Segmentation and fishery characteristics of the mixed-species multi-gear Portuguese fleet

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Duarte, R., Azevedo, M., and Afonso-Dias, M. 2009. Segmentation and fishery characteristics of the mixed-species multi-gear Portuguese fleet. – ICES Journal of Marine Science, 66: 594–606.

Fleet segmentation and knowledge of fishing fleet dynamics are essential to move from single species to fishery/fleet-based advice. The coastal mixed-species multi-gear Portuguese fleet comprises medium-sized (>12 m) vessels, using a diversity of passive gears, and is economically important. For hake (under a recovery plan) and monkfish (overexploited), it contributes >50% to their total annual landings. Commercial daily landings in 2005 from 271 vessels were analysed by region using non-hierarchical cluster analysis and multivariate regression trees. The cluster analysis allowed the identification of regional fleet segments with a low mixture of species throughout the year. The multivariate regression trees were applied to clusters of vessels with a high mixture of species, to explain weekly landing profiles (species) by vessel technical characteristics, fishing license, and main landing port. The results showed a link between exploited species and geographic location, and in the north between vessel size and depth and an inshore/offshore range. Finally, from the analysis and for the most important species exploited by the Portuguese multi-gear fleet, it was possible to define two or three vessel groups that accounted for at least 50% of the landed value.

Keywords: fleet segmentation, mixed-fisheries management, multi-gear, multispecies, non-hierarchical cluster analysis, regression trees.

Received 7 April 2008; accepted 8 December 2008; advance access publication 19 February 2009.

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Introduction

Regulating fleet capacity and fishing activity and adjusting them to the level of sustainable exploitation of marine resources is a major objective of the Common Fisheries Policy (CEC, 2002). A clear understanding of fishing fleet dynamics is essential to reach this objective (ICES, 2003; Ulrich and Andersen, 2004), in particular knowledge of vessel activity in space and time and its relation to target and bycatch species (Biseau and Gondeaux, 1988). Also, understanding fishing fleet dynamics is crucial to changing from single species to fishery/fleet-based advice, and for fisheries management to take account of the mixed-species nature of fisheries and of ecosystem aspects (Vinther *et al.*, 2004). It has been recognized that single annual catch limits (total allowable catch, TAC) cannot alone control fishing mortality (Penas, 2007). If the quota for one stock is exhausted and fishing continues, it is impossible to avoid catches of that species because of the mixed-species nature of most fisheries. The consequences of such management strategies are an increase in discards (CEC, 2007; Suuronen and Sardà, 2007) and/or the increase in illegal commercial sales that have important impacts on both the ecosystem and the economy and may imply considerable costs related to monitoring and control.

An option is therefore to change fisheries management from output controls, e.g. limiting catch, to input controls, e.g. effort control (Shepherd, 2003). The reform of the Common Fisheries Policy points in this direction and defines effort control as an important tool in the context of recovery plans (Penas, 2007). However, input controls are difficult to implement in areas where knowledge of fleet characteristics and dynamics is limited (Murawski *et al.*, 1991). A first step is to undertake fleet segmentation, i.e. to split a fleet into vessel groups with similar characteristics, gear, dynamics, and activity, and to obtain knowledge of exploited areas. Technical measures can then be adapted, because the same solutions are not applicable in all regions (Suuronen and Sardà, 2007).

Most Portuguese non-pelagic fisheries are typically mixed fisheries that catch a wide variety of species, reflecting the biological diversity of the areas they exploit. Portuguese multi-gear fleets use a diversity of gears that allow exploitation of ecological communities in different habitat types, depths, and substrata. The composition of the landings depends largely on the fishing gear used and on the ecological community of the fishing grounds visited, which may change seasonally.

Studies on segmentation have been developed for the Portuguese trawl and small-scale fleets. Landing profiles and fleet components for the Portuguese trawl fleet were defined by Campos *et al.* (2007), who identified three fleet components directed at crustaceans, cephalopods, and a mixture of species where horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*) dominated. For the small-scale fleet, a research project developed for the Algarve defined 42 fishing trip types (constant between 1995 and 1997), with 20, 18, and 22 fleet components for 1995, 1996, and 1997, respectively (Afonso-Dias *et al.*, 1999). Studies of the Portuguese multi-gear fleet are lacking, and detailed information on the activities of this fleet is scarce despite its importance for demersal species such as hake (*Merluccius merluccius*) and anglerfish (*Lophius* spp.), for which it contributes >50% of annual landings.

Fleet segmentation has been traditionally performed by applying multivariate techniques to the species (variables) compositions of individual fishing trips (observations) to define fishing trip types (Lewy and Vinther, 1994; Afonso-Dias *et al*., 1999; Jabeur *et al*., 2000; Pelletier and Ferraris, 2000; Silva *et al*., 2002; Jiménez *et al*., 2004; Tzanatos *et al*., 2006). These fishing trip types may then be used as variables to define groups of vessels (Afonso-Dias *et al*., 1999; Silva *et al*., 2002; Campos *et al*., 2007).

In this study, an alternative method was applied, consisting of an initial global cluster analysis (data aggregated by year and groups of species), followed by the application of multivariate regression trees to vessels showing a high level of mixed landings. This two-step approach allowed a first screening, with identification of vessels showing regular and constant activity throughout the year. The second step concentrated on more complex vessels, with the regression tree having the advantage of finding patterns of vessels not only by using the landings profile but also by applying explanatory variables, such as vessel characteristics and gears licensed.

The objective of our study was to provide a segmentation of the Portuguese coastal multi-gear fleet that can be used to provide information for fish stock assessment and management. The definition of groups of vessels (fleet subsegments) with similar characteristics and similar activities during the year, indicating similar fishing regime and fishing strategy, is a major goal of our work. Also, the seasonality and vessel group specialization of the segments defined are analysed for sensitive species such as hake, currently under a recovery plan (CEC, 2005), and anglerfish, currently overexploited and affected indirectly by the hake recovery plan.

Material and methods

Fleet information

The Portuguese coastal multi-gear fleet is one of the four administrative vessel segments defined for the continental coast by the Portuguese General Directorate for Fisheries and Aquaculture (DGPA). It includes all vessels longer than 12 m with licenses for passive gears. The remaining three segments are the multi-gear small-scale fleet (vessels <12 m), the purse-seine fleet, and the trawl fleet. The coastal multi-gear fleet, hereafter designated as the multi-gear fleet, uses a wide variety of passive fishing gears, gill- and trammelnets, lines and hooks, traps, and pots. Because of its characteristics (larger dimensions and engine power), vessels from this fleet undertake longer fishing trips (≥2 d) than the small-scale fleet.

According to official statistics, the two multi-gear fleets (small scale and coastal) landed 41% by weight and 66% by value of all fish landed from the Portuguese continental shelf in 2005 (INE, 2006). Exploratory analysis of the DGPA data showed that in 2005 the coastal multi-gear fleet contributed 23% (by value) of the total annual landings, but for demersal species such as hake, anglerfish, and octopus (*Octopus vulgaris*), the percentage exceeded 50% of annual landings.

Data

Commercial daily landings for 2005, for each vessel belonging to the multi-gear fleet, were available from the Portuguese DGPA based on auction market records of vessel landings (logbook data were not available). Information included date, port of landing, and landings by species or groups of species in a higher taxa (e.g. genus or family), by weight (kg) and value (€). Information on the gear used was not available, but vessel characteristics (length, gross tonnage, engine power, year of construction) and fishing license information were available for that year.

In all, 307 vessels of the Portuguese multi-gear fleet registered landings in 2005. However, 36 (11.7%) of the vessels recorded few landings (<20 year^{-1}) during 2005 so were excluded from the analysis. The remaining 271 vessels landed 198 different species or taxa. All species were grouped by taxon (Mollusca: Bivalvia, Gastropoda, and Cephalopoda; Crustacea: Palinura and Brachyura; Vertebrata: Elasmobranchii and Teleostei). Fish species were also classified according to their habitat preferences (pelagic, bentho-pelagic, benthic) and depth/offshore occurrence (inshore, offshore, bathyal). Grouping and classification were performed according to Nelson (1994), Saldanha (1995), and Froese and Pauly (2007). Pelagic species were further subdivided into large and small species because they are taken by different gear (pelagic longlines and purse-seines, respectively). Table 1 is a summary of the groupings with the number of species in each group.

In 2005, landings were made at 28 fishing ports along the Portuguese continental coast. For this study, three main regions were considered (Figure 1): the north (from the Spanish border to Nazaré, 39°36'N), the southwest (from Nazaré to Cape São Vicente, 37°01'N), and the south (coast of Algarve, from Cape São Vicente to the border with Spain). These regions have different oceanographic conditions (Cunha, 2001) and different ecological communities and species assemblages (Sousa *et al*., 2005). The Nazaré limit corresponds to the Nazaré Canyon, a sharp physical discontinuity crossing the entire continental shelf, and at Cape São Vicente, the coastline changes from a north/south to an east/west orientation. Previous exploratory analysis of vessel preferences for the same port and region in 2005 showed that 48 and 86% of the vessels maintained, respectively, the same port and region. Moreover, vessels that changed region made at least 70% of their landed value in only one region. Therefore, it was assumed that exploitation took place in the same region as the landings. Vessels were split according to their main landing region, and analyses of landings data, fleet characteristics, and gear licenses were performed by region.

Analysis

As it is assumed that fisher behaviour is driven by profit, fleet segmentation analyses were based on value rather than weight, as recommended by the Study Group on the Development of Fishery-based Forecasts (ICES, 2003). This approach has been followed in other fleet segmentation analyses (e.g. Marchal, 2008).

Two methodological approaches were undertaken. First, for each vessel, the total annual landings by value were obtained by taxon and habitat group, and group proportions were calculated. A non-hierarchical clustering method, partitioning around medoids or PAM (Kaufman and Rousseeuw, 1990), was applied to group proportions to define clusters of vessels, using Euclidean distance to obtain dissimilarities between vessels. The final number of groups was determined by analysing the silhouette coefficient (s), calculated for observation i (annual landings per vessel) as the relative difference between the average dissimilarities from all members of the neighbouring cluster and those from all

Table 1. The number of species landed by the Portuguese multi-gear fleet in 2005 grouped by higher taxon and habitat preferences.

Taxon	Common name	Habitat	Depth classification	Abbreviation	Number of species
Mollusca					
Bivalvia	Scallops, clams, oysters, and mussels	–	–	Mol. bivalvia	8
Gastropoda	Snails and slugs	–	–	Mol. gastropoda	3
Cephalopoda	Octopuses, squids, and cuttlefish	–	–	Mol. cephalopoda	6
Mollusca unspecified					1
Total					18
Arthropoda					
Palinura	Spiny and slipper lobsters	–	–	Crust. Lobsters	7
Brachyura	Crabs	–	–	Crust. Crabs	4
Arthropoda unspecified					1
Total					12
Elasmobranchii	Sharks and rays	Bentho-pelagic	Inshore	Elasm. benthopel. in.	1
			Offshore	Elasm. benthopel. off.	4
			Bathyal	Elasm. benthopel. bat.	10
		Benthic	Offshore	Elasm. benthic off.	6
		Pelagic	Offshore	Elasm. pel. off.	5
Elasmobranchii unspecified					1
Total					27
Teleostei	Teleost fish	Benthic	Inshore	Tel. ben. ins.	8
			Offshore	Tel. ben. off.	14
			Bathyal	Tel. ben. bat.	3
		Bentho-pelagic	Inshore	Tel. benthopel. ins.	11
			Offshore	Tel. benthopel. off.	55
			Bathyal	Tel. benthopel. bat.	11
		Large pelagic	Offshore	Tel. pel. Large.	12
		Small pelagic	Offshore	Tel. pel. Small	15
Teleostei unspecified or diadromous					12
Total					141
Total all taxa					198

other members of the same cluster:

$$s_i = \frac{\min\{d(i,C)\} - d(i,A)}{\max[d(i,A), \min\{d(i,C)\}]}, \tag{1}$$

where $d(i, A)$ is the average within-cluster dissimilarity, and $\min\{d(i, C)\}$ with $C \neq A$ is the average dissimilarity of i from all objects of the nearest neighbouring cluster (cluster showing the lowest average distance to object i, excluding cluster A).

The s_i coefficient has values between 0 (no structure) and 1 (strong structure). The average s_i for each cluster reflects its consistency, and the average across clusters reflects the consistency of the overall cluster structure. The final number of clusters was defined based on the highest overall average s_i. According to Kaufman and Rousseeuw (1990), an overall s_i coefficient of <0.25 indicates the absence of any structure and a value >0.7 a strong structure.

The second approach consisted of a more detailed analysis of clusters with no structure (average $s_i < 0.25$) or substantial mixture of species. The objective was to define clusters of vessels by considering not only species landing composition but also vessel characteristics (fishing gear used and vessel length) and the main port of landing. As information on the gear used for each landing was not available, all fishing gears licensed for each vessel were considered. A multivariate regression tree (Breiman *et al.*, 1984; De'ath, 2002) was fitted to the daily landings by species. The explanatory variables were gear licenses (binary), vessel length (continuous), and main landing port (categorical). As length is correlated with vessel gross tonnage and engine power (Pearson correlation coefficients of 0.807 and 0.805, respectively), those variables were not used in the analysis. The main landing port was established for each vessel based on the total landed annual value. It reflects spatial information on the vessel's activity, and possibly also target species.

Multivariate regression trees explain the variation in a multivariate numeric response using explanatory variables that can be numerical and/or categorical (Breiman *et al.*, 1984; De'ath, 2002). The tree structure grows starting with all data in a single node at the top of the tree and by splitting observations successively into two groups by selecting the explanatory variable that maximizes the homogeneity of the resulting two groups (minimizing the total variance). The terminal nodes represent the final groups. The "one standard error" stopping rule (Breiman *et al.*,

1984) was used to define the optimum tree. According to that rule, the selected tree is the smallest tree with an estimated prediction error no greater than that of the tree with the minimum estimated prediction error plus one standard error.

To characterize leaf nodes, the Dufrêne and Legendre (1997) indicator species index was used to find the most important species in each node. This index takes into account the distribution of abundance between different habitats and the frequency of occurrence in different sites of the same habitat. In this way, it is possible to distinguish species occurring in only one habitat but at a limited number of sites (rare species) from species also occurring in only one habitat, but at the majority of sites (true indicator species). Here, sites correspond to daily landings in a particular vessel group, and clusters to vessel groups.

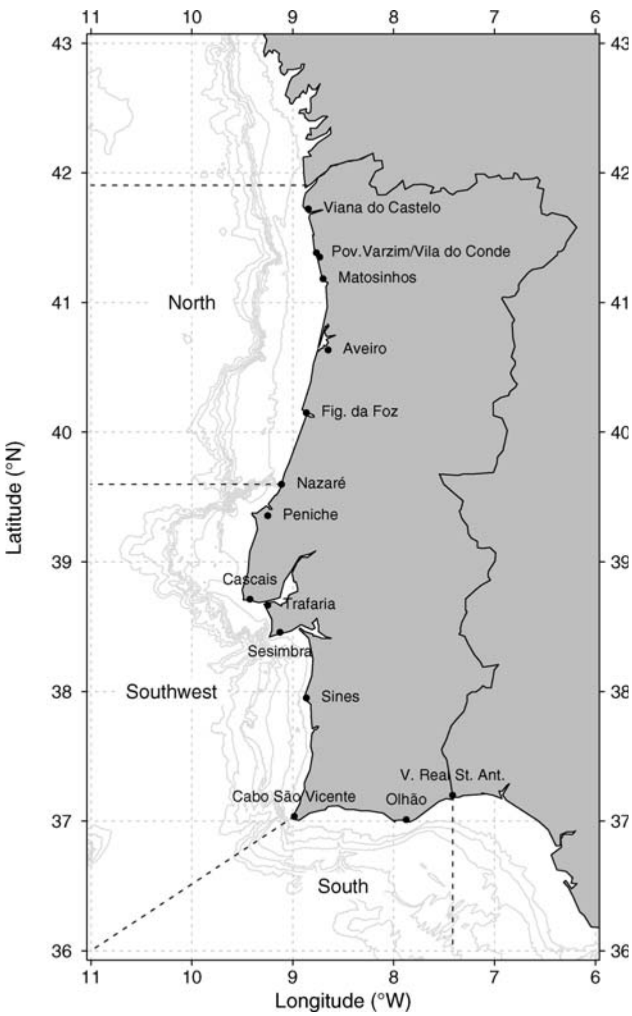

Figure 1. The Portuguese continental coast showing the main landing ports and the geographic regions identified here.

The index of indicator species i in vessel group j (I_{ij}) is calculated as

$$I_{ij} = 100 \frac{N_{ij}}{\sum_j N_{ij}} \frac{n_{ij}}{n_j}, \qquad (2)$$

where N_{ij} is the mean number of individuals of species i landed per vessel in vessel group j in 2005, n_{ij} the number of days for vessel group j for which species i was present in the landings, and n_j the total number of landings for vessel group j. Equation (2) expresses both the degree of species specialization of vessel groups and the species fidelity of vessel groups across time (days).

The proportion by value of each species in the daily landings reflects their importance. This proportion by value was discretized by groups of 10%. Then, the landed weight was summed across days by percentage groups in value (starting from 0%) and divided by the total annual landed weight of the species and vessel group. In this manner, it is possible to assess which species is most important in the total annual landings. Specialized groups will show most landed weight accumulated in daily landings that have a greater proportion of a given species. The seasonality of landings was analysed by vessel group, using cumulative daily landings relative to the total annual value. This more detailed analysis on specialization and seasonality was performed for monkfish (*Lophius piscatorius* and *Lophius budegassa*) and hake.

Computations were performed using the R statistical language (R Development Core Team, 2007). Cluster analysis was performed using R package *cluster* (Maechler *et al.*, 2005), and the multivariate regression trees were fitted using R package *mvpart* (De'ath, 2007).

Results

Characterization of the multi-gear fleet

In 2005, vessel length, gross tonnage, and engine power of the multi-gear fleet decreased from north to south Portugal (Table 2). On average, vessels were larger, newer, and had more powerful engines in the north, and smaller, less powerful, and older in the south.

In all, 22 fishing gear licenses were used by the multi-gear fleet in 2005. The mean number of fishing gears per vessel was ~4 in all three regions (range 1–8). Set bottom longlines for demersal fish were licensed for almost all vessels. Other important fishing gears were the set trammelnets with 100 mm mesh in the north and southwest regions, and baited pots of 30–50 mm mesh in the south region (Figure 2).

More than 140 species were landed in 2005 in the three regions, with the highest value (for 171 species) in the southwest region (Table 3). However, the number of species that accounted for 95% of the landed value by region was much lower, between 30 and 38. The number of single species landings increased from north to south; in the latter, they represented ~35% of the total number of landings (Table 3). Exploratory analysis showed that

Table 2. Mean technical characteristics of vessels by region (range in parenthesis) of Portuguese multi-gear vessels in 2005.

Region	Length (m)	Gross tonnage (t)	Engine power (kW)	Construction year
North	16.3 (12.2–22.1)	30.9 (11.3–63.8)	162.1 (72.0–276.0)	1994 (1955–2005)
Southwest	15.4 (12.0–24.5)	29.2 (7.8–93.0)	146.8 (69.9–327.0)	1991 (1942–2004)
South	14.5 (12.1–19.2)	21.5 (10.9–63.2)	109.6 (62.0–246.8)	1976 (1924–2003)

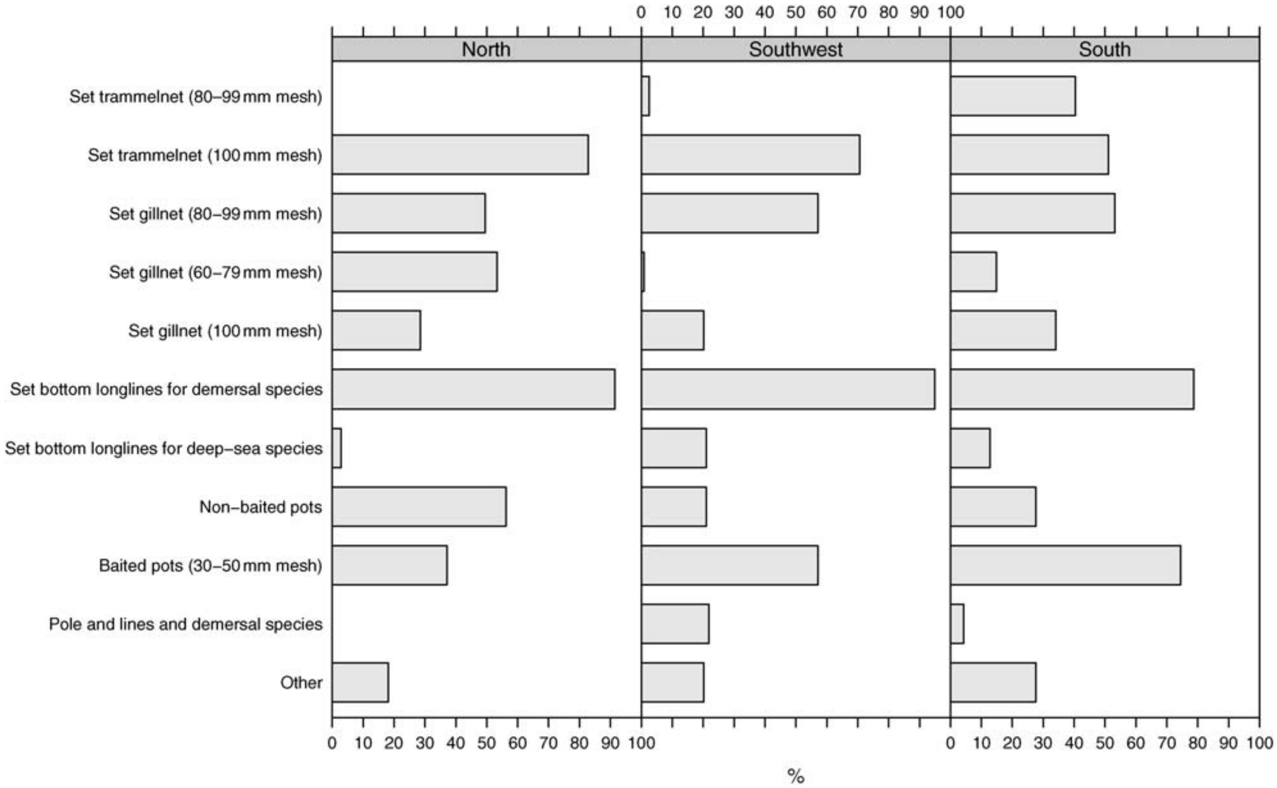

Figure 2. The percentages of vessels in the Portuguese multi-gear fleet with fishing licenses for different gears by region in 2005: north (98 vessels), southwest (119 vessels), south (45 vessels). Mesh sizes (mm) are indicated for trammelnets, gillnets, and baited pots.

Table 3. Summary information by region of Portuguese multi-gear landings, in 2005.

Parameter	North	Southwest	South	Total
Number of vessels (with numbers of landings ≤20 in 2005)	10	23	3	36
Number of vessels (with numbers of landings >20 in 2005)	105	119	47	271
Total number of landings	14 095	15 590	6 938	36 623
Number of species landed	143	171	147	198
Number of species making up 95% of the landings value	30	38	34	44
Percentage of single species landings	9	13	35	16
Mean number of landings by vessel (range)	134 (32–207)	131 (21–215)	148 (21–241)	135 (21–241)
Mean number of species by landing (range)	7.6 (1–28)	6.2 (1–34)	5.6 (1–33)	7.0 (1–34)
Most important species (% value)	*O. vulgaris* (20.1)	*A. carbo* (21.1)	*O. vulgaris* (31.2)	*O. vulgaris* (14.6)
	T. luscus (13.3)	*O. vulgaris* (8.1)	*P. americanus* (10.4)	*A. carbo* (12.5)
	Solea spp. (8.2)	*Solea* spp. (7.2)	*Microchirus* spp. (9.8)	*M. merluccius* (7.3)
	M. merluccius (8.0)	*M. merluccius* (6.8)	*M. merluccius* (8.1)	*Solea* spp. (6.9)
	S. solida (6.3)	*Lophius* spp. (4.4)	*Sepia officinalis* (3.5)	*Lophius* spp. (4.6)
	Other (44.1)	Other (52.4)	Other (37.0)	Other (54.1)

O. vulgaris was important as a single species landed in all regions, but that its importance increased sharply from north to south.

Apart from *Solea* spp., which was the third most important species in both north and southwest, the relative importance of other species differed between regions. The average number of species in daily landings was higher in the north (7.6) than in the southwest (6.2) and south (5.6).

Cluster analysis

According to the silhouette coefficient (s_i), the total number of clusters (vessel groups) obtained from cluster analysis was two in the north, two or six in the southwest, and three in the south (Figure 3). In the southwest region, identification of two clusters resulted in most vessels being in a mixed cluster (with no species group clearly dominating), whereas for six clusters, most vessels were included in five clusters, where 1–3 species accounted for at least 50% of the landed value. The average silhouette was above the threshold value of 0.25, below which there is no substantial structure (Kaufman and Rousseeuw, 1990), for five of the six clusters (Table 4). The remaining cluster (SW3) showed high species mixing and a low average s_i (0.07). Therefore, six clusters were considered in the southwest region. In the north, the two defined clusters included vessels landing almost exclusively the bivalve *Spisula solida* (N2, average $s_i = 1.00$), and vessels landing a mixture of different species and groups of species (N1, $s_i = 0.62$; Table 4).

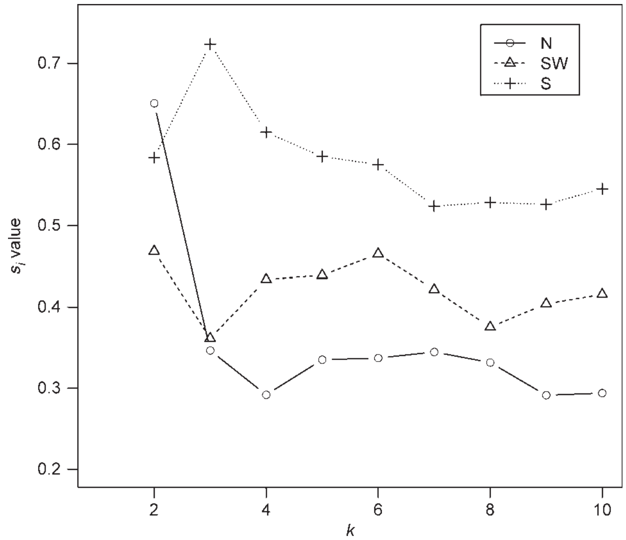

Figure 3. Silhouette coefficients s_i for cluster analysis of daily landings by the Portuguese multi-gear fleet in 2005, by region.

In southwest region landings (Table 4), the most representative species or group of species were: Cluster SW1 ($s_i = 0.37$), bentho-pelagic teleost fish (mostly *M. merluccius* and *Polyprion americanus*), and benthic bathyal teleosts (*Lophius* spp.); SW2 ($s_i = 0.51$), inshore benthic teleosts (predominantly *Solea* spp.), benthic elasmobranchs (*Raja* spp.) and cephalopods; SW3 ($s_i = 0.07$), a mixture of fish and cephalopods; SW4 ($s_i = 0.63$), cephalopods, with *O. vulgaris* reaching 81% of the annual proportion; SW5 ($s_i = 1.00$), bivalve cluster with species of the family Solenidae being the most important; SW6 ($s_i = 0.89$), the bathyal bentho-pelagic teleost *Aphanopus carbo* (75.5%) and bentho-pelagic elasmobranchs.

In the south (Table 4), the three defined clusters all had s_i coefficients >0.5, revealing reasonable to strong structure. S1 is a cephalopod cluster ($s_i = 0.87$), with *O. vulgaris* reaching 93% of the annual proportion, S2 is a bivalve cluster ($s_i = 0.99$), with *Chamelea gallina* as the most important species, and S3 has a mixture of species and species groups ($s_i = 0.56$), with no *O. vulgaris*.

Regression tree analysis for vessels with a high mixture of species

The regression tree analysis was performed on the three clusters that showed a high mixture and overlap of species between groups: N1, SW3, and S3. Owing to a lack of information on gear licenses, nine vessels in the north, one in the southwest, and two in the south were excluded from the analysis. To reduce the inherent noise, daily landings were summed to weekly landings and it was assumed that fishing strategy and regime were constant during each week.

When delimiting the trees by the rule of one standard error, the number of splits were 11 in the north (21% of variance explained), 8 in the southwest (26% explained), and 8 in the south (36% explained). However, these trees were difficult to interpret because of the large number of splits and the few vessels in each terminal node. The final trees were therefore also limited to the number of splits required to maintain at least five vessels in each terminal node (five vessels represent ~20% of the total number of vessels in the southwest and south), leading to three splits in the north, one in the southwest, and two in the south (Figure 4, Table 5). The explained relative error decreased in all regions to 10% in the north, 4% in the southwest, and 16% in the south, although some species clearly dominated the landed value for each terminal leaf node (Figure 5) and helped to differentiate between leaf nodes. The main explanatory variables were vessel length (north and south), fishing gear, set gillnet of 100 mm mesh size (north), set bottom longline for deep-sea species (south), and landing port (north and southwest). The indicator species also facilitated the segregation of the vessel clusters obtained (Table 5). The global pattern of vessels obtained from the analysis revealed four fishing patterns in the north, the first exploiting species such as *Lophius* spp., *M. merluccius*, and ommastrephids in deeper water, a second targeting *Raja* spp., a third characterized by *O. vulgaris*, and a last with *Trisopterus luscus*, *Solea* spp., and *O. vulgaris*. In the southwest, two patterns could be identified: one exploiting *Raja* spp. and *O. vulgaris* and the second exploiting *T. luscus* and also *O. vulgaris*. Finally, in the south, three patterns were identified: the first exploiting *P. americanus*, the second exploiting sparids, and the third exploiting *M. merluccius*. In the south, contrary to the other regions, *O. vulgaris* was not an indicator species.

Main species by vessel group

The proportion of landed value by vessel group (clusters and leaf nodes) for the most important species is presented in Table 6. For two species, *Microchirus* spp. and *O. vulgaris*, several vessel groups contributed to the landings, whereas for other species only one or two vessel groups were important contributors. For *A. carbo*, all landings came from the 18 vessels in cluster SW6, for *M. merluccius* 71% from 49 vessels (nN1, SW1, and nS3), for *Lophius* spp. 67% from 42 vessels (nN1 and SW1), for *P. americanus* 89% from 39 vessels (SW1 and nS1), for *T. luscus* 58% from 53 vessels (nN4), and for *Solea* spp. 77% of the landings came from 82 vessels (nN4 and SW2). The results show that a small number of all multi-gear vessels accounted for a large proportion of the total annual landings of the most important species. In addition, the nine species listed in Table 6 accounted for at least 50% of the landed value in all vessel groups.

Degree of specialization of vessel groups for *Lophius* spp. and *M. merluccius*

Vessels from group nS3 were highly specialized towards catching *M. merluccius* (Figure 6). For those vessels, landings where *M. merluccius* represented ~70% or more in value contributed >80% of

Table 4. Silhouette coefficient (s_i) and the number of vessels for each cluster of the Portuguese multi-gear fleet in 2005.

Parameter	North		Southwest						South		
Cluster	N1	N2	SW1	SW2	SW3	SW4	SW5	SW6	S1	S2	S3
s_i coefficient	0.62	1.00	0.37	0.51	0.07	0.63	1.00	0.89	0.87	0.99	0.56
Number of vessels	97	8	33	29	24	11	4	18	18	5	24

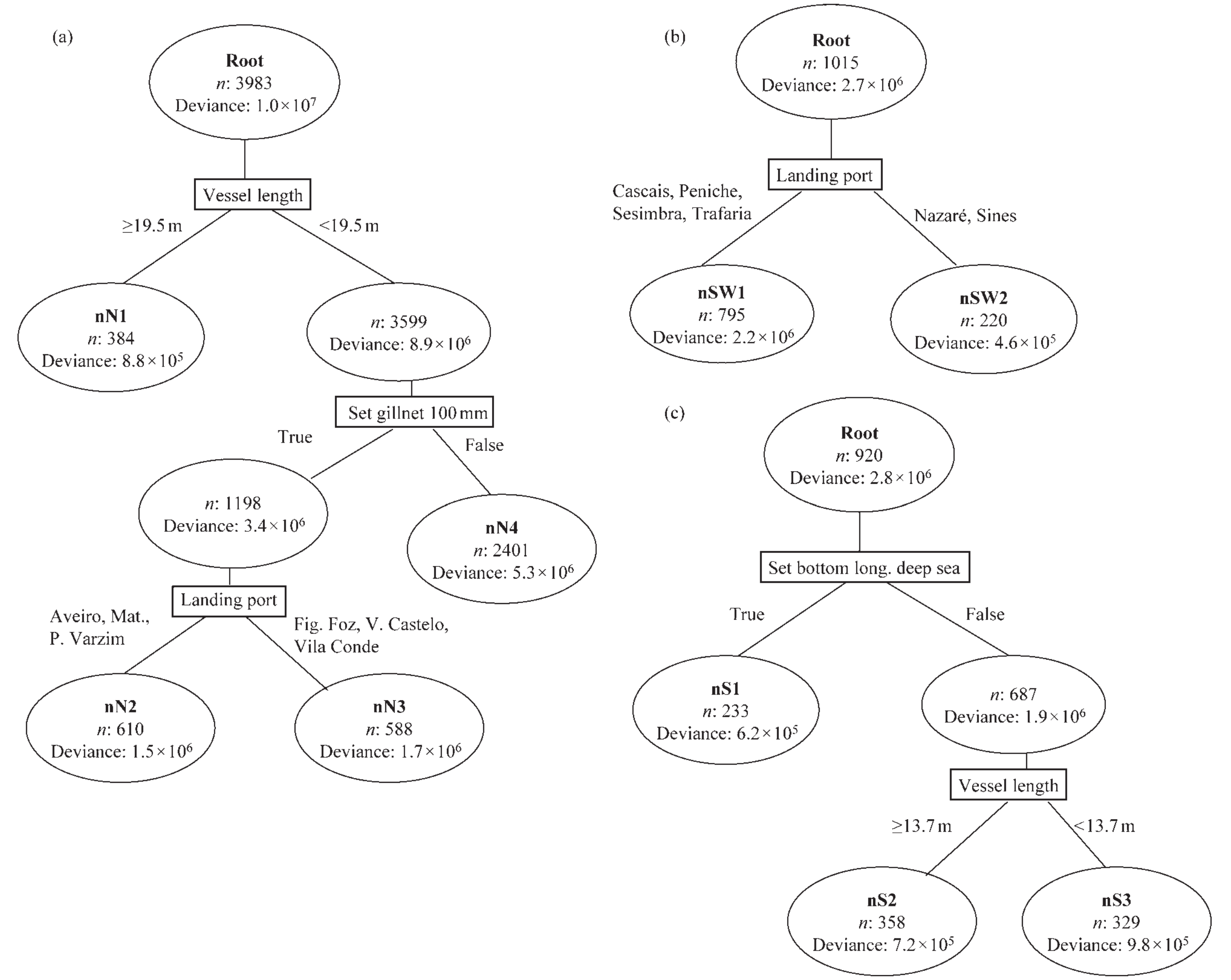

Figure 4. Portuguese multi-gear fleet in 2005. Regression tree for each region with number of landings (*n*) and the deviance in each split and leaf node.

the total landed weight of this species in that group. Vessels catching *Lophius* spp. were less specialized, with some 80% of the landed weight coming from trips where those species represented 50% or less. Comparing both species for the same groups, nN1 and SW1 were slightly more specialized for *Lophius* spp. than for *M. merluccius*, as can be seen from the shape of the curve. All remaining vessels summed as "other" showed no degree of specialization for either species.

The daily cumulative sum of landed values of *M. merluccius* indicated bigger landings between May and October for vessels of group nS3, and between July and October for vessels of group nN1, whereas vessels of SW1 did not show any seasonal pattern. For *Lophius* spp., landings in 2005 were TAC-constrained after August, and all vessel groups' landings increased at the beginning of the year and decreased towards August.

Discussion

The Portuguese multi-gear fleet is a typical mixed-species fleet, exploiting a great diversity of species, almost 200, but with only 44 species accounting for 95% of the total value landed in 2005. The overall average number of landed species by fishing trip was seven. For comparison, a total of 121 species was identified by Pelletier and Ferraris (2000) in the small-scale Senegalese fishery, and 102 in the small-scale fishery of the Mediterranean Patraikos Gulf (Greece), with an average of nine species per fishing operation (Tzanatos *et al.*, 2006). The passive fishing gears used by the Portuguese multi-gear fleet can be selective depending on characteristics such as mesh size, season, region, or depth (e.g. clay pots: *O. vulgaris*; gill- and/or trammelnets; *T. luscus*, *M. merluccius*, *Solea* spp., *Microchirus* spp., *Lophius* spp.; longline: *A. carbo*, elasmobranchs). In some cases, the mixed nature of the fishery is a consequence of the simultaneous use of two or more fishing gears in different geographic areas and depths, a feature very important when implementing management measures that control fishery inputs (e.g. fishing effort control).

In our study, a two-step approach for fleet segmentation was followed, first by carrying out a non-hierarchical cluster analysis including all multi-gear vessels, and second by applying multivariate regression trees to groups of vessels showing a greater mix of species. The reduction of total variance in the regression tree analysis was relatively low as a consequence of heavy mixing and overlap of species between vessels, and also because the tree

Table 5. Summary information from the multivariate regression tree analysis for weekly landings of the Portuguese multi-gear vessel clusters with a broad species mixing in 2005 by region.

Tree node	Number of vessels	Number of landings	Deviance	Indicator species (%)
North				
nN1	9	384	8.8×10^5	*M. merluccius* (52)
				Ommastrephidae (42)
				Lophius spp. (38)
				T. trachurus (37)
nN2	13	610	1.5×10^6	*Raja* spp. (30)
				Scophthalmus rhombus (20)
nN3	13	588	1.7×10^6	*O. vulgaris* (36)
nN4	53	2 401	5.3×10^6	*T. luscus* (42)
				Solea spp. (27)
				O. vulgaris (23)
				Pleuronectes platessa (23)
Southwest				
nSW1	18	795	2.2×10^6	*Raja* spp. (55)
				O. vulgaris (32)
				Solea spp. (31)
nSW2	5	220	4.6×10^5	*T. luscus* (78)
				O. vulgaris (50)
				Conger conger (48)
South				
nS1	6	233	6.2×10^5	*P. americanus* (61)
				Conger conger (48)
				Zeus faber (41)
nS2	9	358	7.2×10^5	*P. acarne* (57)
				T. luscus (53)
				Pagellus erythrinus (52)
				Microchirus spp. (48)
				Mullus spp. (43)
				Diplodus spp. (43)
nS3	7	329	9.8×10^5	*M. merluccius* (65)
				Solea spp. (50)
				Raja spp. (30)

Explained variance by region: 10% north, 4% southwest, 16% south. For each leaf node, the indicator species with indices $\geq$20% are given.

was limited by the number of final leaf nodes. Exploratory analysis with no limits on the number of leaf nodes yielded an explained variance close to values obtained in similar studies for land tree species composition (explained variance between 37 and 50%; Muster *et al*., 2007). Despite the minimal reduction in the variance, a segregation of vessels was obtained for each vessel group (leaf node), and it was possible to identify species contributing a large proportion to the landed value. Indicator species were also identified, characterizing the vessel groups, and distinguishing between them.

The multivariate regression tree uses vessel characteristics as explanatory variables to help in the vessel segregation and in gaining understanding of the segmentation strategy. A link was hence established between these explanatory variables and the landings profiles of the grouped vessels. Some cause–effect relationships could be identified, namely larger vessels exploited deeper resources (hake and monkfish) on the continental shelf, whereas smaller vessels exploited more coastal species, such as *O. vulgaris*, *Solea* spp., and *T. luscus*. The greater autonomy of the larger vessels and their higher engine power (correlated with overall length) allowed them to undertake longer trips to the edge of the continental shelf and the slope. Other identified links related to the exploitation of some species to particular gears and to certain landing ports, possibly related to commercial issues. Additional information has also been used in earlier vessel segmentation studies and was found to be essential (ICES, 2003; Ulrich and Andersen, 2004).

The combination of methods used in the present study seemed to be satisfactory and precluded us from defining fishing trip types. Exploratory analyses not included here were performed to verify the consistency of possible fishing trip types for the Portuguese fleet; clustering methods were applied directly to species landings profiles. Results were poor, however, and the resulting trip types were mainly defined by a single species with the remaining species having a variable and noisy presence. Fishing trip types were defined for the main species only, and different trips for the same species could not be established. Vessel aggregation based on fishing trip types only was unreliable because of crucial discrepancies within the same vessel group in terms of landed species and vessel characteristics.

The species index adopted to characterize groups of vessels here was proposed by Dufrêne and Legendre (1997) for habitat classification. However, application of the method to classify and characterize groups of vessels seems appropriate and straightforward, because it is important to describe the species essentially landed by a certain group of vessels and to determine whether

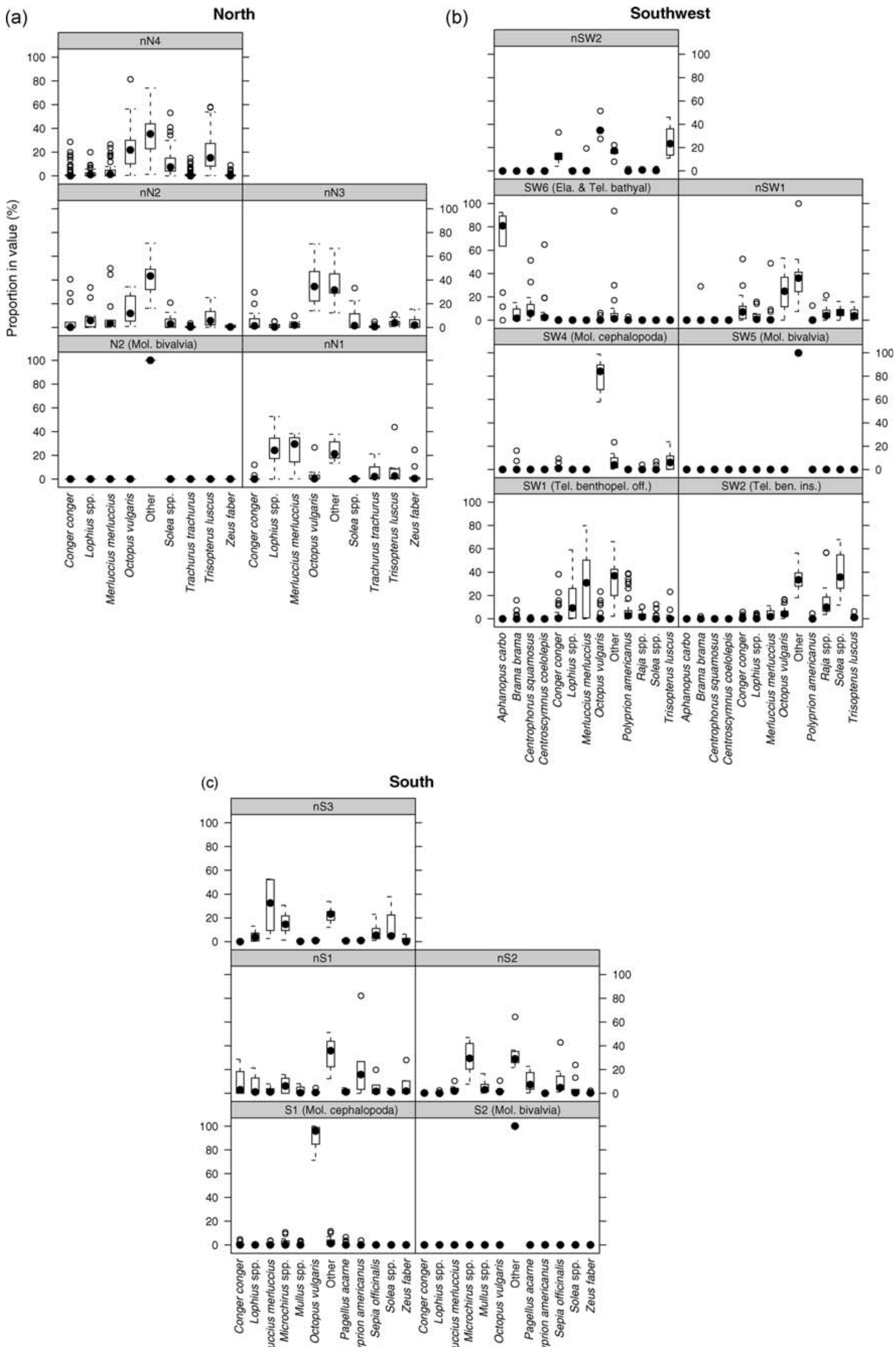

Figure 5. Box-plots of the proportion of the landed value of the most important species, by vessel cluster and region, for the Portuguese multi-gear fleet in 2005 (point, median; box, interquartile range; whisker, most extreme value within 1.5 times the interquartile range).

Table 6. The proportion of the main species landed value by vessel cluster and regression tree node for the Portuguese multi-gear fleet in 2005, and the total proportion of the listed species within each cluster and leaf node.

	North				Southwest						South					
Species	**Node nN1**	**Node nN2**	**Node nN3**	**Node nN4**	**Cluster SW1**	**Cluster SW2**	**Cluster SW4**	**Cluster SW6**	**Node nSW1**	**Node nSW2**	**Cluster S1**	**Node nS1**	**Node nS2**	**Node nS3**	**Other vessels**	**Total**
Number of vessels	9	13	13	53	33	29	11	18	18	5	18	6	9	7	65	–
A. carbo	–	–	–	–	–	–	–	***100.0***	–	–	–	–	–	–	+	100
Lophius spp.	***15.5***	4.9	1.0	7.3	***51.6***	2.0	+	–	3.2	+	–	6.0	+	3.5	4.4	100
M. merluccius	9.4	4.8	1.2	8.1	***48.3***	5.0	+	+	1.5	+	+	1.3	+	***12.9***	5.8	100
Microchirus spp.	1.4	+	+	3.7	3.3	***11.7***	+	+	3.4	–	4.1	***12.3***	***32.7***	***17.5***	9.4	100
O. vulgaris	+	3.5	9.4	***21.1***	1.7	4.0	***17.4***	+	6.9	2.7	***30.5***	+	+	+	1.1	100
P. americanus	+	+	+	+	***48.5***	+	+	1.3	+	+	+	***40.2***	+	+	6.2	100
Sepia officinalis	+	7.5	1.8	***20.6***	1.5	***30.0***	1.1	–	2.1	+	+	6.7	***14.7***	***10.2***	2.7	100
Solea spp.	+	2.5	6.0	***21.7***	2.0	***55.1***	+	–	4.4	+	+	+	+	4.6	1.6	100
T. luscus	4.6	6.9	3.1	***58.4***	2.0	4.0	3.9	+	4.9	6.9	+	+	1.6	+	2.6	100
Intra-vessel group proportion of the listed species (%)	71	66	70	56	63	68	91	76	64	83	96	75	54	59	–	–

Clusters representing <1% for all the species listed are not presented. This was the case for the bivalve clusters (N2, SW5, and S2). Other vessels, vessels excluded from the analysis because they had <20 annual landings or a lack of information on fishing gear licenses; +, values <1%. Emboldened, italicized values are those >10%.

those species occur in the majority or in a limited number of landings of that group. In this way, it was possible to assess the consistency of vessel groups. Our results also showed that the most valuable species for some groups of vessels were not the most important indicator species for that group. This happened when the most valuable species were also commonly exploited by other groups of vessels and were therefore not indicative (e.g. *O. vulgaris* in nN4 is one of the two most important species, but it is only the third indicator species with a relatively low index value). In such cases, indicator species might have lesser importance in terms of landed value, but they still reflect the type of exploitation characteristic for that group of vessels.

The study has shown that certain clusters of vessels targeted mainly one species or group of species during a year, maintaining a consistent strategy (e.g. vessels landing exclusively cephalopods, bivalves, or deep-sea teleosts and elasmobranchs). Such behaviour was clearly a selected strategy because vessels had fishing licenses for a range of gears. As a globally identified pattern, five vessel groups in the southwest were isolated by the cluster analysis that showed lesser mixing of species throughout the year. In the north and south, only one and two vessel groups, respectively, showed this consistency. This might indicate greater exploitation consistency throughout the year by southwest vessels.

There are, however, vessels that changed their target species during the year and/or that used more than one fishing gear in different depths and areas. The decision on target species and gear, area, and depth depends on a multitude of factors, including recent yield patterns and the income earned from a particular species (income also depends on market demand and might be seasonal), information from other fishers, knowledge of fishing grounds, availability of resources (which might also be seasonal), weather conditions, distance to fishing grounds, and cultural/traditional aspects and fisheries management measures (Christensen and Raakjær, 2006). The global pattern for vessels with a greater mix of species shows four patterns in the north, one exploiting species in deeper waters, and the others exploiting more coastal species, with *O. vulgaris*, *T. luscus*, *Raja* spp., and *Solea* spp. being present but at different levels of relative importance. In the southwest, two patterns were identified, also with *O. vulgaris* present, but with either *Raja* spp. or *T. luscus*. Finally, in the south, three patterns were distinguished, one exploiting deeper species, a second exploiting sparids, and a third exploiting *M. merluccius*.

Octopus vulgaris was the most common and widely exploited species of the Portuguese multi-gear fleet in 2005. There were, however, distinct exploitation patterns along the coast. In the south, vessels exploiting *O. vulgaris* had few other species throughout the year and exploitation essentially focused on that species. These vessels formed a distinct group in the cluster analysis, whereas the mixed-species vessels in the south had very low or marginal landings of *O. vulgaris*. In the north and southwest, vessels exploiting *O. vulgaris* tended to mix the catches with other species. This pattern might be the consequence of a traditional fishery operating with pots in the south that progressively extended to the southwest and north (J. Pereira, L-IPIMAR, pers. comm.). The importance of the other species varied by region. For the whole Portuguese coast, *A. carbo*, *M. merluccius*, *Solea* spp., and *Lophius* spp. followed *O. vulgaris* in importance, and all five species accounted for 46% of the landed value in 2005, although there were clear regional differences.

In our study, *T. luscus* was deemed to be an indicator species in the north and southwest and *Pagellus acarne* an indicator species

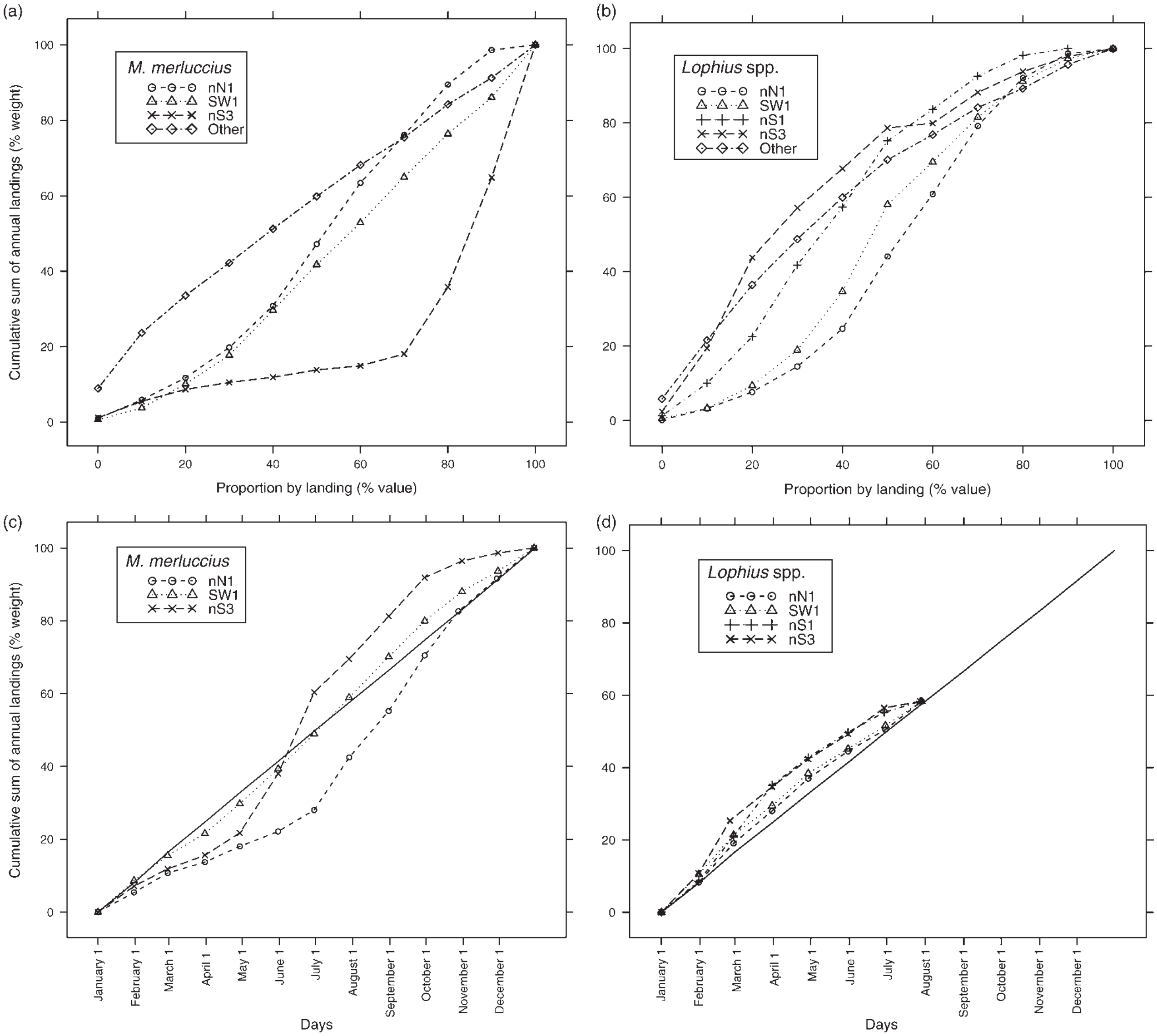

Figure 6. Analysis of specialization and seasonality of *Lophius* spp. and *M. merluccius* landings for the most important vessel groups of the Portuguese multi-gear fleet in 2005. Specialization of vessel groups for (a) *M. merluccius* and (b) *Lophius* spp., with the cumulative relative landings (by weight) plotted against the proportion (by value) in the daily landings. Seasonality of vessel groups for (c) *M. merluccius* and (d) *Lophius* spp., with the cumulative relative landings (by weight) by day.

in the south. Gomes *et al.* (2001), analysing survey data between 1985 and 1988, and Sousa *et al.* (2005), using an 11-year survey time-series (1989-1999), identified spatial patterns of groundfish assemblages along the Portuguese continental shelf. Both studies identified shallow, intermediate, and deep assemblages and two geographic areas, the north and the south (the latitude of the Nazaré Canyon formed the boundary). The shallow assemblage included *T. luscus* as a characteristic species in the north, but its relative proportion decreased significantly to the south, whereas the importance of sparids increased (especially *P. acarne*). This pattern was reflected in the regional importance of the species being exploited.

The results of this study should provide value to management of the Portuguese multi-gear fleet. Species with a broad distribution of landings through several groups of vessels are more difficult to manage, because most vessels would be affected by a management measure. From the present analysis and for the most important species exploited by the Portuguese multi-gear fleet, it was possible to define two or three vessel groups that accounted for at least half of their landed value. Those groups represented a small fraction (10–25%) of all multi-gear vessels, and management measures directed at those species might affect only a limited number of vessels. As an example, for *Lophius* spp., groups nN1 (9 vessels) and SW1 (33 vessels) account for 67% of the landed value, but both clusters represented just 14% of the total number of vessels (307). For *M. merluccius*, 71% of the landed value was accounted for by 16% of the vessels (N1, SW1, and nS3). These results underscore the feasibility of effort-control-based management, which is essential for mixed-species fisheries management (Caddy and Cochrane, 2001).

The results can be verified by the specialization analysis. For both *Lophius* spp. and *M. merluccius*, specialization and seasonality were analysed in detail (Figure 6). A group of vessels showed high specialization for *M. merluccius* and *Lophius* spp. Seasonality was also important, but not as strong as vessel specialization, because landings of both species were registered throughout the year (only *Lophius* spp. was quota-limited after August). This type of information allows one to assess the effect of specific management measures with a seasonal aspect or vessel selection factor.

For management purposes, it needs to be recognized that the segmentation analysis presented here is largely based on the options and fishing strategies adopted by individuals or groups of vessels, because most vessels had several gear licenses. Past landing history does not necessarily indicate the future behaviour of a fleet. Also, because information on the fishing gear corresponding to each particular landing was not available, it was necessary to consider in the analysis all potentially used gear (all the gear licensed for each vessel). This might have limited the analysis, because clusters of vessels whose activity is restricted to only one or a small group of gears could not be directly identified.

Future developments of this research should include the analysis of a longer time-series to determine changes to the structure in 2005, along with their drivers. Such information could then be combined with information from local experts and fishers to validate the results.

Acknowledgements

The study was supported financially by the research project NeoMAv "New Assessment Methodologies" (QCA III, UE co-financed). We also gratefully acknowledge the Portuguese General Directorate for Fisheries and Aquaculture (DGPA) for providing the data, Sarah Walmsley (Cefas) for revising a draft of the manuscript, and Pedro de Barros of the University of the Algarve for making important suggestions for the regression tree analysis. Finally, the manuscript was considerably improved by the suggestions made by Paul Marchal and two anonymous referees.

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