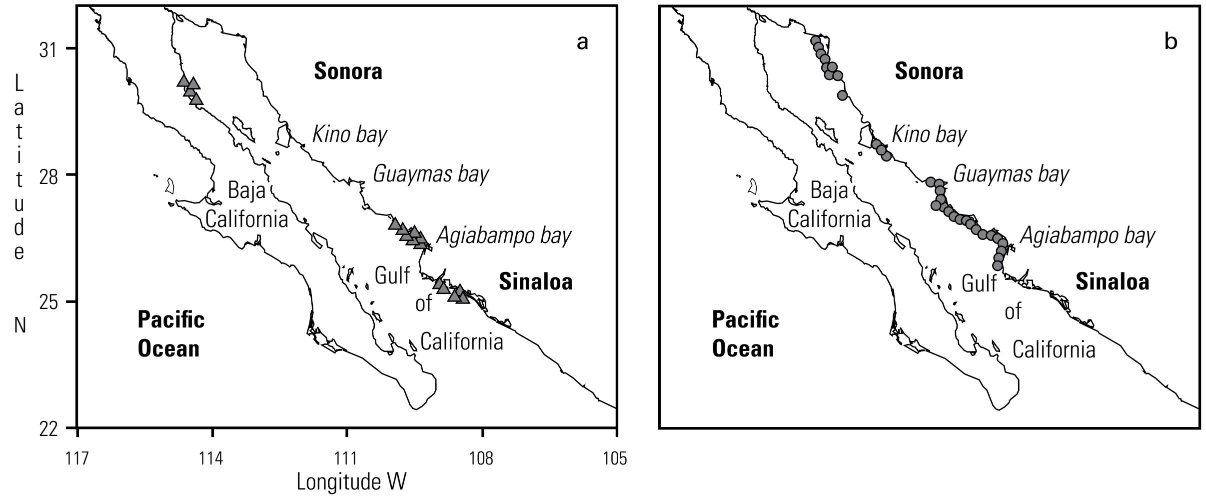

Figure 1a-b. a) Covered areas (▲) by two vessels of the shrimp trawl fleet of Sonora, Mexico during 2002 and 2003, b) Covered areas (●) by two research cruises during the closed shrimp season (2002 and 2003).

Table 1. Flatfish species found in the shrimp trawl bycatch in the Gulf of California during 2002 and 2003.

Family	Species	Common Name	Num. of org. analyzed*
1. Achiridae	*Achirus mazatlanus*	Mazatlan Sole	200
2. Bothidae	*Bothus constellatus*	Pacific eyed flounder	14
3. Cynoglossidae	*Symphurus fasciolaris*	Banded tongue-fish	4
	Symphurus chabanaudi	Chabanaud's tongue-fish	88
4. Pleuronectidae	*Pleuronichthys verticalis*	Hornyhead turbot	1
	Hypsopsetta guttulata	Diamond turbot	2
5. Paralichthyidae	*Citharichthys gilberti*	Bigmouth sanddab	91
	Citharichthys fragilis	Gulf sanddab	214
	Citharichthys xanthostigma	Longfin sanddab	5
	Etropus crossotus	Fringed flounder	125
	Etropus peruvianus	Peruvian flounder	46
	Hippoglossina stomata	Bigmouth flounder	5
	Paralichthys californicus	California flounder	3
	Paralichthys woolmani	Speckled flounder	245
	Syacium ovale	Oval flounder	67

*Num. of org. analyzed = number of organisms analyzed.

Etropus crossotus (Jordan & Gilbert 1882), *Citharichthys gilberti* (Jenkins & Evermann 1889) *Symphurus chabanaudi* (Mahadeva & Munroe 1990), and *Syacium ovale* (Günther 1864) had a wider distributions in the Gulf of California (Fig. 2a-g). Other flatfish species, such as; *Pleuronichthys verticalis* (Jordan & Gilbert 1880), *Paralichthys californicus* (Ayres 1859), *Hypsopsetta guttulata* (Girard 1856), and *Hippoglossina stomata* (Eigenmann & Eigenmann 1890) were only found in one or two trawl samples containing few organisms (Fig. 2h).

The range of depth where the majority of these flatfish were captured was from 10 to 65 m (Fig. 3a-h). The most common capture depth was in the range of 10 to 40 m; however, we obtained some organisms of *P. woolmani* and *S. chabanaudi* which were captured up to a 64 m depth (Fig. 3a, 3f).

Population dynamics of flatfish species. *P. woolmani, C. fragilis*, *A. mazatlanus*, *E. crossotus*, *C. gilberti*, *S. chabanaudi* and *S. ovale* (Günther 1864) were the most abundant flatfish species in this study, see figure 4. The majority of the flatfishes analyzed were small ($20 \geq Lt \leq 380$ mm total length) and the most frequent sizes ranged from 60 to 180 mm in total length (Fig. 5a-o).

Due to the low abundance of *Symphurus fasciolaris* (Gilbert 1892), *Bothus constellatus* (Jordan 1889), *Pleuronichthys verticalis, Paralichthys californicus, Hypsopsetta guttulata, Citharichthys xanthostigma* (Gilbert 1890), *Etropus peruvianus* (Hildebrand 1946), and *Hyppoglossina stomata* in the samples, the population dynamic analysis was only made for: *P. woolmani, Citharichthys fragilis, Achivrus mazatlanus, E. crossotus, C. gilberti, Syacium ovale* and *Symphurus chabanaudi.*

The growth parameters L_∞, K and t_0, obtained from the most frequent and abundant flatfish species showed that these species presented an accelerated growth, most common in species which have a short spawn cycles (Table 2). The growth curves of the most frequent and abundant flatfish species are shown in figure 6. We observed that some species, like *E. crossotus, S. ovale* and *C. fragilis*, have an accelerate growth rate, reaching their maximum size in a short time due to their short life cycle.

Analysis of the recruitment patterns of the most frequent and abundant flatfish species analyzed showed one continuous period in the reproductive recruitment that spans from March to November (Fig. 7a-g). In species like *A. mazatlanus,* this recruitment period is shorter, going from February to July during which time the highest percentage is present (Fig. 7c). Only *S. ovale* present two important recruitments periods: the first one of high intensity during April to August and the second one of lesser intensity during September to November (Fig. 7g).

DISCUSSION

To the date, 29 flatfish species are the largest number of species reported for incidental captures from shrimp trawls in the Gulf of California (Van der Heiden, 1985). This study found 15 flatfish species, belonging to 5 families: Achiridae, Bothidae, Cynoglossidae, Pleuronectidae and Paralichthidae (these five flatfish's families have previously been reported for the Gulf of California); this similar to finding by Grande-Vidal & Díaz-López (1981) and Pérez-Mellado & Finley (1985), who found 4 flatfish families (Bothidae,

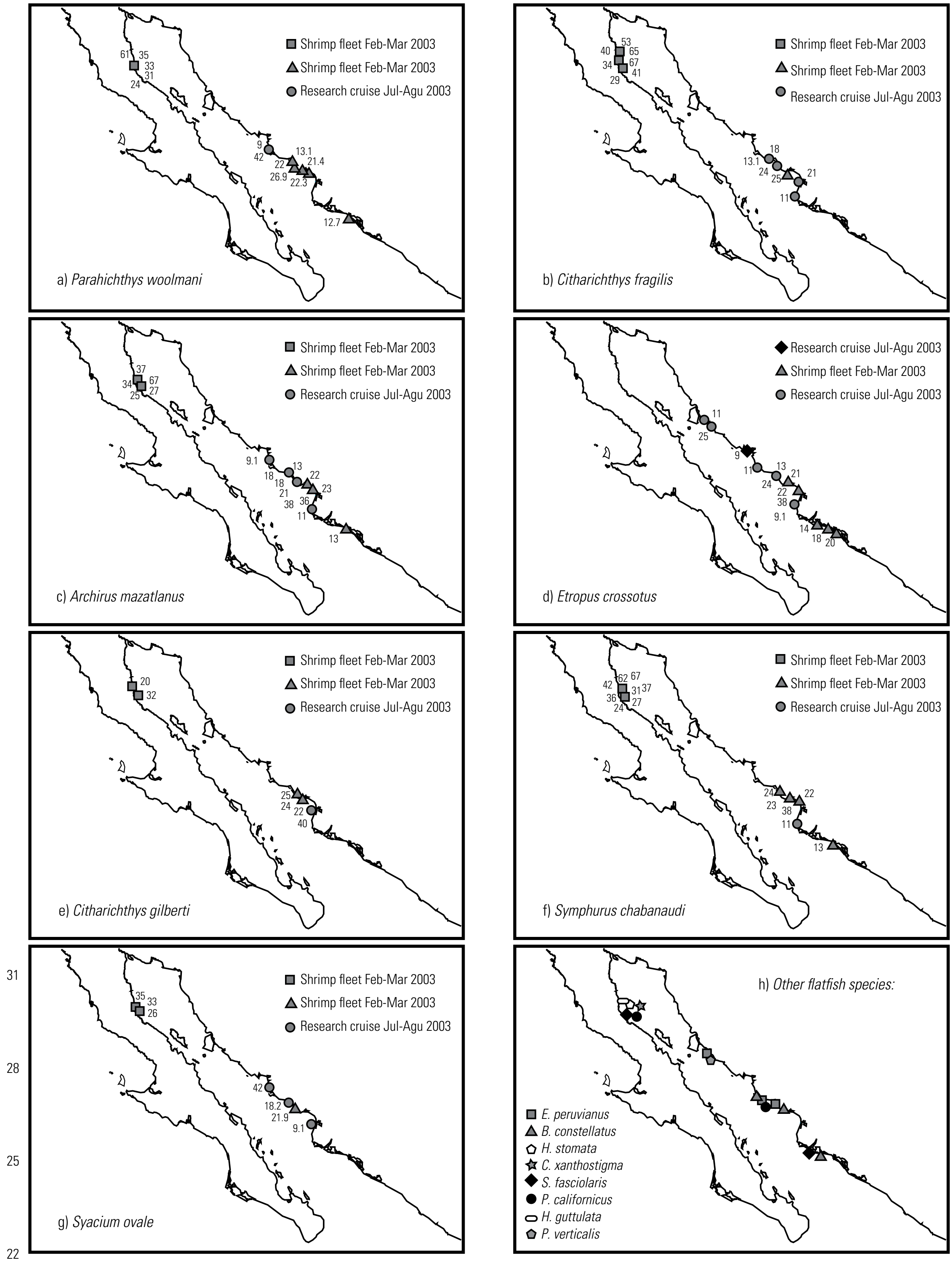

Figure 2a-h. Spatial distribution of the flatfish species in the shrimp trawls bycatch in the Gulf of California during 2002 and 2003. The numbers mean the depth in m wich the organisms were captured.

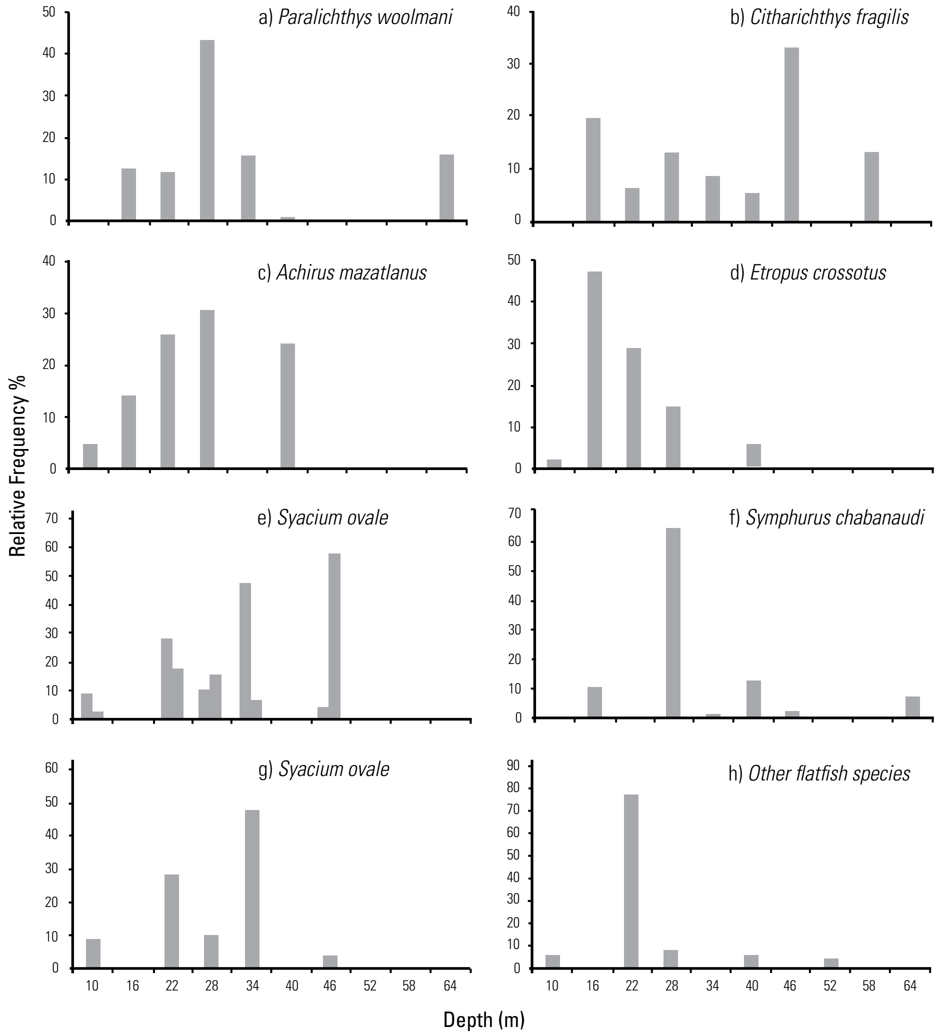

Figure 3a-h. Histograms of the depth which were captured the different flatfish species in the shrimp trawl bycatch in the Gulf of California during 2002 and 2003.

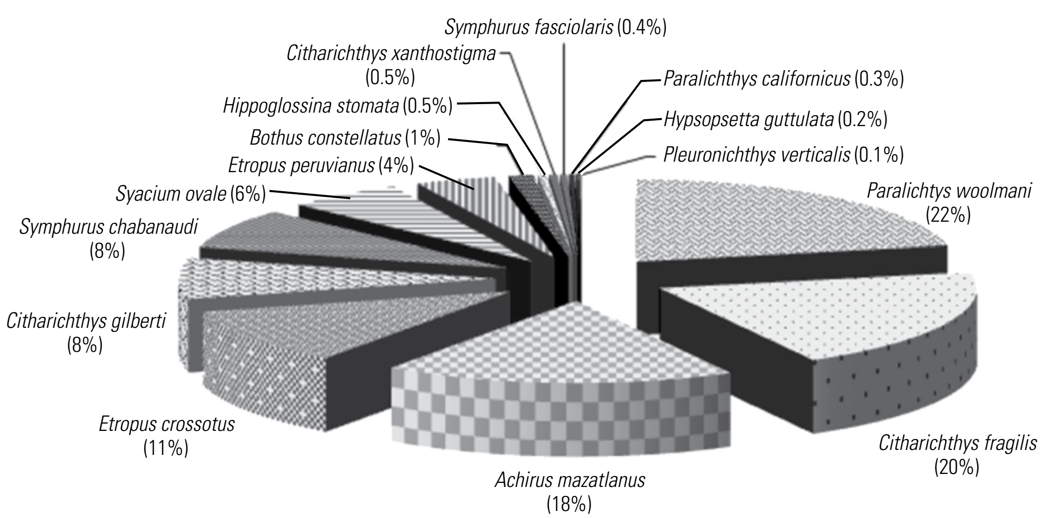

Figure 4. Abundance of the principal flatfishes in the shrimp trawls bycatch in the Gulf of California during 2002 and 2003.

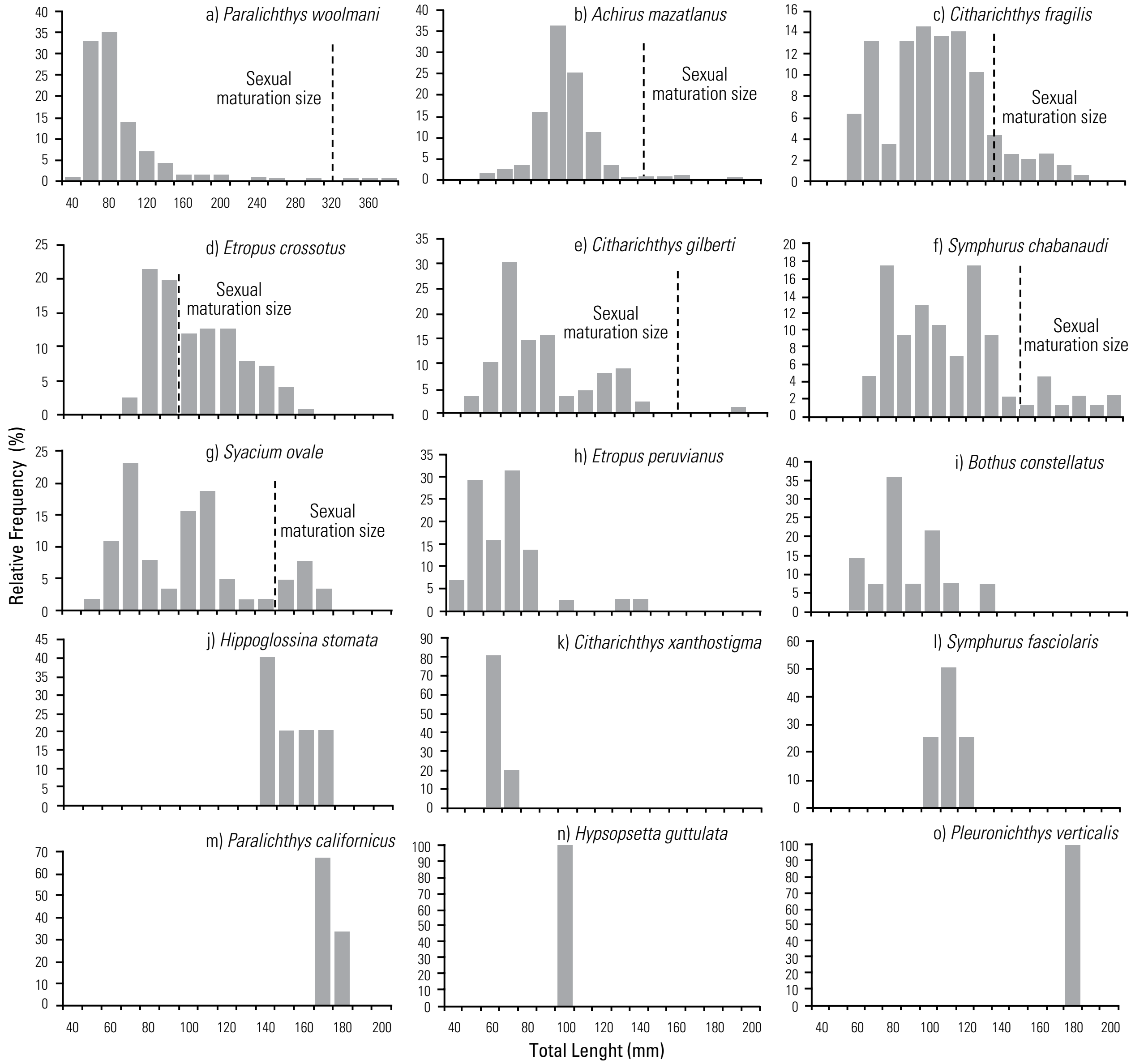

Figure 5a-o. Size structures of flatfish species in the shrimp trawl bycatch in the Gulf of California during 2002 and 2003. For some species the first sexual maduration size is indicated.

Table 2. Growth parameters and longevity of the most abundant and frequents flatfish species in the shrimp trawl bycatch of the Gulf of California during 2002 and 2003.

Species	L_∞ (mm)	K (1/year)	t_0	Longevity 3/K (annual)	Medium size (total length mm)
P. woolmani	388	1.0	–0.39	3.0	101.10
C. fragilis	210	0.92	–0.19	3.2	109.99
A. mazatlanus	200	1.2	–0.14	2.5	112.86
E. crossotus	170	1.6	–0.11	1.8	110.86
C. gilberti	200	1.2	–0.14	2.5	93.18
S. chabanaudi	220	0.71	–0.24	4.2	121.88
S. ovale	173	1.6	–0.11	1.8	105.43

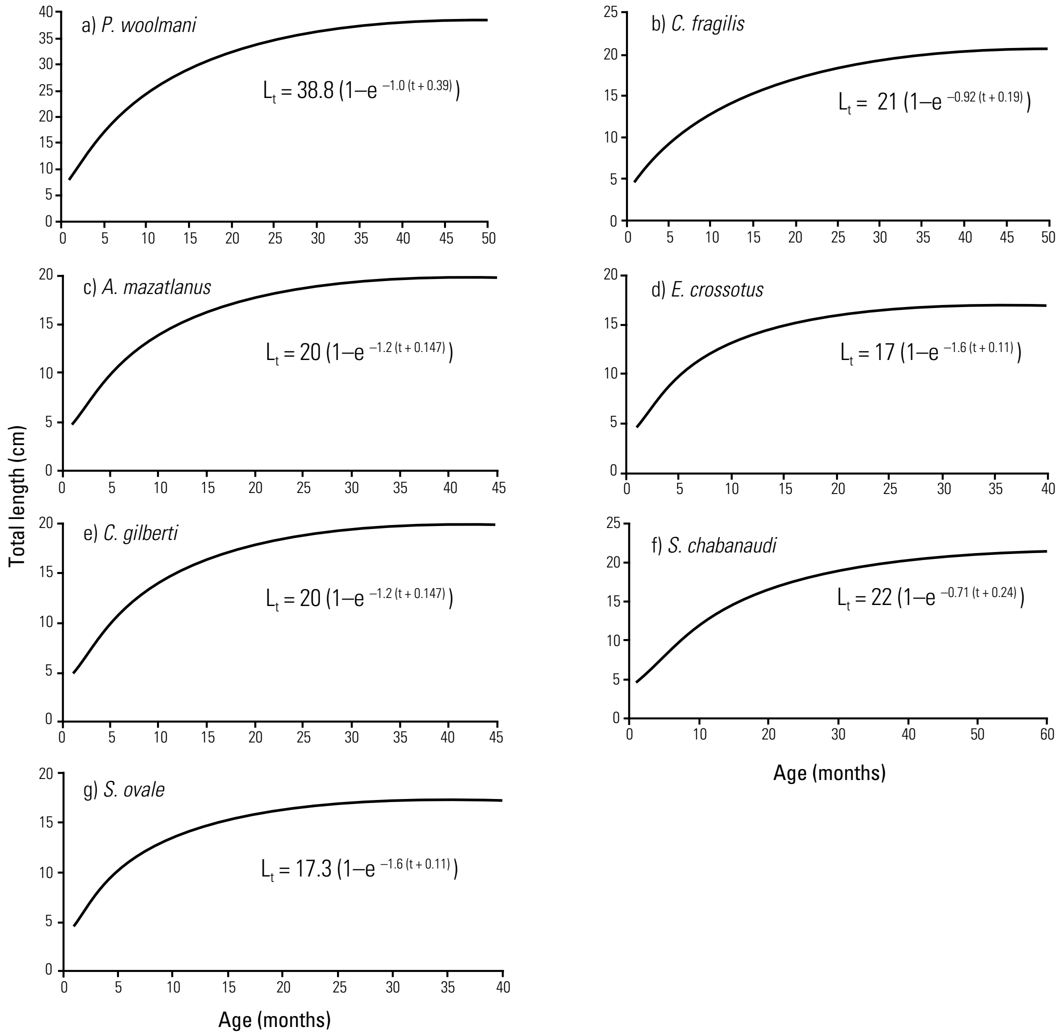

Figure 6a-g. Growth curves of the most abundant flatfish species in the shrimp trawl bycatch in the Gulf of California during 2002 and 2003.

Pleuronectidae, Achiridae and Paralichthidae) in the shrimp trawls carried in the Gulf of California.

According to the latitudinal distribution of the flatfish species found in this study, all these species are endemic to the East Pacific and are residents of this region (Hensley, 1995; Robertson & Allen, 2002). The majority of the species found in this study have a wide distribution ranging from Southern California to the Gulf of California down to Peru. According to Hensley (1995), and Robertson & Allen (2002), some species like *C. fragilis* have a distribution from California to Baja California and even to the middle of the Gulf of California. In this study *C. fragilis* was present in south of the Gulf of California, contrasting the reported distribution. This is, in this work we report the amplification of the area of distribution of *C. fragilis*. Another species found outside its reported range was *C. gilberti* which was found in the north of the Gulf of California. This flatfish species normally has a distribution going from Central Baja California area and the central Gulf of California down to Peru (Hensley, 1995; Robertson & Allen, 2002).

All the flatfish species found in this study were captured within the reported depth distribution by Hensley (1995), and Robertson & Allen (2002). The majority of flatfish species was taken from 10 to 65 m, but the most common capture depth was from 10 to 40 m. This does not mean that this is deepest distribution levels for these species (Hensley, 1995; Robertson & Allen, 2002) since only the areas where the shrimp vessels normally trawl (5 to 65 m) were sampled. According to Petrakis *et al.* (2002), the behavior and geographical distribution can be important factors determining the volume and composition of some species captured, but the effects are dependent on the captured species. This fact could determine species and size differences of the time and depth that the samples were taken. An example of these effects could be the migrations patterns of

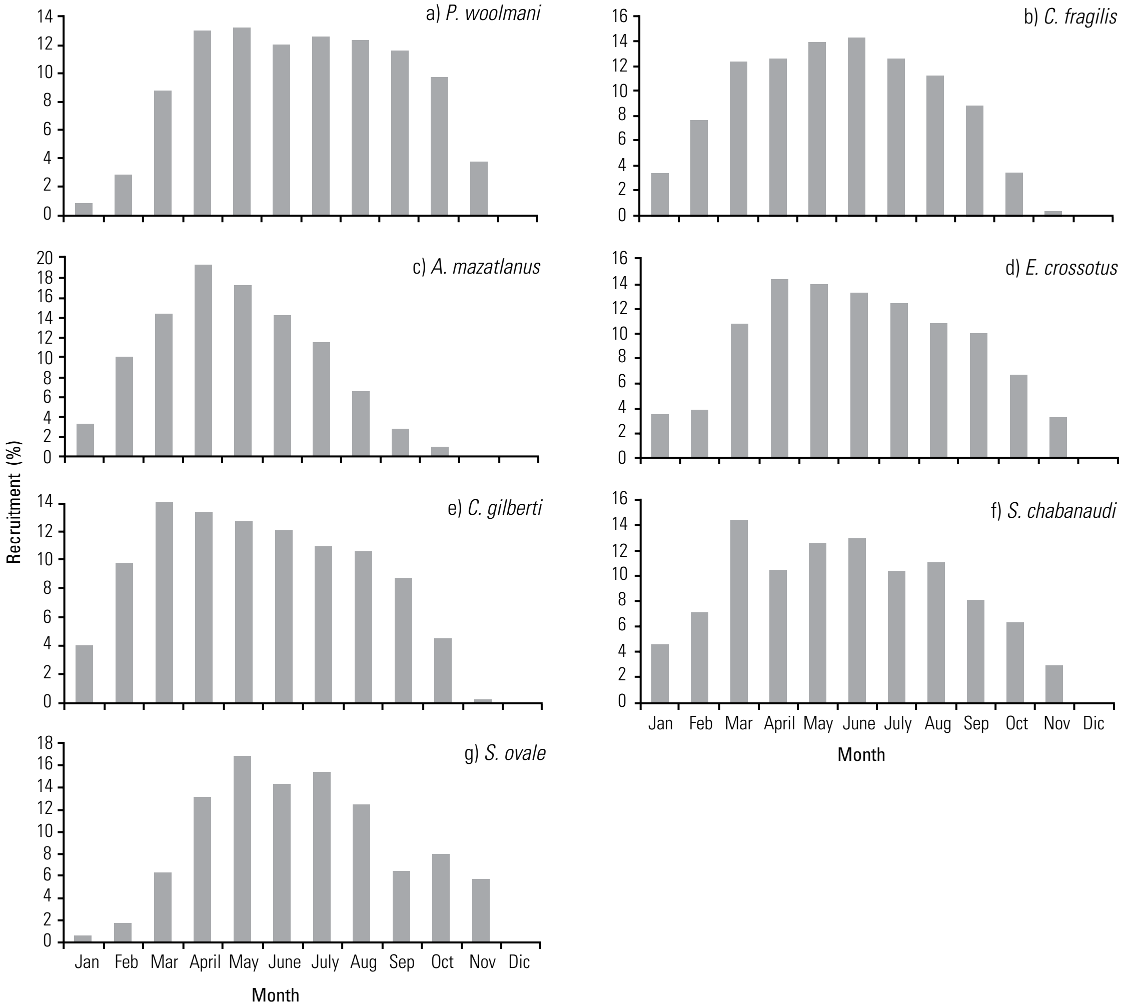

Figure 7a-g. Recruitment patterns of the most abundant flatfish species in the shrimp trawl bycatch in the Gulf of California during 2002 and 2003.

some flatfish species, mainly of the genera *Paralichthys*, *Etropus, Achirus*, which have a reproductive migration from deep waters to the coastal areas (Balart, 1996; Reichert, 2000). For this reason, additional studies, increasing the sampling depth to other areas in addition to where the shrimp fleets operate are needed to further understand the distribution and abundance of these benthonic species and to gain enough information to evaluate the potential effects of fishing on the fish populations.

According to the length frequency diagrams of flatfish species (Fig. 5a-o), the majority of flatfish species were small (ranging from 20 to 200 mm of total length), and only *P. woolmani* surpassed the 250 (20-380) mm of total length (Fig. 5a). This is similar to findings from studies performed by Van der Heiden (1985) and Pérez-Mellado & Finley (1985), where they found out that only the species of the *Paralichthys* genera surpassed 250 mm in the shrimp trawl bycatch in the Gulf of California. The species of this genus habitually reach maximum size between 900 to 2500 mm in total length, and they are generally considered of commercial value (Balart, 1996); meanwhile, other flatfish species captured in the shrimp trawls are generally species that are smaller than 250 mm with little or no commercial value (Hensley, 1995).

The growth parameters obtained in this study for the most abundant and frequent flatfish species (Table 2), correspond with the short longevity of these species (from 1.8 to 3.2 years) with the exception of *P. woolmani* which according to literature have a greater longevity and which correspond with relatively low values of K (growth coefficient) and high values of L_∞ (Hensley, 1995; Reichert, 2000; Fishbase). When the growth parameters were estimated for *P. woolmani* (the most abundant flatfish species in this study), there was an absence of the largest sizes for this species which caused an over-representation of the smallest organisms, increasing the slope of the growth with no defined limits for the asymptotic length and overestimating K. This type of

Table 3. Bibliographic searches about of maximums sizes, longevity and sexual maturation size of some flatfish species.

Species	Maximum size (mm)	Longevity (years)	Sexual maturation size LT (mm)	Source
Paralichthys woolmani	800	5 – 10	325	Fishbase
Citharichthys fragilis	220	1 - 2.5	125	Fishbase
Achirus mazatlanus	210	1 - 2	140	Fishbase
Etropus crossotus	200	1 - 2	92	Reichert (2000)
Citharichthys gilberti	270	1 – 2	160	Fishbase
Symphurus chabanaudi	250	2 – 3	157	Fishbase
Syacium ovale	230	2 – 3	146	Fishbase

problems has also been documented for the blue shrimp (López-Martínez *et al*., 2005) and other fish species and perhaps is due to the these species have a reproductive migration from deep waters to coastal areas (Balart, 1996), causing changes in species and size availability. Another potentially influential factor is that the majority of the shrimp trawls were done at night, because the shrimp fleet in the Gulf of California trawls primarily at night. This could have affected the composition and length structure of the flatfish species in our samples since some flatfish species can have diurnal habits.

Analysis of recruitment for the most frequent flatfish species showed that the highest period of reproductive recruitment was from May to August (Fig. 7). This period occurs during the closed shrimp season, which is from March to September in the Gulf of California. During this time, the species captured incidentally can recuperate and the possible damage caused by the incidental capture of these species lessens. More than 50 % of the organisms sampled were of small sizes and the majority of these were captured before sexual maturation (Table 3), this could potential have an effect on the population level. However, it is necessary to measure the level of abundances of each species within its entire total distribution and the area of trawling of the shrimp fleet to estimate the real effect on these populations.

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