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Landing profiles and typologies of flatfish fisheries on the Portuguese coast*

Célia M. Teixeira[a], Marisa I. Batista and Henrique N. Cabral

Universidade de Lisboa, Faculdade de Ciências, Centro de Oceanografia, Campo Grande, 1749-016 Lisboa, Portugal

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Abstract – Flatfishes represent an important resource in Portuguese fisheries. Although flatfish landings represent a low percentage of total fish weight landed, their importance is higher when commercial value is considered (11%). Official data on flatfish landings from 1992 to 2005 for all landing ports in Portugal were analysed, together with vessel characteristics, in order to detect patterns in flatfish fisheries. Fleet characteristics were heterogeneous, but most of the vessels were multi-gear. Three landing profiles were identified in the flatfish fishery, and the target species of these métiers showed variation in space and in time. Small vessels caught species that occur in coastal areas, mainly soles, bastard sole, flounder, turbot and brill, and usually also presented high landings of octopuses, cuttlefish and rays. Megrims and spotted flounder were caught with others species, like small pelagic fishes and seabreams by coastal trawlers. For this fleet component, catches of flatfish were usually bycatch. Generalized Linear Models (GLM) were used to analyse flatfish landings (LPUE, landings per unit effort and landings in terms of value) between 1992 and 2005 and to evaluate their relationships with several variables. The main effects in the models included year, month, landing port, vessel length class and total landings (kg). The models explained between 15% and 60% of the variability of the LPUE, and 46% to 82% of the variability of landing value, for the flatfish groups considered, with the most important factors being landing port, vessel length class, month, total landing (kg) and landing port: vessel length interaction. These results suggest high spatial and temporal variability. The results of this study may have implications for fishery management, because the LPUE was highest during the important periods of flatfish life cycles, like the spawning season. This fishing pattern has a negative impact on the stocks because of increased fishing pressure during a sensitive period for these species. The adoption of spatial and temporal closures should be implemented.

Key words: Flatfish / Landings / Fleet characteristics / Generalized linear models / Fisheries / Portugal

1 Introduction

Flatfishes inhabit marine environments in nearly every part of the world, ranging from the southern Arctic Ocean to continental seas off Antarctica, but the largest quantities are caught in the temperate and boreal zones of the Northern Hemisphere (Munroe 2005).

In 2005, flatfish catches represented 1.5% of the world marine landings and nearly 70% of these were in the North Atlantic (721 950 t) (source: FAO – http://www.fao.org/fishery/statistics/global-capture-production/query/en). Although flatfish constitute only a minor part of total fish resources, they include high value species and support substantial fisheries.

Fishing is a traditional, culturally important activity in Portugal, dominated by small, local fishing vessels. Flatfish fisheries are widely spread along the Portuguese coast and have traditionally played an important socio-economic role. Flatfish landings account for less than 4% of all the fish biomass landed on the Portuguese coast, but the importance of flatfish fisheries is considerably higher due to the high commercial value of flatfish species, accounting for nearly 11% of the economic value of fish landings (source: *Direcção Geral das Pescas e Aquicultura*, DGPA). The most important flatfish species, in terms of landings, are soles, *Solea solea* (Linnaeus 1758), *Solea senegalensis* Kaup 1858 and *Solea lascaris* (Risso 1810), bastard sole *Microchirus azevia* (Capello 1868), flounder *Platichthys flesus* (Linnaeus 1758), spotted flounder *Citharus linguatula* (Linnaeus 1758), wedge sole *Dicologlossa cuneata* (Moreau 1881), turbot *Scophthalmus maximus* (Linnaeus 1758), brill (*Scophtahlmus rhombus* (Linnaeus, 1758), and megrims *Lepidorhombus boscii* (Risso 1810) and *Lepidorhombus whiffiagonis* (Walbaum 1792).

A multi-gear fleet (artisanal fleet or small scale and coastal multi-gear fleet characterized by the use a multitude of gears to capture species that occur in different depths, habitats and substrata) is responsible for most of the flatfish landings. This fleet consists of almost 6000 vessels, most of which are between 5 and 17 m in total length with an open deck, and thus only fish within a limited distance from the coastline (source: DGPA).

* Supplementary tables are available in electronic form at http://www.alr-journal.org

[a] Corresponding author: cmteixeira@fc.ul.pt

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Only a fraction of these vessels directly fish for flatfishes, since many other species are caught by these multi-species fisheries. The main fishing gears used in flatfish fisheries are trammel and gill nets and bottom trawls. Although an operative artisanal fleet census exists for the Portuguese coast, there is no exhaustive inventory of gears used by this fleet, difficult to link these landings to particular gears. In addition, this fishery activity is widely dispersed, which makes it difficult to obtain data.

Most of the regulations in the Portuguese legislation related to flatfish fisheries concern the establishment of the minimum allowed sizes for each fish species captured, quotas and total admissible captures (TAC). The minimum allowed sizes of captured fish are established for megrims, plaice, soles, bastard sole, brill and flounder. Local quotas only exist for megrims and soles. Only the first three species/species group (megrims, plaice and soles) are regulated with TAC in this area (ICES IX, X e CECAF). Although there are no stock evaluations for the flatfish off the Portuguese coast, their status could be a matter of concern given that these resources present evidence of over-exploitation (Teixeira and Cabral 2009). This is also indicated by information from nearby geographic areas in the Northeast Atlantic, such as the Bay of Biscay (Rice and Cooper 2003).

Multi-species fisheries exhibit fishing practices that vary in space and time, whereby a given fleet may change its target species, gear type or fishing location over a short time scale (weeks to months). These changes may reflect the local abundance of the resource or may be directed by market considerations, such as consumer preferences (Christensen and Raakjær 2006).

The impact of the fleet on resource mortality is, therefore, a complex relationship between fishing practice at certain times of the year and in particular locations. In order to model this relationship it is necessary to identify the fishing tactics or métiers (Biseau 1998) existing in a given fishery.

Although a large number of studies have been made on multi-gear fishery characterization worldwide (e.g. Pech et al. 2001; Colloca et al. 2004; García-Rodríguez et al. 2006; Piniella et al. 2007; Katsanevakis et al. 2010), only Duarte et al. (2009) analyzed and characterized the multi-gear fleet in Portugal, despite its importance.

In this study, the main aims are to determine landing profiles and fishery typologies and evaluate which factors influence flatfish landings, in order to provide a more complete account of this important fishery on the Portuguese coast and allow the establishment of a basis for the implementation of management strategies.

Fig. 1. Map of mainland Portugal with the location of the main fisheries landing ports.1- Caminha, 2- Viana do Castelo, 3- Póvoa do Varzim, 4- Leixões, 5- Aveiro, 6- Figueira da Foz, 7- Nazaré, 8- Peniche, 9- Lisboa, 10- Sesimbra, 11- Setúbal, 12- Sines, 13- Sagres, 14- Portimão, 15- Quarteira, 16- Faro, 17- Olhão, 18- Tavira, 19- Vila Real de Santo António) and the geographic zones identified here.

2 Materials and methods

2.1 Data source

The commercial fishing data to be analysed were obtained from the Governmental Fisheries Bureau (DGPA). The data used in this study spanned a 14-year period (from January 1992 to December 2005). All landings data (in weight and in value) included the year, month, vessel number, number of trips per month, fishing gear and landing port. In addition, the technical characteristics of each vessel (gross tonnage, engine power, length, age and hull material) were also recorded.

The entire flatfish fleet was composed of 5942 vessels operating off the Portuguese coast and landings were made at 19 landing ports. Three areas of the Portuguese coast were considered (Fig. 1): “north” – from Caminha (41° 52′ N, 8° 50′ W) to Nazaré (39° 35′ N, 9° 04′ W), “southwest” – from Nazaré (39° 35′ N, 9° 04′ W) to São Vicente Cape (37° 01′ N, 8° 59′ W), and “south” – from São Vicente Cape (37° 01′ N, 8° 59′ W) to Vila Real de Santo António (37° 10′ N, 7° 25′ W).

The designation of these areas was based on their different oceanographic conditions (Cunha 2001) and different ecological communities and species assemblages (Sousa et al. 2005). The fleet catches a wide diversity of species (nearly 290) and to identify different métiers, several species groups were considered (based on the previous analysis on board the vessels actively target these species): flatfish (soles, bastard sole, flounder, spotted flounder, wedge sole, turbot, brill and megrims), roundfish (small pelagic fishes, seabreams, rays, hake and anglerfishes) and cephalopods (octopus and cuttlefish) (Table 1). The remaining species were grouped in "others".

The monthly landings per unit effort (LPUE) for each vessel and for each species group were calculated by summing the species total monthly landing per vessel and dividing by the number of fishing trips per month.

2.2 Statistical methods

The vessels that landed less than 1000 kg of flatfish per year along the time series were discarded from the analysis. The final data filtering resulted in 375 vessels, which were responsible for 73% of the total flatfish landings.

Classification techniques (hierarchical clustering analysis) based on Euclidean distances and applying Ward's minimum variance criterion (Ward 1963) were used to identify landing profiles (e.g. Tzanatos et al. 2006; Campos et al. 2007; Katsanevakis et al. 2010). All calculations were performed using STATISTICA 9 (StafSoft).

Correspondence analyses (CA) were run to evaluate landing variation with month, gear and landing coast zone. These analyses were performed using CANOCO (CANOnical Community Ordination) version 4.5 (ter Braack and Smilauer 2002).

To investigate the variation in LPUE for flatfish species (soles, bastard sole, flounder, spotted flounder, wedge sole, turbot, brill and megrims) in relation to year, month, landing port and technical characteristics (gross tonnage, length and engine power), a generalized linear model (GLM) (e.g. McCullagh and Nelder 1989; Chambers and Hastie 1992) was applied. Due to the fact that the technical characteristics of the vessels were highly correlated, we used only vessel length. Based on the frequency distribution of vessel length, vessels were assigned to one of four vessel length classes: class 1: $\leqslant 7$ m (19 vessels), class 2: ≤ 8 and ≥ 16 m (212 vessels), class 3: ≤ 17 and ≥ 22 m (70 vessels) and class 4: ≥ 23 m (74 vessels).

Several authors have applied GLM (McCullagh and Nelder 1989) to the problem of estimating standardised catch rates (e.g. Maynou et al. 2003; Maunder and Punt 2004; Sánchez et al. 2004; García-Rodríguez et al. 2006). GLM are an extension of linear models, allowing the incorporation of non-normal distributions of the response variable and transformations of the dependent variables to linearity (McCullagh and Nelder 1989). The general form of GLM is:

$$g(\mu) = \beta^t \boldsymbol{X}$$

where a link function $g()$ is used to achieve linearity in the β^t parameters of the dependent variables $\boldsymbol{X}$. A second part of the model concerns the specification of a variance function (φ) that relates the variance of the response variable to the mean:

$$\text{var}(Y) = \varphi V(\mu), \text{with } \varphi \text{ constant.}$$

The general model used in this study was:

$$\ln \mu_{ymhv} = \beta_0 + \beta_{1y} + \beta_{2m} + \beta_{3h} + \beta_{4v}$$

where μ_{ymhv} is the expected LPUE for year y and month m, landing port h and vessel class v. In this work, β_0 is the LPUE obtained in January 1992 by vessel class 1 at Aveiro port, β_{1y} the LPUE in the year y relative to 1992, β_{2m} the LPUE in month m relative to January, β_{3h} the difference between Aveiro port and the other landing ports, and β_{4v} the efficiency of vessel class v relative to class 1. When the landing in value was the response variable, the explanatory variables were year, month, landing port, vessel length and total landings (kg). Analysis of deviance to evaluate the significance of the variables in the model and of the interactions was performed by forward selection comparing models excluding one term at the time.

When zero values were eliminated from landings, it was seen that data could be close to lognormal, which implies that a lognormal or gamma distribution may be appropriate for positive values (Stefánsson 1996). The results of Myers and Pepin (1990) suggested that, for fisheries data, the use of the gamma density is preferable to the use of a lognormal density, although this seems to apply mainly when there is a considerable probability of small observations, not dealt with otherwise (Pennington 1991) or, in other instances, when the gain is minor (Firth 1988). Although other members of the exponential family could be used, the gamma density was used here when positive values were under considerations (Stefánssons 1996).

The goodness-of-fit of the models was assessed by comparing their relative contribution to total deviance explained. The model was fitted in the R environment (R Development Core Team 2005) using the gamma distribution with a log-link function, adding the first order interactions whenever it resulted in a better models (high proportion of deviance explained). All statistical analyses were performed using R software (R Development Core Team 2005). A significance threshold of $p < 0.05$ was considered in all test procedures.

3 Results

The flatfish fleet consisted mainly of wooden vessels (77.0%); fiberglass vessels represented 19.0% and only 4.0% of vessels were built of steel. The vessels were also old, the average age being 27.8 years (SD = 14.2). The average technical characteristics of the vessel were 16.4 m of length (SD = 7.4), and 54.1 t of gross tonnage (SD = 47.0), and engine power of 260.0 kW (SD = 228.0) (Table 2).

3.1 Landing profiles

The results of the cluster analysis revealed the existence of three main landing profiles (Fig. 2). Landing profile 1 was mainly composed of small pelagic fishes (SPF) (29.3% of the

Table 1. Main species (fish and cephalopods) landed by the Portuguese flatfish fleet between 1992 and 2005.

Group	Latin name	Common name	Landing (kg year $^{-1}$)	Value (€ year^{-1})
Flatfish	*Solea solea*	Common sole	121 558	1 107 502
	Solea senegalensis	Senegalese sole	89 196	751 670
	Solea lascaris	Sand sole	24 035	153 63
	Microchirus azevia	Bastard sole	87 311	543 031
	Platichthys flesus	Flounder)	46 001	158 927
	Citharus linguatula	Spotted flounder	39 937	98 415
	Dicologlossa cuneata	Wedge sole	31 543	103 008
	Scophthalmus maximus	Turbot	11 271	142 029
	Scophtahlmus rhombus	Brill	12 461	126 026
	Lepidorhombus boscii	Four-spot megrim	2 400	17 811
	Lepidorhombus whiffiagonis	Megrim	851	2 400
		Roundfish		
Small pelagic fish	*Sardina pilchardus*	Sardine	259 907	82 719
	Trachurus trachurus	Atlantic horse mackerel	1 667 278	1 664 088
	Trachurus picturatus	Blue jack mackerel	50 035	17 517
	Trachurus mediterraneus	Mediterranean horse mackerel	41	46
	Scomber scombrus	Atlantic mackerel	203 546	83 818
	Scomber japonicus	Chub mackerel	125 693	35 647
Seabream	*Boops boops*	Bogue	19 837	5 210
	Dentex dentex	Common dentex	2 521	12 182
	Dentex macrophathalmus	Large-eye dentex	158	415
	Dentex marroccanus	Morocco dentex	19	65
	Diplodus annularis	Annular seabream	387	413
	Diplodus cervinus	Zebra seabream	308	2 284
	Diplodus puntazzo	Sharpsnout seabream	131	633
	Diplodus sargus	White seabream	1 646	8 597
	Diplodus vulgaris	Common two-banded seabream	21 817	43 968
	Diplodus bellottii	Senegal seabream	18 587	56 650
	Lithognathus mormyrus	Sand steenbras	2 563	5 736
	Oblada melanura	Saddled seabream	7	14
	Pagellus acarne	Axillary seabream	73 961	306 975
	Pagellus bogaraveo	Blackspot seabream	5 269	30 645
	Pagellus erythrinus	Common pandora	6 642	30 705
	Pagrus auriga	Redbanded seabream	80 478	221 308
	Pagrus pagrus	Red porgy	2 180	19 432
	Sarpa salpa	Salema	3 033	1 507
	Sparus aurata	Gilthead seabream	4 184	31 694
	Spondyliosoma cantharus	Black seabream	16 973	43 149
Ray	*Raja brachyura*	Blonde ray	1 879	5 378
	Leucoraja circularis	Sandy ray	1 696	1 984
	Raja clavata	Thornback ray	2 350	6 349
	Raja montagui	Spotted ray	880	2 330
	Leucoraja naevus	Cuckoo ray	2	1
	Raja undulata	Undulate ray	248 590	554 425
Hake	*Merluccius merluccius*	European hake	358 730	1 326 590
Anglerfish	*Lophius budegassa*	Blackbellied angler	306	2 187
	Lophius piscatorius	Angler	16 040	60 757
		Cephalopods		
Octopus	*Octopus vulgaris*	Common octopus	806 802	2 344 834
	Eledone cirrhosa	Horned octopus	19 757	11 929
Cuttlefish	*Sepia officinalis*	Common cuttlefish	167 896	523 255

Table 2. Main technical characteristics of Portuguese flatfish fleet. N: number of fishing boats.

		Age (years)				Gross tonnage (tonnes)				Length (m)				Engine power (HP)				Hull material (%)		
Register port	*N*	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD	Fibre	Wood	Steel
Vila Praia de Âncora	1	–	–	15.0	–	–	–	8.0	–	–	–	10.2	–	–	–	130	–			100
Viana do Castelo	13	10.0	49.0	29.6	12.8	8.4	223.0	92.1	87.7	11.7	32.8	22.0	9.3	64	950	412	315		54	46
Esposende	1	–	–	33.0	–	–	–	13.9	–	–	–	13.4	–	–	–	96	–		100	
Póvoa do Varzim	59	4.0	49.0	20.6	9.5	2.8	87.9	25.8	14.4	7.7	19.2	15.7	2.4	40	359	187	60	2	93	5
Vila do Conde	53	3.0	42.0	21.9	9.3	3.9	187.0	29.7	26.5	9.1	28.6	15.8	3.2	50	630	201	97		94	6
Leixões	13	16.0	52.0	33.8	9.2	4.3	266.0	91.2	107.7	9.2	34.5	19.4	10.6	59	146	400	446		69	31
Douro	5	24.0	49.0	33.8	10.3	2.9	14.7	6.7	5.1	8.0	11.9	9.6	1.5	50	140	83	37		100	
Aveiro	41	6.0	48.0	23.6	11.5	0.9	366.0	179.7	73.7	7.0	34.2	26.2	6.7	10	1000	639	230	3	12	85
Figueira da Foz	12	8.0	49.0	30.3	13.2	92.0	240.0	189.0	47.0	24.0	34.3	30.0	3.3	440	1000	718	184		67	33
Nazaré	1	–	–	29.0	–	–	–	9.3	–	–	–	12.2	–	–	–	110	–		100	0
Peniche	25	10.0	56.0	24.3	11.5	2.5	310.0	89.8	104.4	7.3	35.0	19.2	9.1	40	940	354	306	12	64	24
Ericeira	5	21.0	29.0	24.6	3.6	2.4	3.6	2.7	0.5	7.1	7.6	7.3	0.2	35	62	47	12		100	
Cascais	7	12.0	43.0	26.9	10.8	10.4	29.4	21.7	6.7	12.0	17.6	15.4	2.2	96	257	178	49		100	
Lisboa	3	24.0	54.0	34.3	17.0	2.0	275.0	138.5	193.0	9.7	34.1	24.3	12.9	91	1455	749	683		33	67
Trafaria	4	16.0	28.0	24.8	5.9	1.2	4.8	2.5	1.6	5.8	8.9	7.1	1.4	40	91	66	21		100	
Sesimbra	15	4.0	59.0	37.9	15.4	2.0	20.0	8.7	4.9	7.1	14.7	10.9	2.0	35	140	90	29		93	7
Setúbal	35	8.0	61.0	35.5	13.8	3.6	15.7	7.8	3.7	7.8	13.7	10.3	1.6	35	182	90	38		100	
Sines	16	5.0	50.0	22.8	13.6	0.9	192.0	21.1	46.3	5.3	24.0	11.5	4.3	40	600	123	135	6	75	19
Sagres	8	10.0	56.0	30.1	16.0	3.4	36.7	17.0	14.1	8.2	17.0	13.1	3.9	45	195	130	59		87	13
Lagos	9	11.0	56.0	36.1	19.0	2.6	18.0	8.7	4.5	8.1	12.9	9.4	3.8	35	155	82	36	22	78	
Portimão	7	7.0	64.0	35.0	24.6	14.2	215.0	46.7	74.3	12.4	32.1	16.8	6.9	110	630	211	188		71	29
Quarteira	2	25.0	30.0	27.5	–	4.9	11.3	8.1	–	8.3	12.2	10.2	–	75	160	117	–	50	50	
Faro	5	9.0	48.0	30.4	15.2	3.4	15.2	10.1	5.5	8.9	14.8	12.1	2.5	60	150	108	45		100	
Olhão	13	3.0	81.0	41.8	21.2	5.3	82.1	20.4	20.4	9.8	18.5	13.5	2.7	36	460	144	112	8	92	
Fuzeta	1	–	–	46.0	–	–	–	5.4	–	–	–	9.8	–	–	–	40	–		100	
Tavira	7	26.0	48.0	36.4	8.1	5.7	22.3	13.7	5.4	9.2	14.1	12.4	1.9	60	175	116	44		100	
Vila Real de St. António	12	3.0	86.0	36.3	25.4	1.4	140.6	30.4	36.8	6.0	23.0	14.5	5.6	60	494	202	121	25	67	8

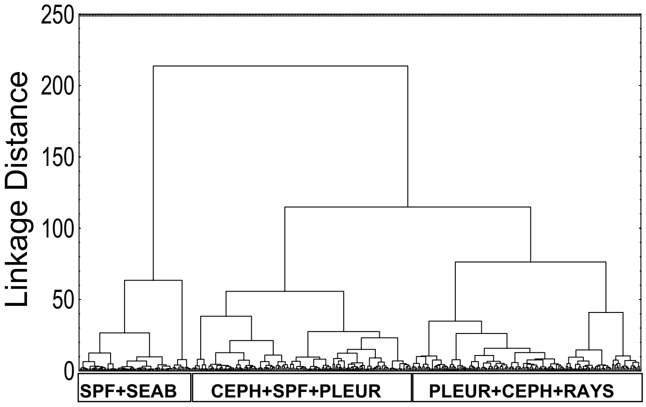


Fig. 2. Dendrogram from hierarchical clustering of the flatfish fleet of the Portuguese coast. The groups individualised corresponding according to landing profiles. SPF: small pelagic fishes, SEAB: seabreams, CEPH: cephalopods, PLEUR: pleuronectiformes.

total landings and 29.2% of their economic value), seabreams (SEAB) (10.1% of the landings, and 8.3% of their economic value) and cephalopods (CEPH) (3.8% of total landings and 9.3% of their economic value). These species groups represent 43.2% of the total landings and 46.8% of the total revenue of the present métier. In this landing profile the pleuronectiformes (PLEUR) represented a residual fraction (2.7% of total landings and 5.3% of their economic value), and the megrims were the more important flatfish (1.2% of total landings, and 0.2% of their economic value) (Table 3). This landing profile corresponded to 75 vessels, mainly steel ones (77.0%). The average technical characteristics of these vessels were 28.9 m length, 198.0 t gross tonnage and an engine power of 715.0 kW. These vessels operated primarily using a trawl (69.0%) (Table 4).

Cephalopods (CEPH) (21.0% of the total landings, 23.6% in economic value), small pelagic fishes (SPS) (18.9% of total landings, 2.8% of their economic value) and pleuronectiformes (PLEUR) (10.5% of the total landings, 22.9% of their economic value) represented the largest species group in the landing profile 2, corresponding to 50.4% of the total landings and to 49.3% of the total revenue of this métier. Soles were the most important flatfishes (5.0% of the total landings, 14.5% of their economic value) (Table 3). This landing profile concerned 147 vessels. The majority of vessels in this second group were made of wood (94.0%), and their average technical characteristics were 15.9 m length, 29.0 t gross tonnage and 199.0 kW engine power. These vessels operated mainly with multi-gear (85.0%) (Table 4).

In landing profile 3, the most important species group were the pleuronectiformes (PLEUR) (21.4% of the total landings, 40.2% of economic value), cephalopods (CEPH) (20.3% of total landing, 18.5% in economic value) and rays (10.3% of the total landings, 7.0% economic value). The landings of the largest species group represented 52.0% of the total landings and 65.7% in total revenue for this métier. Soles were the main flatfish (11.3% of the total landings, 25.1% in economic value) (Table 3). This landing profile corresponded to 153 vessels, 89.0% of which were wooden. The average technical characteristics of the vessels were 10.7 m length, 9.2 t gross tonnage

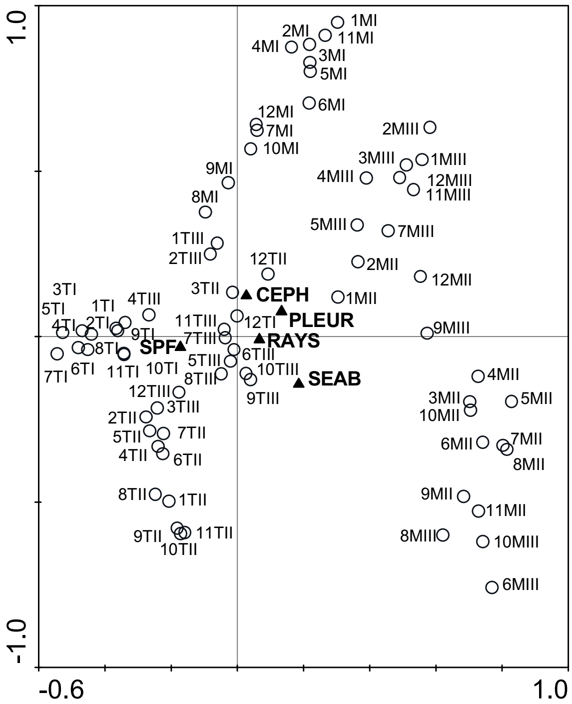


Fig. 3. Ordination diagrams of the correspondence analyses performed on landings per month, gear and coastal region of small pelagic fishes (SPF), seabreams (SEAB), cephalopods (CEPH) and pleuronectiformes (PLEUR). 1- January, 2- February, 3- March, 4- April, 5- May, 6- June etc.; M- multi-gear, T- trawl, I- north, II- southwest I, III- south).

and an engine power of 94.0 kW. These vessels operated primarily with multi-gear (96.0%) (Table 4).

The correspondence analysis (CA), performed using data on landings per month for fishing gear and coastal area, explained 96% of the variance in the first two axes (Fig. 3).

In the ordination diagram it can be seen that seabreams (SEAB) were landed mainly by the multi-gear fleet in the southwest during the March to July period, and in summer-autumn in the south; the trawl fleet also landed these species during September and October in the south. Small pelagic fishes (SPF) were mostly landed throughout the year by the trawl fleet along the coast and by the multi gear fleet in the summer in the north. Pleuronectiforme (PLEUR) and cephalopod (CEPH) landings were linked and were chiefly associated with the multi-gear fleet throughout the year in the north and south. In the southwest, these species were landed by trawl and multi-gear fleets in winter. The trawl fleet landed small pelagic fishes (SPF), pleuronectiformes (PLEUR) and cephalopods (CEPH) in winter in the north and in spring in the southwest and south; small pelagic fishes (SPF) and rays (RAYS) were landed during summer in the south. The multi-gear fleet landed pleuronectiformes (PLEUR), cephalopods (CEPH) and rays (RAYS) in September in the south.

3.2 LPUE modelling

Monthly flatfish LPUE (kg fishing trip^{-1} month^{-1}) and market price (€ kg^{-1}) are shown in Figure 4. The fishery

Table 3. Identification of three landing profiles in terms of species group composition for the flatfish fishery of the Portuguese coast. The most important species group of each profile is shown in bold (those representing a percentage of the total landings or of value >10%).

Species group	Landing Profile 1		Landing Profile 2		Landing Profile 3	
	% landing	% value	% landing	% value	% landing	% value
Anglerfish	1.1	1.3	3.2	5.2	1.3	1.8
Cephalopods	3.8	9.3	**21.0**	**23.6**	**20.3**	**18.5**
Octopus	3.7	8.9	**15.5**	**19.3**	**10.8**	**10.5**
Cuttlefish	0.1	0.4	5.5	4.3	9.5	8.0
Hake	2.5	9.7	6.2	8.6	4.6	5.3
Pleuronectiformes	2.7	5.3	**10.5**	**22.9**	**21.4**	**40.2**
Bastard sole	0.1	0.6	1.9	3.3	7.0	11.2
Brill	0.0	0.4	1.3	1.3	0.6	0.6
Flounder	0.3	0.4	1.6	1.9	0.8	0.4
Megrims	1.2	0.2	0.1	0.1	0.1	0.0
Soles	0.2	1.8	5.0	**14.5**	**11.3**	**25.1**
Spotted flounder	0.4	0.6	0.2	0.6	0.3	0.5
Turbot	0.1	0.5	0.3	1.2	0.6	1.9
Wedge sole	0.4	0.7	0.1	0.1	0.7	0.5
Rays	0.8	2.4	6.0	4.2	**10.3**	7.0
Seabreams	**10.1**	8.3	1.7	2.2	5.3	7.5
Small pelagic fishes	**29.3**	**29.2**	**18.9**	2.8	4.7	1.2
Others	**49.7**	**34.7**	**32.5**	**30.6**	32.1	**18.6**

Table 4. Mean values of the main characteristics of vessels assigned to each profile, resulting from the cluster analysis of the Portuguese flatfish fishery.

	Number of vessels	Hull material (%)			Length (m)	Gross tonnage (tonnes)	Engine power (HP)	Gear (%)		
		Fibre	Steel	Wood				Multi-gear	Puse-seine	Trawl
Landing profile 1	75	1.4	77.3	21.3	28.9 SD = 4.6	198 SD = 52	715 SD = 210	28.0	2.7	69.3
Landing profile 2	147	1.4	4.7	93.9	15.9 SD = 2.7	29 SD = 25	199 SD = 88	85.0	5.5	9.5
Landing profile 3	153	7.8	3.3	88. 9	10.7 SD = 2.5	9 SD = 6	94 SD = 43	96.1	3.2	0.7

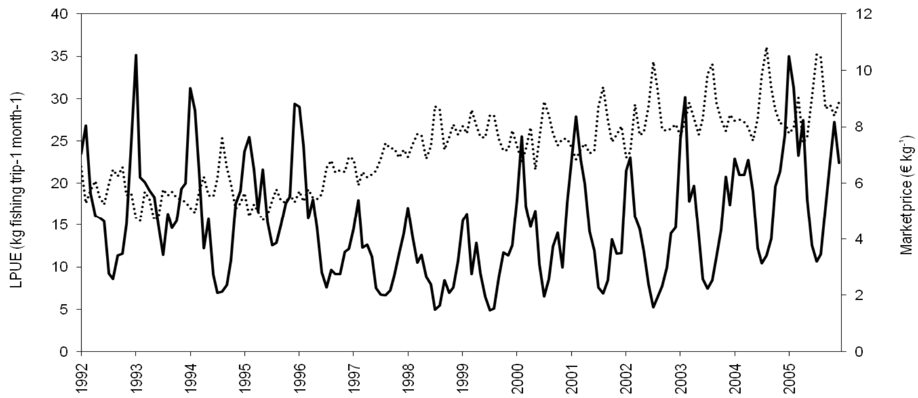


Fig. 4. Monthly LPUE (solid line) and market price of flatfishes (dashed line) between 1992 and 2005.

presented high seasonality, with higher LPUE values occurring in colder months (January and February) compared to summer (July), when the LPUE values were lower. The monthly price series (€ kg^{-1}) also showed high seasonal variation, but the highest prices were bid in the summer (August), and the lowest prices in the winter (January and February).

GLM explained between 60.2% and 14.8% of the variations in the LPUE, with landing port, vessel length, month and landing port:vessel length interactions being the most important explanatory variables (Table S1). When considered the landings in terms of value, GLM explained from 46.4% to 81.6%, with landing port, vessel length, total landing (kg) and landing port:vessel length interactions being the most important explanatory variables (Table S2).

All species or species group showed highly seasonal trends in LPUE.

For soles January and February were the months with highest landing values, July and August the months with the highest market price (Fig. 5a) and Leixões the most important landing port (Fig. 6).

Landing values of bastard sole were higher between November and March, the highest market price reached between June and August (Fig. 5b) and the most important landing port being Olhão (Fig. 6).

LPUE of flounder was high from January to February. The highest market price was registered in July to August (Fig. 5c), and Lisboa was the most important landing port (Fig. 6).

Spotted flounder showed values highest from March to September, the highest market price between October to April (Fig. 5d), and Olhão the most important landing port (Fig. 6).

LPUE of wedge sole was highest from October to January. The highest market prices were recorded from March to April (Fig. 5e), and Aveiro was the most important landing port (Fig. 6).

The LPUE of turbot showed highest values between March and May, the highest market price from July to August (Fig. 5f), and Figueira da Foz the most important landing port (Fig. 6).

LPUE of brill showed highest values between December and February, the highest market prices recorded between July to August (Fig. 5g), and Leixões the most important landing port (Fig. 6).

LPUE of megrims was highest values reached between January and March, the highest market price found from December to January (Fig. 5h), and the most important landing port being Aveiro (Fig. 6).

4 Discussion

The flatfish fisheries of the Portuguese coast are characterized by their multi-species and multi-gear nature. The fishing fleet that catch flatfish is mainly composed of small vessels with low gross tonnage and engine power, and about 70% of the boats were constructed more than 20 years ago. This fleet is similar to those of the small-scale fisheries operating in the Mediterranean (e.g. Jiménez et al. 2004; Tzanatos et al. 2005; Piniella et al. 2007), and very different to those in the North Sea, which are made up of recent and large beam trawlers with high engine power (Rijsndorp et al. 2006; Hoff and Frost 2008).

This study identified three landing profiles in the flatfish fishery, as landings of the target species of these métiers (small pelagic fishes, seabreams, cephalopods, pleuronectiformes and rays) showed variation in space and in time. The vessels had different exploitation patterns along the coast. The diversity of landing profiles on the Portuguese coast increased from north to south, and was similar between the southwest and south. These results are in agreement with the Sousa et al. (2005). The north-south biological discontinuity is a result not only of the physical discontinuity induced by the Nazaré canyon, but also of other factors like differences in shelf and coastal morphology, bathymetry, river runoff and ocean currents. The fishing in the north seems to be more organized, because the métiers appears more defined, contrasting with the southwest and south where the definition of the métiers is not marked. This greater diversity may reveal a greater "opportunism" in exploring métiers. Some species represent high proportions of the landings because are very abundant, but others, like flatfishes and cephalopods, are attractive to fishermen even if their landings are small, because of their high market price, and this leads to opportunistic fishing.

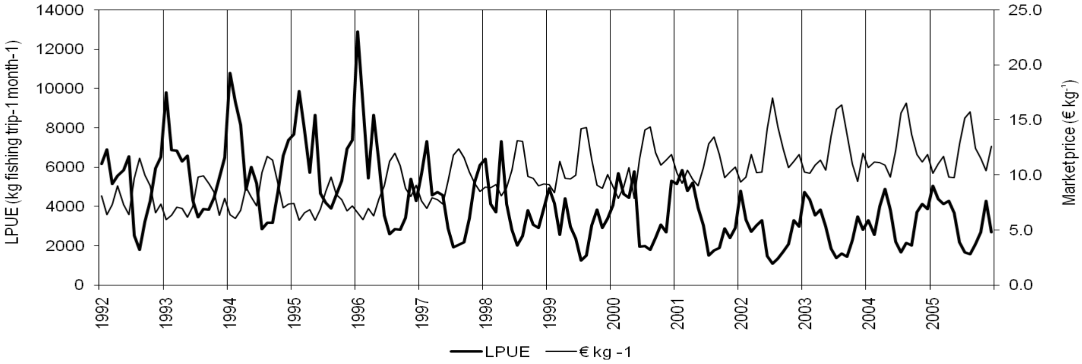
Variation in landings of the species can be explained by the great dynamism associated with this fleet, since fishing tactics change through the alternate use of different gears, depending on the abundance of species. The changing patterns of fishing tactics (fishing location, fishing gear or target species) is due to a variety of factors, including the weather conditions, knowledge of fishing grounds, seasonal availability of resources, market demand, recent fishing yield and income, tradition and information and rumours about the yields of other fishermen (Christensen and Raakjær 2006).

The hierarchical analysis showed that flatfish target species (soles, bastard sole, flounder, turbot and brill) were caught by wooden vessels operating with gill nets and trammel nets (multi-gear fleet cluster). These target species occur near the shores, typically in sandy and muddy grounds in the continental shelf, from 10 to 200 m deep (Nielsen 1986a, 1986b; Quéro et al. 1986) and were landed together with cephalopods (octopuses, cuttlefish) and rays. The small size of the vessels may limit the distances travelled to areas surrounding home ports, especially in winter when bad weather conditions occur more often. The limitations imposed by vessel size, in terms of mobility, lead to fishermen having in-depth knowledge of their fishing area and thus becoming the "area specialists", as outlined by Hilborn (1985) and Pet-Soede et al. (2001). The choice of switching target species between flatfishes and cephalopods when fishing with small vessels depends on the fishing area (Batista et al. 2009).

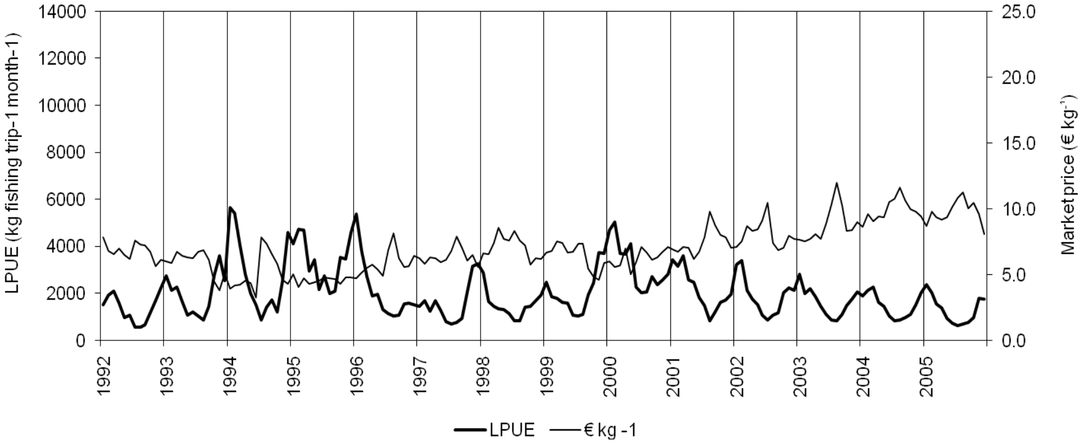
The large vessels with the highest gross tonnage and engine power, operating with trawl nets, landed megrims, spotted flounder, wedge sole, small pelagic fishes and seabreams. These flatfish species occur at depths between 300 and 800 m (Nielsen 1986a, 1986c; Quéro et al. 1986), and are mainly bycatch of this fleet cluster.

Flatfish market prices per weight vary inversely with landings: the selling price increases during summer due to the lower landings registered in this period and to the highest market demand related to tourism. Nevertheless, the increase in flatfish market prices during summer did not compensate the profit reduction caused by the reduction in landings, which differs from the situation reported for other flatfish fisheries (Wilde 2003). During summer, the more valuable flatfish species are sold directly to restaurants and local fish markets, promoting parallel markets and causing the underestimation of landings in this season. As a consequence, the official landings records are indeed underestimates of the catches of commercially important flatfish species.

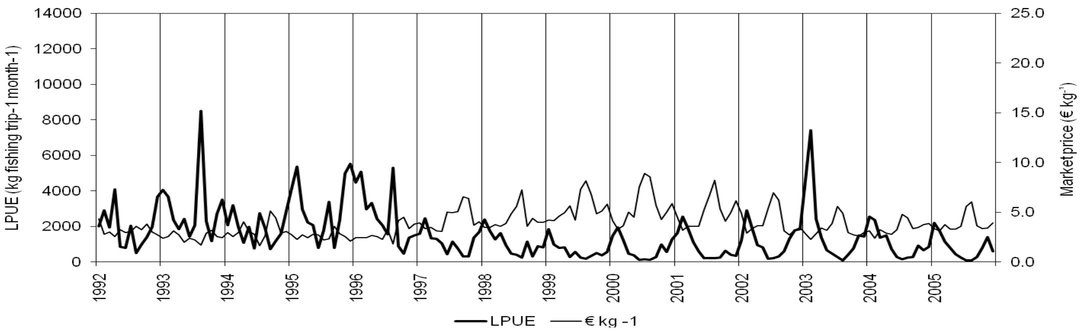
Among the predictors considered in the GLM for the majority of the flatfish species groups in this study, landing port, vessel length, month and landing port:vessel length interaction were the most important factors that had significant relationships with LPUE. The explanatory variables that best explained the variation of the value of landings were landing port,



(a)



(b)



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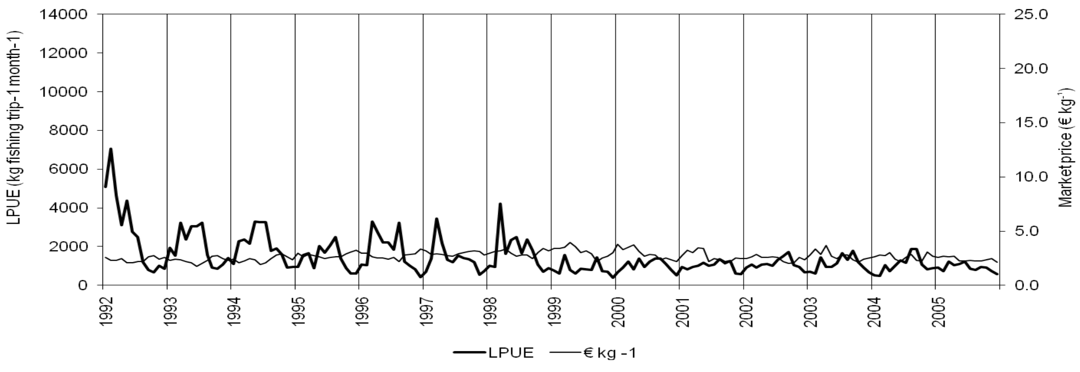

(d)

Fig. 5. Monthly average values of LPUE (kg fishing trip^{-1} month^{-1}) for (a) soles, (b) bastard sole, (c) flounder, (d) spotted flounder, (e) wedge sole, (f) turbot, (g) brill and (h) megrims.

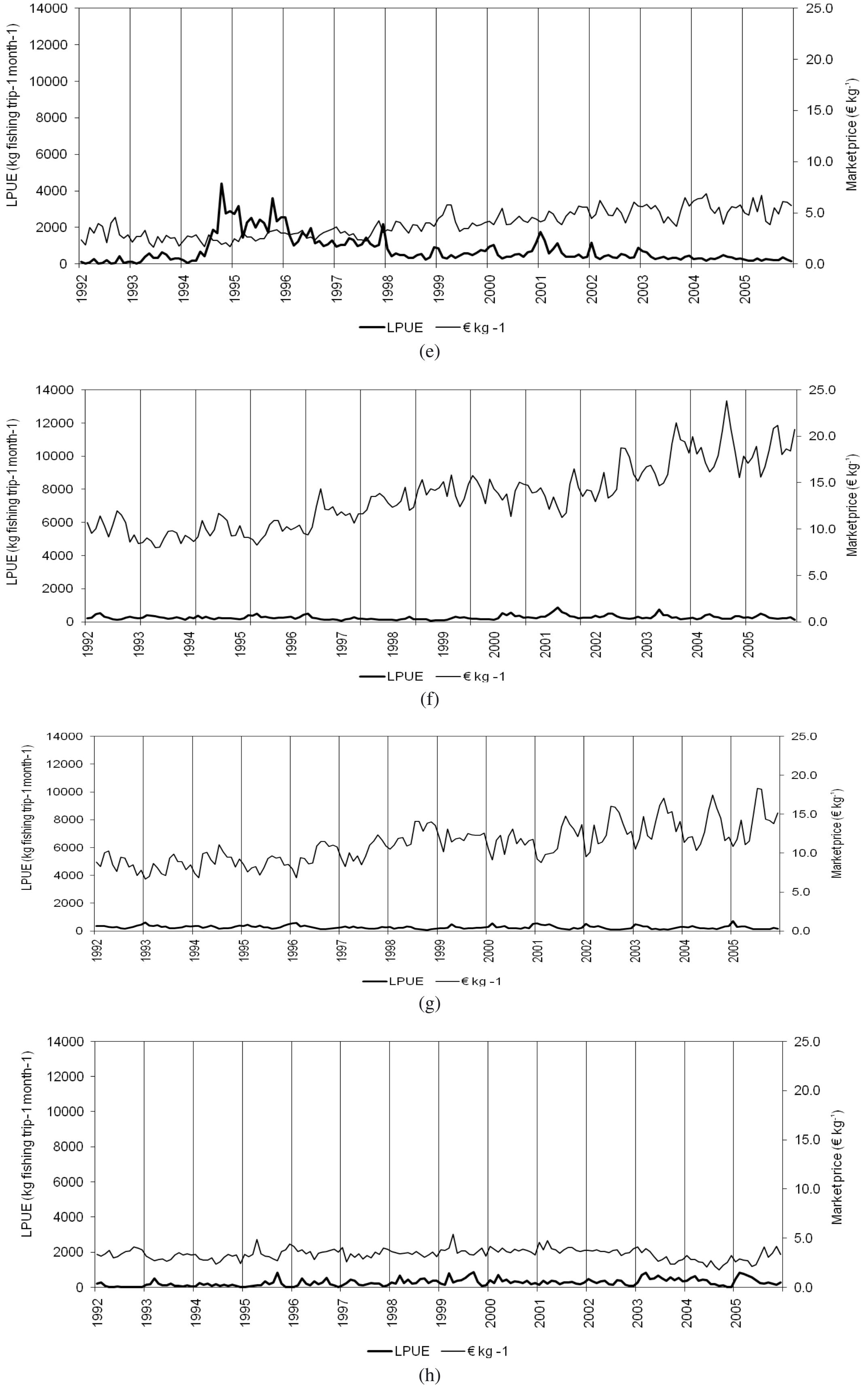

Fig. 5. Continued.

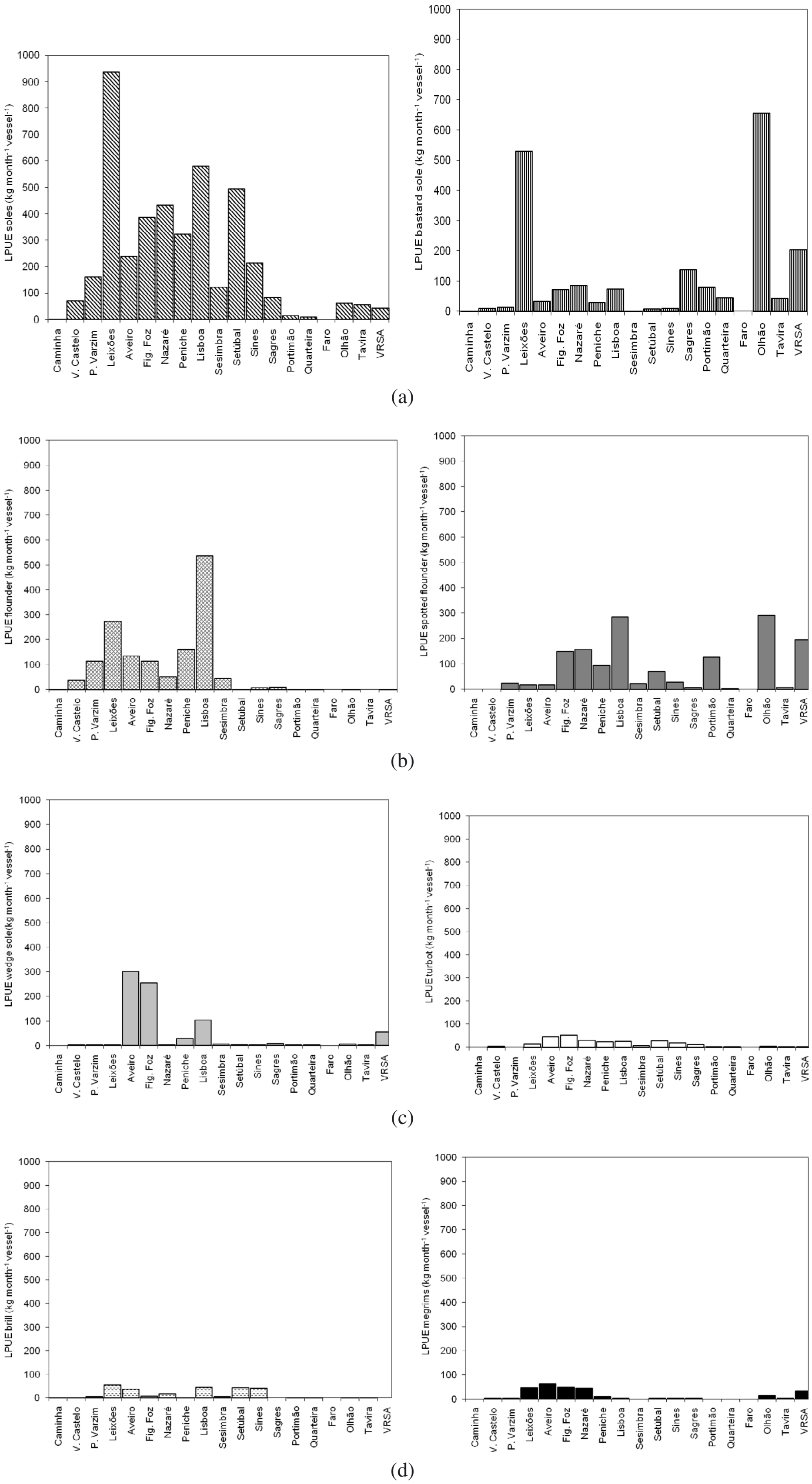

Fig. 6. Average values of flatfish LPUE (kg month^{-1} vessel^{-1}) in the main important landing ports on the Portuguese coast, between 1992 and 2005. (a) Soles and bastard sole, (b) flounder and spotted flounder, (c) wedge sole and turbot, (d) brill and megrims.

vessel length, total landing (kg) and landing port:vessel length interaction. This suggests that high space and time variability of the catches of these species and technical characteristics of the vessels also contribute to LPUE variability. The significance of landing port:vessel length interaction corroborates this conclusion, which could mean that the landing rate depends not only on the availability of the resource to the fishery but also on the importance that the technical characteristics of the vessels have for the success of the catch, which has also been outlined by several authors (e.g. Goñi et al. 1999; Ye et al. 2001; Maynou et al. 2003; Mahévas et al. 2004). The value of landings depends not only the high spatial and temporal variability of resources and the technical characteristics of the vessels, but also on the quantity of fish landed. The selling prices are determined also by the quantity landed, although most of these species reach high prices; the opposite result was obtained by Sanchez et al. (2004) for species with high economic value.

The exploitation patterns of flatfish species differed according to latitude: soles, wedge sole, megrims and turbot were caught in higher quantities in the north of Portugal; flounder and brill were mainly caught off the southwest Portuguese coast; and bastard sole and spotted flounder on the south coast. The location of some small fishing métiers can be confined to only a few or one fishing ports, although other métiers can have a wide distribution (Silva et al. 2002). The exploitation of certain species in different locations of their distribution area is related to the particular habitat, as well as to patterns of species migration. Also, several flatfish species have their northern or southern distribution limits along the Portuguese coast which may also explain these differences (Ekman 1953; Briggs 1974).

The large variability observed in LPUE of the flatfish species groups considered in this study suggests that resource abundance may also be extremely variable both seasonally and interannually. Teixeira and Cabral (2009) showed that these species were caught mainly during the spawning season, when they concentrate near the coast, which can also induce increase of LPUE values.

Several authors have studied the relationships between vessel characteristics and fishing power or fishing effort (e.g. Houghton 1977; Biseau 1991). Fishing effort depends not only on the vessel characteristics, but also on crew (Taylor and Prochaska 1985; Le Pape and Vigneaux 2001), gear technology and on-board equipment (Marchal et al. 2007).

Effective fisheries sustainable development requires a significant investment to collect the required information (FAO 1999; Garcia and Staples 2000). Scientific studies to sustain and improve management measures are scarce for Portuguese fisheries. Problems in the management of flatfish fisheries include the lack of assessment of resource abundance and the limitation of management measures to control net and mesh sizes, minimum fish size and TAC. This is of particular concern since there is evidence of flatfish stocks overexploitation: there are 16 flatfish stocks considered overfished in the ICES region and 9 in the NAFO area (Rice and Cooper 2003; Rijnsdorp et al. 2007). Some management measures are being applied in these areas, notably a recovery plan for sole in the Bay of Biscay (COM 2003). Following a precautionary approach, these measures should probably be expanded to adjoining areas, together with the development of management-oriented studies.

The results of the present study may have implications for fisheries management because the LPUE of some métiers are higher in the important periods of the life cycle of target species, particularly in the case of flatfishes that are landed in their spawning season (Teixeira and Cabral 2009; Andersen et al. 2010). This pattern has a negative impact on the stocks because of increased fishing pressure in a sensitive period for these species. The adoption of spatial and temporal closures should be implemented as the protection of estuarine systems and shallow coastal areas, which are used as nursery grounds by certain species (soles and flounder), would be extremely important to the recovery of overexploited stocks.

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Supplementary tables

Table S1. Results of the GLM per landings per unit effort (LPUE) flatfish groups (soles, bastard sole, flounder, spotted flounder, wedge sole, turbot, brill and megrims) from 1992 to 2005 on the Portuguese coast. Values of deviance for each factor, residual deviance and percentage of the total deviance explained by each factor (% Expl.) and *p*-value.

Table S2. Results of the GLM per landing value of flatfish groups (soles, bastard sole, flounder, spotted flounder, wedge sole, turbot, brill and megrims) from 1992 to 2005 on the Portuguese coast. Values of deviance for each factor, residual deviance and percentage of the total deviance explained by each factor (% Expl.) and *p*-value.

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