Changes in catch and bycatch composition and in species diversity of a semi-floating shrimp-trap fishery in three eastern Atlantic island ecosystems with different degrees of human alteration

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Summary: Composition and bycatch of semi-floating shrimp-trap fisheries (SSTF) were compared among areas with different levels of anthropogenic alteration of marine ecosystems. The three areas selected were Madeira, the Canary Islands and Cape Verde. Mean species richness and diversity of the SSTF did not show significant differences among areas. The dominant species in catches of the SSTF for all regions studied was the main target species, *Plesionika edwardsii*, which accounted for 96.0% of the catch in Cape Verde, 75.8% in Madeira and 59.1% in the Canary Islands. Targeted pandalid shrimps accounted for more than 96.8% of total catches for all areas combined. Numbers of non-target species caught were 18 (Madeira), 14 (Canary Islands) and 16 (Cape Verde), of which 13 (Madeira), 8 (Canary Islands) and 11 (Cape Verde) were always discarded. Bycatch accounted for 0.5% (Madeira), 0.7% (Canary Islands) and 3.1% (Cape Verde) in numbers. Shark species accounted for 0.11% of all individuals caught. A total of 5 species in Madeira, 6 in the Canary Islands and 4 in Cape Verde, accounting for 0.2% to 0.8% of total catches, were not landed due to the small size of individuals or low numbers of individuals caught (self-consumption). The present results suggest that the selectivity of traps for the main target species, *P. edwardsii*, in SSTF changes due to changes in species dominance, which are probably linked to the degree of human fishing exploitation of the marine ecosystems in each area.

Keywords: abundance; diversity; bycatch; semi-floating shrimp traps; *Plesionika edwardsii*.

Cambios en la composición de la captura y de la captura accesoria y en diversidad específica en una pesquería con nasas camaroneras semi-flotantes en tres ecosistemas insulares del Atlántico oriental sujetos a distinta presión antrópica

Resumen: Se comparó la composición de las capturas y la captura accesoria de la pesquería de camarones con nasas semi-flotantes (SSTF) entre áreas con diferentes niveles de alteración de sus ecosistemas marinos por la acción humana. Se seleccionaron tres áreas: Madeira, Canarias y Cabo Verde. La riqueza de especies y la diversidad de la pesquería no mostraron diferencias significativas entre áreas. La especie dominante en las capturas de la SSTF fue la principal especie objetivo, *Plesionika edwardsii*, en las tres regiones estudiadas, variando desde 96.0% (Cabo Verde) hasta 59.1% (Canarias), con 75.8% en Madeira. Los camarones pandálidos objetivo de la pesca representaron más del 96.8% de la captura total en el conjunto de las tres áreas. El número de especies no-objetivo capturadas fue 18 (Madeira), 14 (Canarias) y 16 (Cabo Verde), de las cuales siempre fueron descartadas 13 especies en Madeira, 8 en Canarias y 11 en Cabo Verde. El porcentaje de individuos (en número) de las capturas accesorias en relación con las capturas totales representó el 0.5% en Madeira, 0.7% en Canarias y 3.1% en Cabo Verde. Las especies de tiburones representaron solo el 0.11% de los individuos capturados. Cinco especies en Madeira, seis en Canarias y cuatro en Cabo Verde representaron entre 0.2 y 0.8% del total de las capturas no desembarcadas debido a su pequeño tamaño o al bajo número de individuos capturados (auto consumo). Los resultados obtenidos sugieren que las nasas de la SSTF cambian sus características de selectividad con respecto a la especie objetivo principal, *P. edwardsii*, debido a cambios relativos entre las especies dominantes, lo que probablemente está relacionado con la explotación pesquera de los ecosistemas marinos en cada área.

Palabras clave: abundancia; diversidad; captura accesoria; nasas semi-flotantes; *Plesionika edwardsii*.

INTRODUCTION

The impact of the fishing activity on non-target species or bycatch species, together with overexploitation of target species and impacts on habitats, is considered one of the main problems of marine ecosystems (Dulvy et al. 2003, Kappel 2005, Shester and Micheli 2011). At a global level, bycatch has been estimated at 27 million t per year (Alverson et al. 1994), but more recently Kelleher (2005) estimated worldwide discards at an average of 7.3 million t per year. Increasing awareness of the potential impacts of such high levels of unwanted catch on marine ecosystems is becoming an issue of global importance (Stobutzki et al. 2001, Bellido et al. 2011).

Small-scale fisheries have often been described as more selective and more sustainable than industrial fisheries (Chuenpagdee et al. 2006, Jacquet and Pauly 2008, Zimmerhackel et al. 2015). However, the bycatch level in small-scale fisheries can cause major ecological impacts and, when scaled to per-unit of total catches, be comparable to that in industrial fisheries (Bellido et al. 2011, Shester and Micheli 2011, Zimmerhackel et al. 2015).

In view of these findings, two priority goals emerge: a) to determine and reduce the impact of fishing activity on bycatch species, and b) to find a selective gear that minimizes the capture of non-target species. These goals are of particular importance when the fishing activity is focused on shrimp species, for which the biomass discarded is higher than the marketable biomass (33.0% of all world fishery discards) (Alverson et al. 1994, Stobutzki et al. 2001, Bellido et al. 2011), and attaining them will help the search for alternatives to bottom trawling.

Continental shelves are among the richest ecosystems of the sea (e.g. Stobutzki et al. 2001), supporting more than 95.0% the world's fisheries (Pauly and Christensen 1995, Pauly 2008, Sadovy et al. 2013), so they are among the marine ecosystems with the clearest signs of overexploitation. Although subjected to a lower fishing intensity, deep ecosystems, including the ones on the slope, are extremely sensitive to fishing activity (Cartes et al. 2007, Pajuelo et al. 2010, 2016), and bycatch has become a major conservation issue (Harrington et al. 2005).

Since 1975 shrimp species of the *Plesionika* genus have been fished with highly selective semi-floating shrimp traps operating between 100 and 500 m depth throughout the Mediterranean Sea (González et al. 1992, García-Rodríguez et al. 2000). Since 1997 (González 1997), this fishery has expanded to the northeastern

Atlantic islands, where a small-scale fishery developed, first in the Canary archipelago (González et al. 2001) and many years later in Madeira (González et al. 2016). Only experimental fishing has been conducted around Cape Verde to date. However, the development of these fisheries has not been monitored and information on its impact on target and non-target species (in particular sharks) has not been available.

To bridge this gap, a research programme was developed to evaluate the composition of the catch of the shrimp fishery with semi-floating traps off Madeira, the Canary Islands and Cape Verde. Of particular interest was the bycatch of top predators because of their importance for ecosystem functioning (Pajuelo et al. 2010). In addition, the quantification and diversity of bycatch species is relevant for the current fisheries policy of the European Union, which aims to reduce the catches of some species groups to zero over a short period (Clarke 2009). A second objective of this study was to evaluate the behaviour of the fishing system at different levels of ecosystem exploitation.

MATERIALS AND METHODS

Sample procedures

Fishing operations (n=90) were done during six research cruises (15 fishing operations each) carried out in the Madeira (n=30), the Canary (n=30) and Cape Verde (n=30) archipelagos, to compare the composition and bycatch of the semi-floating shrimp-trap fishery (SSTF). The research cruises were conducted in the same period of the year (May-July 2017).

Three areas with different levels of fisheries-impacted ecosystems were selected: (1) Cape Verdean waters, a pristine deep ecosystem with little anthropogenic alteration, where no benthic fisheries exist below 100 m; (2) Canary Islands waters, the most fisheries-impacted of the three archipelagos, with full fishing activity from 0 to 1000 m depth and multiple gears such as benthic traps, semi-floating shrimp traps, trammel nets, purse seines, longlines, hand lines and poles; and (3) Madeiran waters, an example of medium fisheries impact.

Fishing operations (n=90) were performed around the islands and not only on a particular side of them. Each fishing operation (n=90) was performed with one ground line (trap-line) with 75 traps equally spaced (25 m) along the length of the fishing rope. Each fishing operation was done at a particular location and a specific depth, with no replicates. Atlantic chub mackerel (*Scomber colias*) was used as bait in the traps. All

fishing operations were conducted over approximately 24 h to include the entire distribution range of species affected by diel migrations. Each fishing operation (30 at each archipelago) was carried out covering a bathymetric range between 175 and 490 m depth, corresponding to the maximum abundance depth for the target species *Plesionika edwardsii* at the three archipelagos combined (González et al. 2016). The traps were suspended 2.4 m above the bottom. The semi-floating trap is a cylinder conical trap with a base length of 56 cm and a height of 57 cm, covered with 15×20 mm mesh. Each trap has one truncated cone-shaped opening with a 23 cm outer diameter and 19 cm inner diameter. The specimens caught were identified to species level according to the WoRMS Editorial Board (2018).

The species caught were classified as target species (*P. edwardsii* and other pandalids of the *Plesionika* and *Heterocarpus* genera) or bycatch. Bycatch is considered the incidental catch of non-target species (NMFS 2016) and was further classified into two categories: (1) catch of species or sizes that are discarded because they are not marketable or have no economic value, and (2) catch of regulated species or sizes that are discarded due to regulations (Dunn et al. 2011, Zimmerhackel et al. 2015, NMFS 2016).

Data analysis

For each species the abundance in number of individuals and percentage was estimated by areas. For each main group (crustaceans, osteichthyans and chondrichthyans) and for the target/non-target species, the number of species and the abundance were calculated by areas.

A dominance curve, a plot of percentage cumulative abundance by numbers against the species rank, was applied to investigate changes in species dominance in the SSTF by area (Clarke 1990).

The analyses focused on the macrofauna caught by the SSTF. For each trap-line, the species composition and abundance (expressed as the number of individuals per trap-line) were recorded. Standardization and logarithmic transformation were applied to data of each trap-line prior to the analysis (Clarke and Warwick 2001), after which a resemblance matrix using the Bray-Curtis similarity index was constructed (Clarke and Warwick 2001, Clarke and Gorley 2006). Of the total trap-lines of the SSTF (n=90), only valid fishing operations (n=87) were used to test differences in species composition and abundance among areas. This was done using a distance-based permutational multivariate analysis of variance, PERMANOVA (Anderson et al. 2008). The factor considered to explain the ordination of the trap-lines of the SSTF was the area (archipelagos). PERMANOVA was performed to test the null hypotheses of no differences among the assemblages of the SSTF among areas. The permutation method used was the unrestricted permutation of raw data with a maximum number of permutations of 9999 due to their good empirical results in the maximum discriminant power (Anderson and Legendre 1999, Anderson and ter Braak 2003). For each factor, a pseudo-F test

(p-F) and a pairwise test for significant effects were estimated. Statistical analyses were performed using Primer v.6 with PERMANOVA+ software (Clarke and Warwick 1994, Anderson et al. 2008).

The Similarity percentage (SIMPER) analysis procedure was used to identify the species (within and between samples) that contribute the most for a significant intergroup dissimilarity between areas and for a significant intragroup similarity (Clarke and Warwick 1994, 2001). Statistical analyses were also performed with PERMANOVA+ (Clarke and Warwick 1994, Anderson et al. 2008).

Biodiversity was tested among areas. Species diversity of the SSTF was estimated for abundance data with the Shannon-Wiener diversity index (H') and species richness (S) (Magurran 1988) using the DIVERSE subroutine within the Primer v.6 software. Species diversity of the SSTF was tested for differences among areas by an ANOVA test, considering each trap-line as one observation. This analysis was used to evaluate the null hypothesis of equality in S and H' for the SSTF among areas with a critical value of $F_{0.05,2,86}$=3.15.

Abundance of the most important pandalid species (*H. ensifer, P. edwardsii, P. ensis* and *P. martia*), individually and as a whole, and sharks were compared using a catch per unit effort (CPUE) unit estimated as the average number of shrimps per trap at each line (for shrimps), and as the square root of the total count per line (for sharks). Data of abundance were compared by an ANOVA test. This analysis was used to evaluate the null hypothesis of equality in CPUE among areas with a critical value of $F_{0.05,2,86}$=3.15.

Statistical significance was set at p<0.05 for all statistical tests performed.

RESULTS

Of the 90 fishing operations carried out around the three archipelagos combined, 29 in Madeira, 28 in Canary Islands and 30 in Cape Verde were considered valid.

A total of 64332 individuals representing 17 crustacean species (63568 individuals, 98.8%) and 28 fish species (764 individuals, 1.2%) were recorded. Only three species of Elasmobranchii (belonging to 3 families and representing <0.1% of the individuals caught) and 23 species of Actinopterygii (16 families, 1.1% in number of individuals) were caught (Table 1). In number of individuals, shrimps of the family Pandalidae (98.7%) dominated the SSTF. By region, the SSTF in Madeira was dominated by pandalid shrimps (99.5%) followed by the fish family Congridae (0.1%). In the Canary Islands, pandalids (99.3%) dominated the catches of the SSTF, followed by the fish family Sparidae (0.2%). In Cape Verde Islands, pandalids represented 96.9% of the catches of the SSTF, followed by the fish family Moridae with 1.9%. In all three regions the dominant species in the catches of the SSTF was the main target species *Plesionika edwardsii*, which accounted for 96.0% in Cape Verde, 75.8% in Madeira and 59.1% in the Canary Islands. The pandalid target species accounted for more than 96.8% of the total catches.

Table 1. – Species composition of macrofauna in numbers and in percentage of the semi-floating shrimp-trap fishery in Madeira, the Canary Islands and Cape Verde.

Family	Species	Madeira		Canary Islands		Cape Verde	
		Numbers	%	Numbers	%	Numbers	%
Aristeidae	*Aristaeopsis edwardsiana* (Johnson, 1868)			4	0.016		
	Aristaeomorpha foliacea (Risso, 1827)	4	0.018				
Epialtidae	*Anamathia rissoana* (Roux, 1828)					3	0.018
Galatheidae	Galatheidae not id.			6	0.023		
Homolidae	*Homola barbata* (Fabricius, 1793)	12	0.055	4	0.016		
Lysmatidae	*Ligur ensiferus* (Risso, 1816)	3	0.014				
Majidae	Majidae not id.					1	0.006
Oplophoridae	*Systellaspis pellucida* (Filhol, 1884)	12	0.055	9	0.035		
Pandalidae	*Heterocarpus ensifer* A. Milne-Edwards, 1881	84	0.388	4789	18.625	35	0.207
	Plesionika edwardsii (Brandt, 1851)	16424	75.791	15197	59.102	16267	96.009
	Plesionika ensis (A. Milne-Edwards, 1881)	24	0.111	3150	12.251	83	0.490
	Plesionika gigliolii (Senna, 1902)	11	0.051				
	Plesionika martia (A. Milne-Edwards, 1883)	122	0.563	32	0.124	13	0.077
	Plesionika narval (Fabricius, 1787)	4210	19.428	2294	8.922	7	0.041
	Plesionika williamsi Forest, 1964	683	3.152	65	0.253	6	0.035
Polybiidae	*Bathynectes maravigna* (Prestandrea, 1839)			5	0.019		
	Bathynectes piperitus Manning & Holthuis, 1981					3	0.018
Centrophoridae	*Centrophorus squamosus* (Bonnaterre, 1788)					12	0.071
Etmopteridae	*Etmopterus pusillus* (Lowe, 1839)	3	0.014			6	0.035
Somniosidae	*Centroscymnus crepidater* (Barbosa Bocage & Brito Capello, 1864)	3	0.014	3	0.012		
Centriscidae	*Macroramphosus scolopax* (Linnaeus, 1758)			11	0.043		
Congridae	*Conger conger* (Linnaeus, 1758)	24	0.111	25	0.097	9	0.053
Labridae	*Acantholabrus palloni* (Risso, 1810)	2	0.009			7	0.041
	Lappanella fasciata (Cocco, 1833)					4	0.024
Moridae	*Gadella imberbis* (Vaillant, 1888)					2	0.012
	Gadella maraldi (Risso, 1810)	5	0.023				
	Laemonema laureysi Poll, 1953					2	0.012
	Physiculus caboverdensis González, Triay-Portella & Biscoito, 2018					44	0.260
	Physiculus cyanostrophus Anderson & Tweddle, 2002					269	1.587
	Physiculus dalwigki Kaup, 1858	8	0.037				
Muraenidae	*Muraena helena* Linnaeus, 1758	5	0.023	10	0.039	20	0.118
Myrocongridae	*Myroconger compressus* Günther, 1870					9	0.053
Nettastomatidae	*Nettastoma melanurum* Rafinesque, 1810	1	0.005				
Ophichthidae	*Echelus myrus* (Linnaeus, 1758)					8	0.047
Ophidiidae	*Benthocometes robustus* (Goode & Bean, 1886)	3	0.014				
Phycidae	*Phycis phycis* (Linnaeus, 1766)	6	0.028	6	0.023		
Scorpaenidae	*Neomerinthe folgori* (Postel & Roux, 1964)					3	0.018
	Pontinus kuhlii (Bowdich, 1825)	7	0.032	11	0.043	103	0.608
Sebastidae	*Helicolenus dactylopterus* (Delaroche, 1809)	4	0.018	17	0.066	4	0.024
Serranidae	*Anthias anthias* (Linnaeus, 1758)					5	0.030
	Serranus atricauda Günther, 1874					8	0.047
Sparidae	*Dentex macrophthalmus* (Bloch, 1791)			41	0.159		
Synaphobranchidae	*Synaphobranchus affinis* Günther, 1877	7	0.032				
	Synaphobranchus kaupii Johnson, 1862	3	0.014				
Tetraodontidae	*Sphoeroides pachygaster* (Müller & Troschel, 1848)			34	0.132	10	0.059
		21670	100	25713	100	16943	100

A total of 18 non-target species were caught in Madeira, 14 in the Canary Islands and 16 in Cape Verde, of which 13, 8 and 11 species, respectively, were always discarded. Bycatch (in numbers) accounted for 0.5% of catches in Madeira, 0.7% in the Canary Islands and 3.1% in Cape Verde. The bycatch can be divided into three types according to the reason for not landing them: regulatory discards, species that are not marketable and individuals that are not marketable due to size. Bycatch due to regulations included only three individuals of *Etmopterus pusillus* and three of *Centroscymnus crepidater* in Madeira, three of *C. crepidater* in the Canary Islands, and 12 of *Centrophorus squamosus* and six of *E. pusillus* in Cape Verde. The capture of deep shark protected species was low, accounting for 0.11% of all individuals caught. The most frequently caught non-marketable species were *Gadella maraldi*, *Physiculus dalwigki*, *Synaphrobranchus affinis* and *Synaphobranchus kaupii* in Madeira; *Macroramphosus scolopax*, *Systel-laspis pellucida* and *S. affinis* in the Canary Islands; and *Acantholabrus palloni*, *Lappanella fasciata*, *Physiculus cyanostrophus* and *Physiculus caboverdensis* in Cape Verde. A total of 5 species in Madeira, 6 in the Canary Islands and 4 in Cape Verde, accounting for 0.2% to 0.8% of total catches, were not landed due to the small size of individuals or low numbers of individuals caught (self-consumption).

The k-dominance curves for species abundance (Fig. 1) showed that the distribution of the number of individuals among species at Cape Verde differed markedly from that at the Canary Islands or at Madeira, which had a smaller number of dominant species. The patterns of the dominance curves of the three areas indicated different patterns of distribution of individuals among species, with the highest number of individuals aggregated in a single species at Madeira.

The results of PERMANOVA analysis (Table 2) in abundance indicated significant differences in the catch assemblage of the SSTF among archipelagos ($p<0.001$).
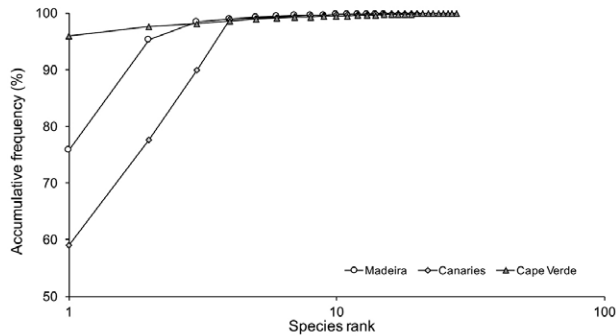
Fig. 1. – K-dominance curves of the number of individuals caught in Madeira, the Canary Islands and Cape Verde.

Table 2. – Results of the PERMANOVA analysis. *values indicate significant differences at p<0.05; df, degrees of freedom; SS, sum of squares; p-F, pseudo F value; p, p value; t, t value.

Source	df	SS	p-F	p
Isles	2	42878	17.62	0.0001*
Res	84	1.02E5		
Total	86	1.45E5		
Groups			t	p
Canary Islands, Madeira			3.12	0.0005*
Canary Islands, Cape Verde			5.32	0.0001*
Madeira, Cape Verde			4.27	0.0001*

Pairwise comparisons showed that the trap-lines (assemblages) among archipelagos were significantly different in all cases (Canary Islands-Madeira p<0.0005; Canary Islands-Cape Verde p<0.0001; Madeira-Cape Verde p=0.0001).

The results of the SIMPER analysis of abundance showed that a few species provided the greatest contribution for defining the assemblages of the SSTF in each area, with an average similarity of 55.0 in Madeira, 44.3 in the Canary Islands and 73.8 in Cape Verde (Table 3). Considering the cumulative contribution roughly at 90%, the species that most contributed to intragroup similarity were the three pandalid species *Plesionika edwardsii*, *Plesionika narval* and *Plesionika williamsi* in Madeira; a more diverse set of four species including *P. edwardsii*, *Heterocarpus ensifer*, *P. narval* and *Plesionika ensis* in the Canary Islands; and the pandalid *P. edwardsii* and the fish *Physiculus cyanostrophus* in Cape Verde (Table 2). The target species of the SSTF, *P. edwardsii*, had a contribution of 80.8% in Cape Verde, 72.2% in Madeira, and 39.2% in the Canary Islands (Table 3).

The comparison among areas, measured as the dissimilarity between each pair of areas, considering the number of species that cumulatively have a contribution of around 90%, is presented in Table 2. The values of dissimilarity ranged from 49.3% (between Cape Verde and Madeira) to 62.8% (between Canary Islands and Cape Verde). Five species, *H. ensifer*, *P. edwardsii*, *P. ensis*, *P. narval* and *P. cyanostrophus*, provided the greatest contribution (>76%) to discriminate the SSTF between the Canary Islands and Cape Verde. The pandalid species *H. ensifer*, *P. edwardsii*, *P. ensis*, *P. narval* and *P. williamsi* were found to contribute the most to the average dissimilarity between the SSTF of Canary Islands and Madeira. Six species, *P. narval*, *P. cyanostrophus*, *P. williamsi*, *P. edwardsii*, *H. ensifer* and *Pontinus kuhlii*, were found to be the discriminating species most contributing to the dissimilarity of the SSTF between Madeira and Cape Verde (Table 3).

By area, the greatest mean species richness (S) values of the SSTF was found in Cape Verde (S=6.71±1.73 [mean±sd]) and the lowest in the Canary Islands (S=6.26±33.13). The highest diversity values (H') for the SSTF were also recorded in Cape Verde (H'=1.20±0.36), being lower in Madeira (H'=1.19±0.45) and in the Canary Islands

Table 3. – Results of the SIMPER routine to analyse the contribution (C, in %; cut off=90.0%) in abundance of typifying species to within-group similarity and showing species that most contribute to intergroup dissimilarity.

Madeira Average similarity: 54.96		Canary Islands Average similarity: 44.34		Cape Verde Average similarity: 73.77	
Species	C%	Species	C%	Species	C%
Plesionika edwardsii	72.21	*Plesionika edwardsii*	39.23	*Plesionika edwardsii*	80.83
Plesionika narval	17.55	*Heterocarpus ensifer*	29.28	*Physiculus cyanostrophus*	10.86
Plesionika williamsi	5.29	*Plesionika narval*	14.99		
		Plesionika ensis	13.39		

Canary Islands - Cape Verde Average dissimilarity: 62.76		Canary Islands - Madeira Average dissimilarity: 59.06		Madeira - Cape Verde Average dissimilarity: 49.26	
Species	C%	Species	C%	Species	C%
Heterocarpus ensifer	20.26	*Heterocarpus ensifer*	20.37	*Plesionika narval*	21.17
Plesionika edwardsii	19.31	*Plesionika edwardsii*	20.13	*Physiculus cyanostrophus*	13.08
Plesionika ensis	13.74	*Plesionika narval*	16.67	*Plesionika williamsi*	13.07
Plesionika narval	13.14	*Plesionika ensis*	14.19	*Plesionika edwardsii*	10.02
Physiculus cyanostrophus	10.01	*Plesionika williamsi*	10.95	*Heterocarpus ensifer*	7.27
Pontinus kuhlii	4.31	*Plesionika martia*	4.05	*Pontinus kuhlii*	5.81
Physiculus caboverdensis	2.48	*Conger conger*	2.09	*Plesionika martia*	4.67
Plesionika williamsi	2.03	*Helicolenus dactylopterus*	0.52	*Plesionika ensis*	4.59
Plesionika martia	1.86	*Sphoeroides pachygaster*	0.39	*Physiculus caboverdensis*	3.24
Conger conger	1.57			*Conger conger*	2.03
Sphoeroides pachygaster	1.35			*Myroconger compressus*	1.25
				Muraena helena	1.23
				Homola barbata	1.20
				Centrophorus squamosus	0.91
				Helicolenus dactylopterus	0.84

(H'=1.17±0.41). The tests for homogeneity of variances for indexes of species richness (S) and diversity (H') were not rejected (p=0.124 and p=0.746, respectively). The ANOVA test showed no significant differences either in species richness (p=0.143) or in diversity (H') (p=0.438).

The standardized CPUEs, estimated as the average number of shrimps per trap in each trap-line (for shrimps) and as the square root of the total count per line (for sharks), showed that all pandalid species (*H. ensifer, P. edwardsii, P. ensis* and *P. martia*) individually had significant differences in CPUE level among areas (ANOVA Brown-Forsythe, p<0.033). However, when all species were analysed together, no significant differences in CPUE level among areas were found (ANOVA, Brown-Forsythe, p=0.055). Shark CPUE values were also significantly different among areas (ANOVA Brown-Forsythe, p=0.031).

DISCUSSION

Fishing produces ecological impacts on the biological community structure by exploiting non-target, high-trophic-level species that are important in the structure of the ecosystems, such as sharks (Myers et al. 2007, Shester and Micheli 2011, Zimmerhackel et al. 2015). The ratio of deep sharks increases with depth (Clarke et al. 2015), and their exploitation causes changes in the community via trophic cascades (Pauly et al. 1998, Lewison et al. 2004, Zimmerhackel et al. 2015). In the fishing system analysed herein, the bycatch volume varied from 0.5% to 3.2% in numbers. These values are in accordance with those of Kelleher (2005), who indicated that small-scale fisheries have a low or negligible discard rate (3.7% of total catches). The bycatch of the SFTF was diverse but showed a low number of individuals per species. Individuals of bycatch composition are mainly discarded because they are not marketable, but a low percentage are discarded because of regulatory restrictions. In addition, a very low proportion are discarded because they are undersized commercial species, but their bycatch makes an almost negligible contribution to the stock mortality.

The low number of individuals of non-target species caught confirmed the high selectivity of this fishing gear for a low number of target species of pandalid shrimps. Also, the overall bycatch of protected species such as sharks recorded in the present study was very low in comparison with that recorded in other small-scale activities in the area, such as the *Aphanopus* fishery, in which the ratio in number of individuals is one deep shark per target individual of black scabbardfish (Pajuelo et al. 2010). Cape Verde was the only area in which a single species, the morid *P. cyanostrophus*, was associated with the bycatch in the assemblage of the SSTF. Differences in the bycatch among areas can be best explained by a combination of local oceanographic factors and biogeographical patterns of the region considered. According to Spalding et al. (2007), Madeira and the Canary Islands belong to the Macaronesian ecoregion within the Lusitanian biogeographic province of the Temperate Northern

Atlantic realm, whereas Cape Verde belongs to its own ecoregion within the West African transition province of the Tropical Atlantic realm.

Estimated bycatch ratios of between 0.5% and 3.2% in numbers were significantly much lower than the current global fisheries bycatch estimates of 40.4% (Davies et al. 2009), and lower than those recorded in many small-scale fisheries such as lobster traps (15.1%), drifting gillnets (18.5%), fixed gillnets (34.4%) or bottom longlines (42.0%-50.0%) (Pajuelo et al. 2011, Shester and Micheli 2011, Zimmerhackel et al. 2015). The level of bycatch recorded is in agreement with that reported by Shester and Micheli (2011), who pointed out that bycatch and habitat impacts of traps are non-significant. This low level of bycatch in a fishery is extremely positive, because a high level of bycatch has important ecological consequences at the species, population/stock (Hall et al. 2000, Lewison et al. 2004) and ecosystem levels (Dulvy et al. 2003, Kappel 2005, Read et al. 2006), particularly for shark species due to their life strategies (Hall et al. 2000, Stevens et al. 2000, Figueiredo et al. 2008). These impacts include reduction of the reproductive rates, reduction of population biomass, and less resilient marine ecosystems (Zimmerhackel et al. 2015).

Differences found in the catch assemblage of the SSTF among archipelagos indicate that the relative composition among species in the catches is different, and that the fishing system affects them in a different way.

These differences seem to be associated with the degree of human fishing exploitation of each area due to this fishing gear and particularly to other fishing systems used in the area, such as bottom traps, lines and longlines (Pajuelo and Lorenzo 1995, Pajuelo et al. 2011, Biscoito et al. 2015). In the area where there is no fishing exploitation, the main target species represented 96.8% of the catches but, when the exploitation increases in each area, there is a relative increase of the other pandalid target species that occupy the niche left by the species directly or indirectly affected by the fishing exploitation.

The archipelagos that showed the greatests differences were the Canary Islands and the Cape Verde, i.e. the most exploited and the unexploited marine areas, respectively, while Madeira was in an intermediate position in accordance with its moderate degree of exploitation. As the degree of exploitation changes from one area to another and as the communities are altered or degraded (Pajuelo et al. 2010, 2011, Shester and Micheli 2011, Zimmerhackel et al. 2015), the present results suggest that the structure of catches and their relative proportions change, and therefore the assemblages obtained with SSTF will change. These changes are supported by historical data. In the Canary Islands, the first fishing surveys with semi-floating shrimp traps in 1997 yielded 90.1% of *P. edwardsii* in the catches, with only 8.8% of other pandalids, mainly *P. narval* and *H. ensifer* (González 1997). In Cape Verde, the first fishing surveys with this selective fishing system in 2010 yielded 93.4% (Santiago island) and 96.9% (Boa Vista island) of *P. edwardsii* (unpublished data).

However, it is important to point out that these changes do not generate an increase in the species exploited, or a reduction in the standard mean abundance for each SSTF between areas, given that no changes are found in diversity, so there are only changes in the species dominance in the assemblage. CPUE data confirm these results, showing that values for each individual species differed among areas. However, pandalids as a whole showed no differences in CPUE values among areas.

The present results suggest that semi-floating shrimp traps do not change their selectivity for the main target species, *P. edwardsii*, because of a change in selective capacity or losses of selective capacity in an exploited marine ecosystem versus a pristine area such as Cape Verde, but because of changes in the community. Changes in the community produce changes in the species dominance, probably associated with the degree of human exploitation in the marine ecosystems, which is the case of the overexploited Canary Islands waters. In Madeiran waters, the situation seems to be intermediate. Despite these changes in relative abundance between the main target species and other target species, the bycatch rate is always very low regardless of the marine ecosystem conditions.

Taking into account that 22 million fishers work globally in small-scale fisheries and that these fisheries provide over 50% of the world's catches (Berkes et al. 2001, Chuenpagdee et al. 2006, Teh and Sumaila 2013), the use and development of this kind of selective fishing system makes an important contribution to reducing bycatch and conserving the community and habitat, especially in deep-sea marine ecosystems.

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